Hospital Operations Management – a Lean healthcare approach to improve medical imaging management processes of a Portuguese Public Hospital

Leandro Gustavo Barretiri

UMinho | 2021

Universidade do Minho
Escola de Engenharia

Leandro Gustavo Barretiri

Hospital Operations Management – a Lean healthcare approach to improve medical imaging management processes of a Portuguese Public Hospital

July 2021

Universidade do Minho
Escola de Engenharia

Leandro Gustavo Barretiri

Hospital Operations Management – a Lean healthcare approach to improve medical imaging management processes of a Portuguese Public Hospital

Master's Thesis
Industrial Management and Engineering (Integrated Master's)

Work done under the guidance of
Professor Rui M. Lima
Professor Bruno Gonçalves

July 2021

DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

Este é um trabalho académico que pode ser utilizado por terceiros desde que respeitadas as regras e boas práticas internacionalmente aceites, no que concerne aos direitos de autor e direitos conexos.

Assim, o presente trabalho pode ser utilizado nos termos previstos na licença abaixo indicada.

Caso o utilizador necessite de permissão para poder fazer um uso do trabalho em condições não previstas no licenciamento indicado, deverá contactar o autor, através do RepositóriUM da Universidade do Minho.

Licença concedida aos utilizadores deste trabalho

Atribuição

CC BY

https://creativecommons.org/licenses/by/4.0/

ACKNOWLEDGMENTS

This work was part of Project HOMLean, "Hospital Operations Management: a Lean Healthcare Framework", POCI-01-0145-FEDER-030299, funded by FCT–Fundação para a Ciência e Tecnologia, within program FCT/COMPETE2020/POCI Projetos de Investigação Científica e Desenvolvimento Tecnológico (IC&DT) - 02/SAICT/2017.

Special thanks to supervisors Rui M. Lima and Bruno S. Gonçalves for their availability and support. In addition to these exceptional tutors, I had the opportunity to work with Cristiano Jesus, who, much more than a colleague, was extra support for the research and writing moments. My appreciation also extends to Jorge Pereira for all his help and patience.

Thanks also to Anastasiya Moroz, Eda Aksu, Fernanda Muller, Giselle Mendes, Karina Nagao, Maryam Salati, Taís Magalhães, Rim Zgueb, Brando Bigliardi, Caio Fleming, Cristiano Seiji, Diego Mattos, Emídio Carvalho, Eduardo Ferreira, Hesam Ipchihagh, Thiago Barretiri, and all who, in one way or another contributed to this learning experience of mine.

Finally, a very special thank you to my parents (Inês Barretiri and Adão Barretiri) and Spinoza`s God.

Only a mind that is aware of not knowing is able to open up to the possibility of learning something new

Emídio Carvalho

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

ABSTRACT

The main objective of this study is to promote improvement in the management of hospital operations in the imaging sector of a Portuguese public hospital by providing waste reduction and consequently improving patients' experience. These aspirations include increasing hospital service quality in a continuous and efficient way. This management mindset uncovered flaws such as the existence of divergences between Medical Appointment (MA) and Magnetic Resonance Imaging (MRI) exam scheduling causing the occurrence of ineffective MA (occurring without the respective MRI exam results), the presence of constraints for MRI capacity planning, and the existence of constraints for monitoring equipment availability in the imaging sector. The main aspects considered in this study were the waiting time for MRI exams and the management of imaging resources. One-year retroactive encrypted data from MA and MRI requisitions were provided by the hospital for the development of an algorithm – using Excel Visual Basic for Applications (VBA) and Power Query – to identify the occurrence of ineffective MA. Outcomes obtained from the algorithm revealed 16% of ineffective MA in the period of a year analyzed, which represents a financial loss of €99,580. Also, an optimization model was developed to estimate the optimal monthly MRI production in a dynamic three-year time horizon. The model goal is to minimize yearly MRI exam realization costs and maximize the internal production to gradually reduce the response time, which will consequently decrease the waiting list for MRI exams. The capacity planning optimization model revealed the need for maximum production of MRI for a period of 18 months so that the waiting time for MRI exams reduces from 11 to 3 months. For the issue regarding the existence of constraints for monitoring equipment availability, a dynamic table was developed in Microsoft Excel to calculate the availability of all imaging sector equipment to be implemented by the MRI department. The greatest contribution of this research for hospital managers' decision-making is by allowing them to improve the imaging sector operations management to maximize internal resource utilization and to deliver a higher quality health service.

KEYWORDS

Ineffective medical appointments, Lean Healthcare, operations management, MRI capacity planning, performance indicators

RESUMO

O principal objetivo deste estudo é promover a melhoria na gestão das operações hospitalares no setor de imagiologia de um hospital público Português, proporcionando a redução do desperdício e, consequentemente, melhorando a experiência dos pacientes. Portanto, aumentar a qualidade do serviço hospitalar de forma contínua e eficiente faz parte das expectativas. Essa mentalidade de gestão possibilitou a identificação de falhas, como: existência de divergências entre o agendamento de consultas médicas e exames de Ressonância Magnética (RM) resultando em consultas médicas ineficazes (que ocorrem sem os respectivos resultados de exames de RM); presença de restrições para o planejamento da capacidade de ressonância magnética; existência de restrições para monitorar a disponibilidade de equipamentos no setor de imagiologia. Os principais aspectos considerados neste estudo foram o tempo de espera por exames de RM e a gestão dos recursos de imagiologia. Dados criptografados retroativos de um ano de consultas médicas e requisições de RM foram fornecidos pelo hospital para o desenvolvimento de um algoritmo – com o uso do Excel Visual Basic for Applications (VBA) e Power Query – para identificar a ocorrência de consultas ineficazes. Os resultados obtidos com o algoritmo revelaram 16% de consultas ineficazes no período de um ano analisado, o que representa uma perda financeira de € 99.580. Além disso, um modelo de otimização foi desenvolvido para estimar a produção mensal ótima de RM num horizonte de tempo dinâmico de três anos. O objetivo do modelo é minimizar os custos anuais de realização de exames de RM e maximizar a produção interna para reduzir gradativamente o tempo de resposta, o que consequentemente diminuirá a lista de espera para exames de RM. O modelo de otimização para planeamento de capacidade revelou a necessidade de produção máxima de ressonância magnética por um período de 18 meses para que o tempo de espera pelos exames de ressonância magnética diminua de 11 para 3 meses. Para a questão da existência de restrições para monitorar a disponibilidade de equipamentos, foi desenvolvida uma tabela dinâmica no Microsoft Excel para calcular a disponibilidade de todos os equipamentos do setor de imagiologia a ser implementada pelo departamento de ressonância magnética. A maior contribuição desta pesquisa para a tomada de decisão dos gestores hospitalares é permitir que melhorem a gestão de operações do setor de imagiologia para maximizar a utilização de recursos internos e fornecer um serviço de saúde com maior qualidade.

PALAVRAS-CHAVE

Consultas médicas ineficazes, gestão de operações, indicadores de desempenho, Lean healthcare, Planejamento de capacidade de RM

INDEX

FIGURE INDEX

TABLE INDEX

SYMBOLS AND ACRONYMS

ADA - Anomaly Detection Algorithm

BPMN - Business Process Model and Notation

CAT - Computed Axial Tomography

HOM - Hospital Operations Management

JIT - Just-in-time

LE - Lean enterprise

MA - Medical Appointment

MRI - Magnetic Resonance Imaging

MTBF - Mean Time Between Failure

MTTR - Mean Time to Repair

NHS - National Health Service

OEE - Overall Equipment Effectiveness

OM - Operation management

ORE - Operating Room Effectiveness

S-D - Service-Dominant

SVSM - Service Value Stream Management

TPM - Total Productive Maintenance

TPS - Toyota Production System

TTA - Total Time Available

TTAV - Total Time of Added Value

TTS - Total Time Scheduled

TTU - Total Time Used

VBA - Basic for Applications

VSM - Value Stream Mapping

WID - Waste Identification Diagram

WIP - Work in Progress

1. INTRODUCTION

The introduction of the study is displayed in this chapter. Firstly, a broader contextualization of the topic is provided with the background of the study. In the sequel, research questions and the research objectives designed for the study development are presented. Additionally, the study relevance is described followed by the research methodology approach related to this project development and the thesis structure.

1.1 Study Background

The current economic scenario requires, from public and private health service providers, alternatives to reduce existing failures in hospital management. There is a call for a health system that ensures high levels of quality in the care provided to patients, capable of simultaneously retaining or reducing existing health costs and wastes (Waring & Bishop, 2010). Waste also called non-value-added activities, includes any work, money, and time consumption that does not add value to the final consumer (Radnor et al., 2012). From a Lean thinking perception, all waste has to be eliminated from the root. Anyhow, there are activities that do not add value to customers but are essential for the process, such as financial control (Melton, 2005). Waste occurs from the operational method of the process and its identification has no endpoint (Emiliani, 1998).

Kumar and Reinartz (2016) highlight that company's success comes from its ability to deliver customers valuable satisfaction and also adding value to the organization by converting customer perceived value into considerable gains. By customer perceived value the authors refer to the consumer's feeling about what is being sacrificed and which benefits he or she is receiving as recompense. In this line of thought Womack and Jones (1996) state that value is a measure defined only by the customer. For Kuuru et al. (2020) and Falivena and Palozzi (2020), value-added activities are activities that add value from consumers' viewpoint.

Propitiating a positive experience to the end-user is a fundamental value proposition. Customer experience exists through direct and indirect interactions between the consumer and company. If service is the customer's expected outcome, its quality is primordial for a positive interaction (Meyer & Schwager, 2007). To succeed with this strategy, companies must fully comprehend the customer's journey, understanding what they expect before the experience, and how they will evaluate the lived experience (Berry et al., 2002).

Focusing on the health industry, the occurrence of ineffective medical appointments represents a significant misuse of the hospital's resources and time, which culminates in dissatisfied patients with the inefficacy of medical treatments. Mittal et al. (2014) imply that the maximization of healthcare resource utilization results from the implementation of a robust appointment system.

Currently, in the literature, it is common to find studies about missed medical appointments due to patients' fault. Regardless of the reason for the patient not attending the scheduled appointment, and because of the waste elimination process that private and public sectors are going through, there is a call for a reduction in appointments failures due to the high cost associated (Bades et al., 2018), and many researchers already proposed different solutions for patient no-show events. However, it seems that there a is a lack of studies related to possible inefficiencies, such as scheduling errors and ineffective medical appointments. By ineffective appointments, this research refers only to the medical appointments that happen with no, or low, benefit for patients, not being addressed in this study the medical appointments in which patients do not show.

Public hospitals are currently facing difficulties in meeting the crescent demand for MRIs while trying to handle shorter outpatient waiting times. Additionally, patient no-show is a global issue experienced by many hospitals, and according to Tsai et al. (2019), the burden associated with this matter is the missed medical appointment, which implies a quality loss in service provided due to improper occupation of existing resources. This is an issue which is also presented when health organizations are responsible for the unattended appointment or the occurrence of ineffective appointment.

Missed appointments (a consequence of the patient no-show for a scheduled medical appointment) results in the inability to use this medical availability for another patient, which culminates in delay in medical treatment and financial losses for the health system. Thus, ineffective medical appointments generate negative results with the addition of an unnecessary motion for a hospital visit that does not add value to the patient.

As stated in the Toyota Production System (TPS) and also presented as a Lean Manufacturing principle, unnecessary motion is considered waste, what within service system was adapted to unnecessary people movement. Dinis-Carvalho et al. (2017) describe people motion waste as any human motion from one point to another without resulting in added value to the customer. The occurrence of ineffective appointments causes delays that result in an increase in the hospital waiting list. From the patient's perspective, in addition to unnecessary motion, other factors such as extra transport expenses and changes in family and work routines are consequences of people's movement waste.

The Lean concept was conceived in Japan from favorable results experienced by Toyota Motor Corporation (Womack et al., 1990). The Toyota company focus, during the post-war national revitalization phase, was to deliver consumers cheaper products and services in the shortest time possible by reducing waste and using fewer resources (Bhamu & Sangwan, 2014). Likewise, Jones (2014) expresses the advantages of Lean principles adoption on creating value for consumers by eliminating waste.

Lean manufacturing implementation was expanded from shop floor practice to all organization sectors in the 1990s with the term Lean enterprise concept (Womack & Jones, 1994, p. 93). For this purpose, re-engineering processes such as Six Sigma and Lean Thinking are examples that enable the organizational restructuring process in order to add value to the customer, reduce waste and ensure the increase of economic performance (Radnor & Boaden, 2008). In particular, Lean healthcare, a set of operational concepts, emerges as a relevant approach, with the objective of providing correct care at the appropriate time, with high quality, based on ethics and patient well-being (Waring & Bishop, 2010).

Lean thinking is the mindset related to focusing on the value chain present in the whole company. When well established, this cultural characteristic enables any workers to analyze any process and evaluate how it can be organized so that value is added efficiently (Poppendieck, 2011). Lean thinking translates the participation of workers directly connected to a product or service on the process of design improvement or development, instead of a project isolated developed by CEOs and office workers (Atkinson, 2004). To succeed through the Lean thinking practice, organizations have to enhance customer satisfaction by continuously tracking waste and flow. Moreover, the possible success improvements obtained from Lean philosophy implementation must be clearly communicated (Melton, 2005).

Weinstock (2008) stresses that the patient must be a priority during the transition process from the current management model in health services to Lean healthcare, so understanding what the patient values are the main indicator that determines what are the fundamental changes. According to Coulter (2015), this new approach aims to meet users' needs transparently and ensure that the needs presented in the patient experience surveys and questionnaires are discussed in medical forums and treated with due importance. Increasing patient satisfaction does not only mean making them "happier" with the service provided but rather increasing quality in the health sector, providing greater interaction between patients and health professionals (Glickman et al., 2010).

Lean ideology application implies the use of several techniques/tools, such as hospital operations management, associated with operations management and supply chain management sectors, which aims to understand the initial state of operations management in hospital environments (Souza & Lima, 2020). Other useful tools to identify waste and areas of the value chain with the greatest potential for adding value to the customer are Value Stream Mapping (VSM) (Lima et al., 2020). For an equipment-centered analysis, an indicator used to identify the relationship between system capacity and demand is the ORE (Operating Room Effectiveness) adapted from the OEE (Overall Equipment Effectiveness) performance indicator, which aims to improve operational efficiency and reduce waste in operating rooms (Souza & Lima, 2020).

A health facility that currently presents a scenario with opportunities for improvement is a Portuguese public hospital, particularly in the imaging service, where the management of the waiting list for the MRI exams, Computed Axial Tomography (CAT) and Ultrasound represents a challenge to reduce the growing waiting lists in a context where the increasing demand (Figure 1) for complementary diagnostic procedures and therapy in Portugal (*MCDT's - SNS*, 2020) exceeds responsiveness. Another present challenge is the need for an integrated system that makes it possible to schedule appointments based on the existence of the respective exam results that correspond to the purpose of the medical appointment.

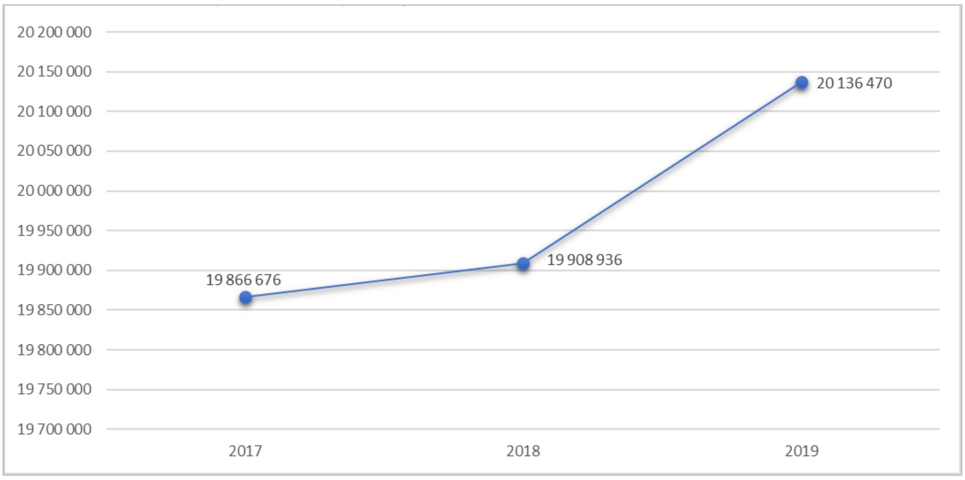


Figure 1 - Complementary diagnostic procedures requested in Portugal (2017 – 2019)

This study was developed for the improvement of hospital operations management in the interface between the imaging and medical appointments sectors of a Portuguese public hospital. The problems were previously identified by the hospital management and presented to the research team as an urgent case to be solved.

One of the existing problems in the imaging sector of the cited hospital is the occurrence of ineffective medical appointments due to the lack of capacity of the imaging sector to meet requests in the due date. It is a problem present in several hospitals, both public and private, which can be also associated with the medical appointments that happen with no relevance to the patient, representing unnecessary visits to the hospital.

Another issue presented by the imaging sector administration is the absence of a robust production capacity planning tool for MRI scans capable of maximizing internal production and consequently reducing the MRI's waiting list. The hospital under-study has the option of outsourcing MRIs to assist patients more quickly, but it is a much more expensive option compared to the costs of in-house production. In this sense, maximizing internal production can be converted into monetary waste reduction.

Another issue raised by the hospital administration is the absence of a maintenance control system for performance indicators related to the availability of all imaging types of equipment. Obtain availability and downtime measures according to preventive and corrective maintenance is an important step for the future calculation of the OEE of all imaging equipment to implement the Total Productive Maintenance (TPM) in a near future.

1.2 Research Questions

Lean thinking is a methodology mainly used in the manufacturing sector to deliver products focusing on the value-added activities. However, the service sector is adapting the Lean implementation in parallel with improved operations management to achieve better outcomes focusing on customer satisfaction. Therefore, this dissertation development was motivated by the following research questions:

- How does the identification of delayed MRI exams impact the reduction on ineffective medical appointments occurrence within health organizations?
- How does the implementation of a capacity planning optimization model can contribute to reducing patients' waiting time in the hospital imaging sector?
- How the implementation of an availability analysis system, by using performance indicators, turns into an important step to obtain the Overall Equipment Effectiveness (OEE) of the hospital's imaging sector?

1.3 Objective

This master's thesis was developed at the imaging sector of the hospital under-study and aims to fill existing gaps in the health area and improve scheduling of complementary means of diagnosis and therapeutics, which implies an analysis of the opportunity of finding, quantifying, and developing alerts that indicate the existence of medical appointments without the respective result of the requested examination. Another aspect of the utmost importance to be addressed is the existence of long waiting lists for exam scheduling such as Magnetic Resonance Imaging, Computed Axial Tomography (CAT), and X-ray.

Bearing in mind the importance of improving the patient's experience, it is an existing concern in the development of this dissertation to implement a performance analysis routine through performance indicators to expose the existence of wastes that are not evident to the hospital administration. Subsequently, it is intended to analyze and quantify the necessary capacity to reduce the wait to schedule exams. These approaches are intended to assist researchers and managers in transforming the hospital environment with a focus on providing high-level service and waste reduction.

The general objective of this research is to improve the hospital operations management through the application of Lean healthcare principles, tools, and indicators, uncovering and contributing for reducing the existence of wastes that are not evident to the administration of the hospital under study.

The specific objectives of this project are:

- Identify and characterize the operations management processes at the imaging service of the hospital under-study.
- Analyze the operations management processes for implementing Lean healthcare principles, tools, and indicators in the hospital imaging service.
- Implement an algorithm for ineffective medical appointment identification.
- Define capacity levels for partial reduction of MRI exams waiting list.
- Implement the maintenance control system to measure the availability of all equipment in the hospital imaging sector.

1.4 Research Methodology

The present research explores the presence of operations management improvement opportunities within a large Portuguese public hospital. This dissertation is an outcome of the HOMLean, "Hospital Operations Management: a Lean Healthcare Framework". Programa FCT/COMPETE2020/POCI Projetos de Investigação Científica e Desenvolvimento Tecnológico (IC&DT) - 02/SAICT/2017. Projeto POCI-01-0145-FEDER-030299. Grant: 211.901,87 €. Coordenadores: Dinis Carvalho e Rui M. Lima. Dates and duration of the project: 2018–2021 (41 months). Foremost, an action research methodology was conducted within the imaging sector of the under-study hospital for greater visualization of the sector's current state of operations management wastes identified in the hospital.

Aiming to access renowned data sources and to realize the extent of research available for Lean implementation in the health sector, scientific data suppliers such as Research Gate, Emerald Insight, JSTOR, and Springer Professional have been used as on-line databases also including B-ON, the on-line University of Minho library. Besides many relevant articles related to Lean healthcare some prominent books related to Lean production and Lean service have been investigated for a deeper understanding of the Lean concept. In order to have stronger bases for literature review, websites have been also analyzed, especially the United Kingdom National Health Service (UK NHS), the Centers for Medicare and Medicaid Services (CMS), and the Gallup web pages, where relevant satisfaction surveys, such as the Hospital Consumer Assessment of Healthcare Providers and Systems (HCAHPS) survey and the Gallup's Q^{12} employee engagement survey instrument was discovered.

Given the huge number of research papers resulting from the first stage of the investigation related to the Lean concept, results were funneled by using keywords related to the research questions. Thereafter the most relevant articles were selected to conduct the literature review.

The action research methodology was applied to the development of tools for solving problems regarding the occurrence of ineffective medical appointments, the presence of constraints for MRI capacity planning and the existence of constraints for monitoring equipment availability at the imaging sector of the under-study hospital.

The action research methodology and the used tools and technologies are described next.

1.4.1 Action Research

The development of this dissertation is based on an action research methodology, with investigation procedures, for the perception of existing obstacles. A deductive approach was applied through bibliographic research and documentary investigation in order to obtain relevant data for project development.

According to Susman and Evered (2016), an action-research approach must follow the following process: (a) diagnosis phase of the current scenario in which the problem exists; (b) action planning phase to identify possible alternatives to solve the problem; (c) taking actions phase, in which the alternatives presented in the previous phase are analyzed and selected; (d) the evaluation of the results phase, that aims to evaluate the possible consequences of the selected actions; (e) the conclusion phase of the study in which the final results and possible opportunities for future studies are presented.

A wide literature review was addressed in this study to identify the main obstacles that exist as well as the main techniques and tools used to overcome these obstacles. In this way, it was identified a growing application of Lean techniques adapted to the health system, with Lean healthcare being the main focus of the literature review addressed in this dissertation.

The action planning phase, which is the second step, was conducted on the project team's research lab. The third step, the taking action phase, was also conducted in the research lab through supervisors' monitoring in parallel with the hospital management team. The fourth phase, results evaluation, was the phase of greater contact with the hospital administration with the occurrence of virtual meetings and also face-to-face meetings. The last step of the action-research methodology, which is the conclusion phase, will be presented after the problem description and after the analysis and discussion of the results section of this dissertation.

1.4.2 Research Tools and Techniques

For a better understanding of the methodology used in this study, including tools and technologies, the entire study process covered at the participating Hospital is described in general.

Within the scope of this dissertation, integrated into the research team of the HOM Lean project, the research conception and initiation were carried out to serve as the basis for the planning and execution phase of the project that aims to develop solutions based on operations management techniques and Lean principles for existing problems in the imaging sector.

In the diagnostic phase, the imaging exam scheduling system was inspected with a more detailed check on how the data are related between the examining doctors and the imaging sector. The main objective was to obtain relevant information and collect the necessary data for a critical analysis of the current state of the imaging sector. To that end, meetings were held with the administration of the sector for a correct perception of urgent issues to be addressed by the team participating in the Lean healthcare operations management project to be implemented at the hospital.

In the action planning phase, based on the diagnosis made in the previous phase, technological tools were select for the solution development. At this stage, the Excel VBA function and the *power query* connection technology were chosen. In this phase, tests were carried out with the use of encrypted databases provided by the hospital so that the algorithm under development could be tested and validated by the project team.

After obtaining the final version of the alerting tool algorithm for the identification of ineffective medical appointments, weekly tests were conducted for the final validation of the tool in practical application by the hospital management. During this phase, the algorithm was validated by the hospital administration in the first weeks, with some requests for final adjustments so that the maximum information was obtained through the reports generated by the alerting tool, thus enabling more efficient decision-making.

In the analysis and discussion phase, the results obtained with the ineffective medical appointments identification tool were evaluated, as well as possible improvements to be achieved for the hospital and for the patients. The results obtained in the analysis of retrospective data were also compared with the analysis of future data to diagnose if there was an increase in the number of ineffective medical appointments as well as to assess the feasibility of the proposed improvements. Possibilities for further work with a greater focus on improving the service provided to the patient were also discussed.

Considering that the hospital administration indicated the need for an improved capacity planning system, it was decided to develop an optimization model to minimize yearly imaging exam costs and maximize the internal production to gradually reduce the response time, which will consequently decrease the imaging exams waiting list.

Considering that the optimization model can be adapted to different specialties and that the MRI waiting list is the one experiencing longer response time, it was decided to develop the optimization tool based on MRI exam data. The project intends to estimate the optimal monthly MRI production at the hospital. A time horizon of three years, containing detailed information about the ideal amount of daily production, is included in the evaluation. The OpenSolver tool for Microsoft Excel with the Simplex method was used as an optimization engine.

Focusing on reducing wastage and improving patient experience within the imaging sector of the under-study hospital, also a maintenance control system to measure the availability of all equipment in the imaging sector was implemented with the use of Microsoft Excel for the development of algorithms to identify the impact of preventive and corrective maintenance on the availability of equipment. The outputs obtained are performance indicators such as Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) presented in graphs on a control panel.

1.5 Thesis Structure

This dissertation is structured in seven chapters. The introduction composes the first one, intending to explore and analyze the study background, delineating the study objectives, and the research questions.

Followed by the concept definitions and the study relevance along with its limitations. The first chapter is completed by detailing the research methodology and the ongoing structure description.

The literature review compounds the second chapter, to broadly understanding and getting acquainted with the topic based on the perspective of different renowned authors on Lean theories. It displays the current state of Portuguese health service, the Lean background, and the upward application of Lean in the service sector including specific tools and prominent wastes. In the sequence a brief description of the Lean implementation as well as the benefits, challenges, and criticisms linked to the Lean philosophy. This chapter ends with greater visualization of the Lean philosophy applied to the health sector.

The third chapter describes the hospital where this research has been developed. In addition to a brief description of the history of the hospital, this chapter describes in more detail the internal structure, computer, and communication systems, including also relevant statistical data about the imaging service sector, the area in which the research was conducted.

The fourth chapter is where the characterization of the problem is presented and also where a description of the current state of the under-study hospital imaging sector is made. This practical part of the action research began with the analysis concerning the information transmitted by the sector's administration about a prevailing problem earlier identified.

The improvements proposals for the issues presented in the previous chapter are better explained, including its implementation process, in the fifth chapter. Later, in chapter six, the results obtained from the implementation of improvements are presented and discussed.

Last but not least, chapter seven presents the final conclusions and recommendations for future work on improving operational management, improvements that fit the imaging sector, and other sectors of public or private hospitals. The study limitations are also presented in the last chapter.

2. Conceptual Background

This chapter addresses the Portuguese National Health Service (NHS) and is also dedicated to contextualizing Lean production, emphasizing relevant diagnostic, and improvement tools. Adding to the brief Lean production introduction, a deeper approach is developed to better expose the transition phase from Lean Manufacturing to Lean healthcare, highlighting its particularities and limitations. Considering the parallel intention present in this thesis on maximizing the patient experience within the health organization while improving patient flow, the customer experience marketing approach is reviewed on the intention to demystify the customer-centric mindset and its value perception.

Figure 2 represents the structure of the literature review as a funnel, starting from a broader concept about the covered topic to a more specific conceptualization. This approach reveals to be useful for better distribute relevant subtopics by categorizing different theories.

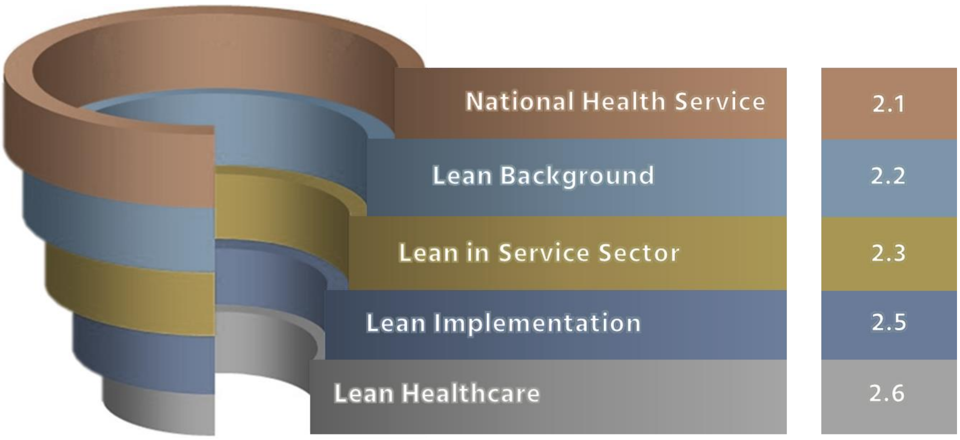


Figure 2 - Literature Review Structure

2.1 National Health Service

The Portuguese public health service system was established in 1979 by the National Health Service creation (Major & Magalhães, 2014). According to the authors, the system development was based on the British NHS model, which suggests for all citizens, free access to high-quality health assistance. Major and Magalhães also highlight the Portuguese health system evolution, following a European trend, in merging hospitals into major hospital centers.

The main purpose in the Portuguese national service creation was to guarantee to all the right to health protection based on the users' socio-economic conditions. Currently, with the aging aggravation that increases the population with chronic diseases and people with different pathologies, the Portuguese NHS faces new challenges. Advances in technology and the need to purchase new equipment to meet demand require a large investment which results in difficulties in guaranteeing a quality service due to the lack of resources and capacity (Ministério da Saúde, 2018).

According to Nunes (2017), after the setback period (2011 – 2015) marked by the economic crisis that overwhelmed Portugal, some improvements with the intention to modernize and restructure the Portuguese NHS have already started. The author concluded that even with a large amount of work already done to enhance patients' satisfaction, there is still a lot of room for improvement in the health sector so that the population can be served, according to their needs, in an agile way.

The dispatch number 199/2016 was published in 2016 to improve hospital management in an integrated model, including other participating agents. This project also aims to relieve the burden imposed on the Portuguese state and protect the NHS so that health is guaranteed to all users in a sustainable manner (Diário da República, 2016).

2.2 Lean Background

Since Lean thinking represents the theoretical basis for the development of this dissertation, this section presents a review and analysis of the concepts associated with the Lean philosophy. In this manner, the evolution of the Lean thinking concept and its principles are presented.

2.2.1 A Brief History of Lean Production

The Lean production concept was mainly inspired by the Toyota Production System (TPS) (Ohno, 1988; Monden, 1983) which, in turn, was based on the mass production Ford system (Krafcik, 1988). By comparing Lean production to the Ford mass production system, Womack et al. (1990) describe Lean production as a combination of positive aspects from craftwork and mass production system, where the advantages result in a robust production process, culminating in the nullification of repetitive and exhaustive working methods.

Womack et al. (1990) also disclosed Lean production as a groundbreaking approach, using technology as an ally, capable to amplify products' variety and lessen defects through a consistent chase for perfection rather than the comfort state achieved by the Ford system when a simple "good enough" target was reached. The innovative essence of Lean production derives from the TPS methodology, that instead of identifying workforces only as replaceable parts inserted into the shop floor, merged the automated machines mass production prospects to the craftsmen intellectual talent, propitiating the birth of a teamwork culture concentrated on value creation and waste elimination in order to achieve optimum performance process, simply called as continuous improvement culture (Womack et al., 1990; Krafcik, 1988).

Lean production is a flexible methodology applicable practically in every culture within any organization from developed to underdeveloped countries (Womack et al., 1990, p. 9). In the authors' words: "the fundamental ideas of lean production are universal applicable anywhere by anyone... and many non-Japanese companies have already learned this".

Keeping up with this argument, Kim et al. (2006) assert that the implementation of Lean production in the health sector reveals, from previous studies, to be an opportune procedure to support hospital managers to enhance patient satisfaction by consuming fewer resources, aiming to reach a similar success achieved by the manufacturing sector. Lewis (2000) concluded, from an empirical investigation, that the acquisition of financial advantages from Lean practices, depends on the organization's experience in converting added value into considerable profit.

2.2.2 Toyota Production System (TPS) as a Basis for Lean Philosophy

Assumed by Womack and Jones (1996) as a model for the Lean philosophy, the Toyota production system (TPS) was initiated in the 1940s by Taiichi Ohno and Eiji Toyoda (Monden, 1983). Due to poor car demand present in the post-war period, Toyota Motors was not able to adapt to the mass production system used by Ford Company to the Japanese scenario (Petersson et al., 2010). Based on the idea that just a low percentage of total effort and time spent on goods production was being converted into value-added for the final customer, the main intention of TPS was to improve the efficiency of the manufacturing process through a reduced production line, capable of sustaining a continuous flow (Melton, 2005).

TPS is globally represented by the TPS house (Figure 3), which has become a symbol for TPS among the industry sectors. Just-in-Time and Jidoka are the two main pillars of the TPS house, whereas the kaizen strategy is the focus of the whole process. All parts interact to compose the house (Liker, 2015). Parts are characterized as follow:

- *Just-in-time* (JIT) is the most popular aspect of TPS house and sometimes wrongly assumed as a synonym of TPS (Towill, 2010). JIT principle translates the Toyota founder's (Toyoda Kiichiro 1894 - 1952) intention to create a production system based on the market demand. In other words, a fast pull production system that allows the components flow to deliver the right quantity at the correct place in the expected time (Liker, 2015).

- *Jidoka*, represents the machine automation with human interaction. The reduction of the machine's dependence on man is the fundamental principle of this process.. Besides ensuring quality standards on final products, this principle enriches the teamwork spirit (Chiarini et al., 2018, p 3; Liker, 2015).
- *Kaizen* is a *mandatory* principle in a Lean system (Liker, 2015). As continuous improvement core, kaizen is the cultural behavior that stimulates workers to diagnose improvement possibilities which result in personal positive outcomes, teamwork, and organizational growth. Kaizen philosophy is the most relevant aspect of TPS due to its innate concern for human well-being (Chiarini et al., 2018).
- *Heijunka* stands for processes leveling and supports JIT and Jidoka pillars. This principle works as the house foundation and its main goal is to standardize processes through a leveled workload and a leveled order flow (Liker, 2015). Standardized work is the TPS feature capable of sustaining the improvements already developed within the company (Hall, 2004).

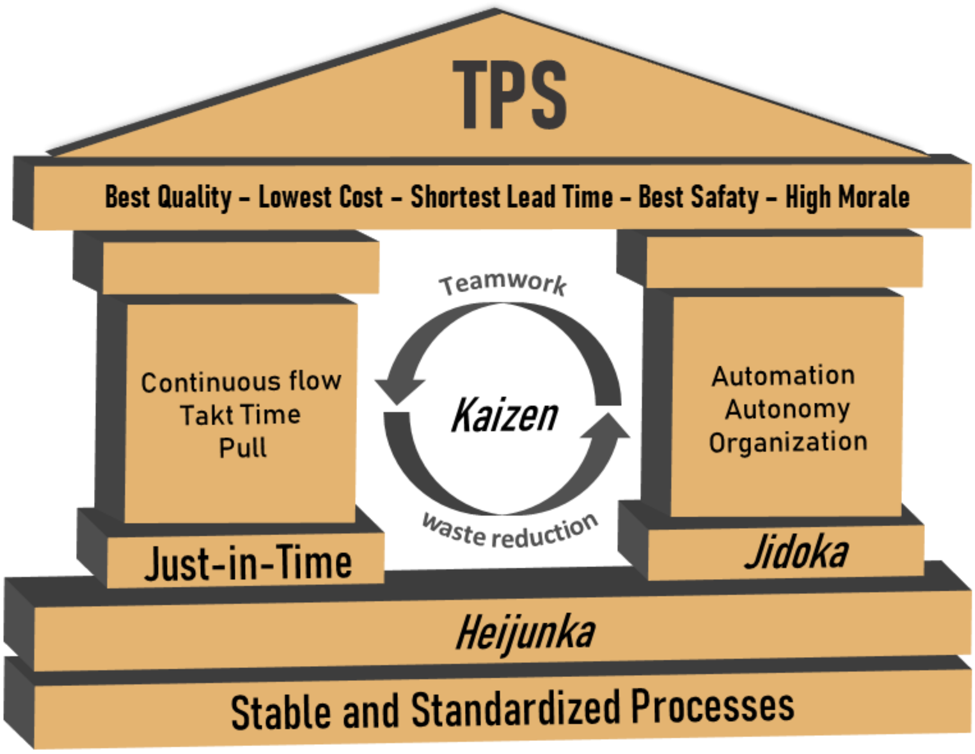


Figure 3 - The Toyota Production System House (Adapted from Liker, 2015, p. 7).

Customer satisfaction is the TPS true north, the tools and applications are flexible and never considered as a final solution for problem-solving. The whole process is prepared for improvements and any methodology can be changed or removed if better approaches are founded. For TPS, people development is an investment that results in greater competitiveness, so that organizations must admit employees as assets of extreme importance (Hall, 2004; Spear & Bowen, 1999).

2.2.3 Five Lean Principles

Lean can also be described by the five cardinal Lean principles identified by Womack and Jones (1996). These principles are the base of the continuous improvement process followed by the Lean philosophy to reduce waste (*muda* in Japanese) and add value (Radnor et al., 2012), and are discussed in the following:

- Value: There is an intrinsic need to define value. Understand what consumers really value through the value chain is the ground zero of Lean implementation (Kuuru et al., 2020; Falivena & Palozzi, 2020). Kumar and Reinartz (2016, p. 60) sustain the idea that achieving "enduring customer value" depends on value created from the company to the consumer associated with value created from consumers to the company.
- Value stream: It must be identified. This process includes all activities necessary to deliver customers the final product or service. In this phase, activities that add value and do not add value are identified. The priority is given to the customers' perspective, instead of satisfying the departments' ambitions (Womack & Jones, 1997).
- Flow: It is directly related to the value stream—the connection of activities and events that really create value for the consumer. Flow involves culture, people, and processes. For Lean thinking, the organization works as a structure where the resources are linked by processes that finally manufacture the product to be sold (Melton, 2005). Flow in Lean manufacturing is the continuous stream of production from raw materials to the end product without constraints interruptions (Emiliani, 1998).
- Pull: To propitiate pull production a revolutionary change is needed, customer demand must be the production planning guide, which results in the reduction of excess production (Womack & Jones, 1997). The pull concept in Lean production stands for producing what customers need, respecting the ordered volume (Emiliani, 1998).
- Perfection: The four previous principles are interrelated to the continuous Lean quest for perfection. Given that perfection will be never reached, the Lean perfection concept translates the infinite improvement space present on organization processes (Emiliani, 1998). This management approach ensures the endless elimination course of non-value-adding activities within the Lean thinking cycle (Radnor et al., 2012).

These five principles were originally developed in the manufacturing industry, but, when adapted and properly applied, can be also used in the service sector (Gupta & Sharma, 2016). Organizational competitiveness and positive customer experiences are expected results from the application of Lean concepts in the service industry for waste elimination and process stability (Andrés-lópez et al., 2015). The process (Figure 4) represents the five principles adapted for healthcare. Since identifying value stream implies an in-depth analysis of the patient's journey, the second principle is a relevant step, due to its capability for value-added identification. Other principles remain the same as in manufacturing (Westwood et al., 2007).

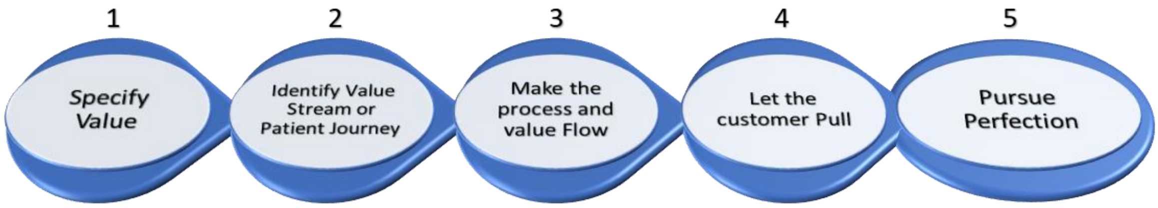


Figure 4 - Five Principles of Lean (Adapted from Westwood et al., 2007, p. 4)

2.2.4 Lean Viewed as a Philosophy

Lean production philosophy reveals to be very useful when applied holistically and understood as a strategy of mutual benefit and not just as a toolkit capable of reducing waste to increase business profit (Hallam & Contreras, 2017; Waring & Bishop, 2010). The core concept of Lean philosophy is to sharpen the sense of respect for people (workers and customers) while avoiding the seven key wastes (mudas) (Shah & Ward, 2003).

Radnor et al. (2012, p. 365) cite the five Lean principles, in which the first "Define Value" aims to add value to customers, whereas the entire process provides firms' ability to reduce waste, ensure a continuous flow of products, service, and information in a systematic looping. The author's definition of Lean is: "a management practice based on the philosophy of continuously improving processes by either increasing customer value or reducing non-value adding activities (muda), process variation (mura), and poor work conditions (muri)."

This definition translates the Lean philosophy concern on employees' and customers' satisfaction. However, this methodology can facilitate the customer value identification process but does not guarantee its triumph (Radnor et al., 2012). The authors justify the reason why Lean fails in a service context implementation due to leaders' lack of knowledge about the importance of applying Lean philosophy as a transparent and integrated methodology, where the process is not minimized by a sectorized implementation resulting in internal competitions for mediocre prizes, contrariwise it is an ideology in which the whole team understands from the heart the Lean meaning and its call for a unified group that works in harmony to benefit the whole.

Chiarini et al. (2018) observe that, in the 1980s, during the Lean incubation phase in Western industries, Lean production methodology was possibly misunderstood as a toolkit containing instructions for improved management outcomes. Even with the evolution of Lean perception in Western organizations, that added a philosophical concept to the tools and to the management methods (Jørgensen et al., 2007; Bhasin & Burcher, 2006), there are distinctions between the original TPS developed in Japan and the Lean production system latter implemented in Western corporations (Hall, 2004). The author stresses the special attention given from TPS to the human development concept as the biggest and most relevant contrast. On the other hand, Hall highlights the Lean ability to predict necessary cultural changes and anticipate organizational issues faster than TPS, due to higher employee participation through the Lean implementation process.

For Chiarini et al. (2018) the smooth and triumphant TPS employment in the 1950s is directly related to Asian culture and its ancestral religious influences. Krafcik (1988) presents a similar idea that a successful implementation of a Lean-TPS philosophy depends on an open-minded culture, enabling an innovative concept to turn into reality before becoming obsolete. The same importance is given by Womack and Jones (2015), presenting Lean solutions as cornerstones for organization sustainable progress. Womack and Jones also reinforce that management style is not, most of the time, updated during Lean conversion, making it difficult to turn Lean philosophy into a routine. Chiarini et al. (2018), focused on customer satisfaction and comparing Western Lean-TPS adoption to Japan's TPS, stress that adapting management style before changing the whole company's culture is a much simpler and less invasive process.

Bhasin and Burcher (2006) submit that adopting Lean as a philosophy settles on the firm's frame of mind instead of a transitory procedure for operational performance improvement. The authors also advocate the importance of a value perception from customers' viewpoints to enhance team players' capability in providing the expected solutions. For Repenning and Sterman (2002) Lean practices tend to fail, when assumed and applied as a trend rather than embraced and implemented as a philosophy from companies' core principles. Lean has to be flexibly digested, by the whole company, like an endless journey and an unacceptable "good enough" mode (Karlsson & Hlström, 1996). For Bhasin and Burcher (2006), enterprise cultural development towards a Lean thinking mindset comprehends the Lean quest for waste elimination. They argue that the philosophical influence, inherited from TPS, contributes so that the same effort spent on waste disposal is also used to ensure that respect for humanity is practiced in all aspects.

The evolution of Lean philosophy is displayed in Figure 5.

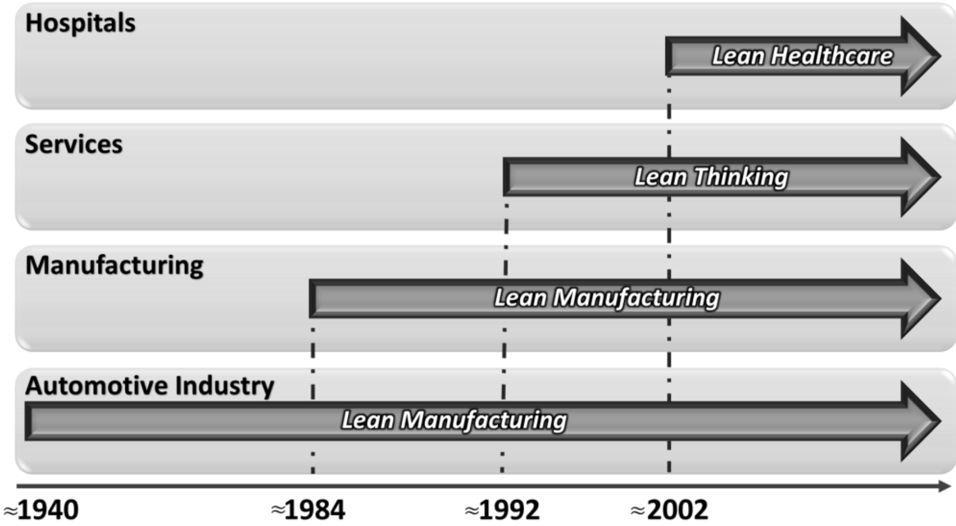


Figure 5 - Evolution of lean philosophy (Adapted from Laursen et al., 2003, p. 14)

2.3 Lean in Service Sector

Considering that healthcare organizations have as their main activity the provision of health services to patients, this section aims to address in more detail the change from the one-time product sales economy to a service economy, as well as the implementation of the Lean philosophy in this sector, including the covered wastes and the used tools.

2.3.1 Service Science

Mature economies, such as the ones from Europe, North America, and Japan are conquering competitive advantage by shifting from a one-off product sale economy toward a service economy. This phenomenon, known in the manufacturing sector as "servitization", refers to industries' process of integration of products and services. In other words, it is the industry's ability in selling end products as a service and not only focusing on optimizing the traditional product-centric economy. By implementing digital technologies, such as cloud computing, virtual reality and artificial intelligence, organizations can accomplish the fusion between service and smart products to extend the value co-creation stream present between producers and users so providing innovative service to final consumers (Marx et al., 2020; S. Kim & Toya, 2019).

According to Marx et al. (2020) the innovative or smart service emerged during the changing wave from a product-dominant logic to a service-dominant logic. The authors describe the smart service concept as the customers´ possibility to keep generating value while using a service or product, this is what value co-creation stands for, the ability of users and companies to create value together. Kim and Toya (2019) support the necessity for manufacturing organizations to embody the value creation concept on the merging process into the service sphere, a practice that requires structural changes in the organization for a successful servitization starting point.

The first article about service-dominant logic named "Evolving to a New Dominant Logic for Marketing" by Vargo and Lush was published in 2004. This event coincided with the same year that U.S. Council on Competitiveness devised a new service innovation methodology called "service science" briefly described as "a new discipline to innovate services and service systems with scientific methodology" (Kim, 2009, p.3). As the most important attribute of a service-oriented system, Kim punctuates great consumer participation in product and service designing and improvement phases. Spohrer and Kwan (2009) present the service system, a core concept of service science, as a value co-creation structure of stakeholders, technology, and value proposition that integrates the whole system by applying shared information.

Assuming that consumers need solutions instead of products, Kim (2009) sustains that academic areas as economy and markets, science and engineering, social science, and business administration must work cooperatively in an attempt to design a proper solution to the final consumer. Under the cover of the service science area, new disciplines related to all study fields are springing up. Service engineering, service economy, service education, service design, and service technology are relevant examples that deserve greater attention from researchers (Kim, 2019).

Given that the focus of this study is concerned with applying engineering methodologies to the health service system, a more meaningful approach to service engineering will be prioritized. According to Klaus-peter (2003), the act of employing contemporary engineering expertise to build up innovative services, in an efficient way, translates the service engineering approach. In other words, service engineering is a standardized development of services adopting suitable methods, tools, and models already in use in product development. In this context, service engineering is a much more technical procedure compared to the marketing approach in modern service deployment (Bullinger et al., 2003).

The service engineering approach tends to fail when focused mostly on production techniques to develop modern service systems, based on this outcome Marx et al. (2020, p. 2) and Jussen et al. (2019, p. 1) point out the crescent need for a "smart service engineering". Marx et al. (2020) highlight the importance for enterprises to pay attention to the value-in-use, which is directly connected to the smart product's capacity to monitor users' behavior, which therefore enables manufacturers to vision improvement possibilities. The authors recommend special attention to four high-priority perspectives on the service engineering methodology: (1) service, (2) product, (3) software, and (4) data. They also defend that a multidisciplinary integration is crucial for a smart service engineering implementation that benefits both users and entrepreneurs.

Modern service engineering revels to be an exceptional concept due to its broad approach. Besides dealing just with the technical aspect of the service system, a deeper understanding is necessary to also contemplate the commitment, the relationship, the perception, and the human involved aspects so that the service system can keep itself updated. Pertaining to enhance the value co-creation on modern service systems, Freund and Spohrer (2012, p. 1) draw attention to the relevance of the "human side of service engineering" concept. Regarding the importance of the human side, the authors stress the practitioners' lack of commitment to include all stakeholders (e.g., consumers, workers, civilians, and businesspeople) in the design process of different types of service systems like transportation, economics, politics, education, and healthcare. The role of a smart service system is to improve the capabilities of all involved parties and also to anticipate the needs of customers and employees, supporting them during the interaction (Freund & Spohrer, 2012).

While some service science's researchers endorse the importance of a collective approach among different academic areas for better service system outcome, Freund and Spohrer (2012) suggest that the progression of modern service system rely upon an empathetic mindset from service engineers. The authors sustain the idea that it is service engineers' responsibility to prepare and habilitate consumers to positively contribute to the continuum of value co-creation. Empowering users to interact and also benefit from the value co-creation process results in self-esteem and capability improvement, in short, customer satisfaction (Freund & Spohrer, 2012).

2.3.2 Lean Service

Service activities, such as finance, human resource, product development, and engineering, represent more for organizations, in terms of profitability, when compared to the goods production process. According to George (2003), the manufacturing work is responsible for only 20% of organizations' income, while service operations are in charge of the 80% left. In contrast, George sustains that improvement possibilities are higher on service applications, given that 50% of service activities add no value for customers. Ojasalo and Ojasalo (2020) defend that the alliance of the Service-Dominant (S-D) logic and Lean innovation approach can propitiate significant improvements for the service sector.

For Lean innovation, similar to the S-D logic approach, listening to customers, and understanding their core values is essential for sustainable service improvement. Customers should participate in all product or service development processes, from the conception phase to the incremental stage (Maurya, 2012). Lean service innovation can assist the progress of value-in-use creation, by allowing organizations to continuously learn from customers (Ojasalo & Ojasalo, 2020). The authors explain that S-D logic can add to the Lean service innovation approach for an earlier customer core value identification.

Customers expect to satisfy their latent needs when opting for a specific service. In order to deliver positive experiences, organizations have to increase service quality and continuously eliminate waste activities to reduce also the time required to perform the service and the high cost associated with the slow process. During the service's work in progress (WIP) there are unnecessary complexities that cause the delay which in turn result in customer dissatisfaction (George, 2003). Regarding the health environment, patients play the role of clients and crave effective treatment, thus, the need for waste reduction is as significant as in the industrial sector.

The Lean service concept is about providing pleasant experiences for consumers through the service process, from waste elimination and efficiency improvement which results in organizational competitiveness and customer loyalty (Andrés-López et al., 2015). Lean thinking, when applied in service sectors such as retail, airline, finance, and hospitals generated positive financial outcomes (Gupta & Sharma, 2016). According to de Souza (2009), the main aspects of progress in the health sector related to the Lean implementation is staff inclusion in decision making and continuous improvement. Empowering employees to participate in processes improvement, within the work areas in which they operate, is an important step after CEOs embrace the Lean service approach (Maleyeff, 2006).

2.3.3 Lean Wastes in Service Sector

George (2003) advocate that losing a customer should be considered the biggest business loss in Lean thinking. He also disputes that, by eliminating all internal waste taken into account by the Lean-TPS philosophy, the likelihood of external customer losses will be lower due to a more efficient and a reduced cost service provided. Both in the manufacturing and services sectors, there are operations and processes that aim to meet customers' needs and expectations while cultivating loyalty bonds. Patient medical care is comparable to a production line, where the patient is submitted through a process that starts on triage, progressing to medical appointments and exams until the final prescription. During this process, wastes must be identified and wherever possible eliminated (Song et al., 2009).

Toyota detected the seven types of wastes (Mudas) (El-namrouty & Abushaaban, 2013; Slack et al., 2007), sketched in Figure 6, and further described in Table 1.

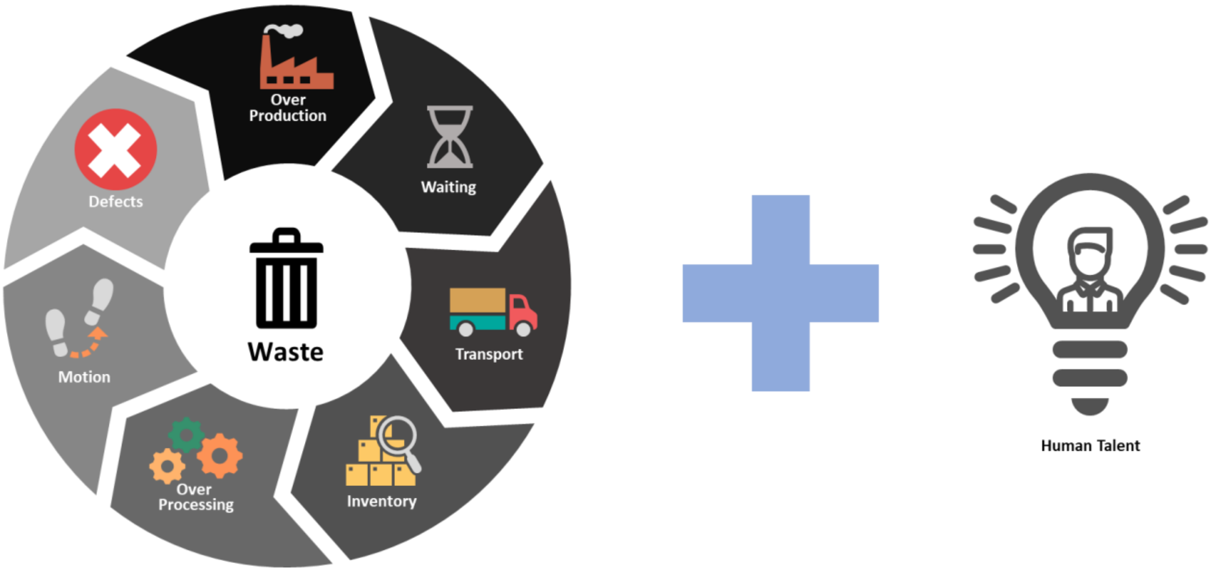


Figure 6 - The seven types of waste (Adapted from Melton, 2005, p. 665)

In addition to Muda, there are two more waste components, Mura and Muri. Poor production planning, irregular changes in demand, and batch production lead to Mura waste. On the other hand, the system overload, due to out of balance use of assets configures in Muri waste (Ohno, 1988). Figure 7 exemplifies the TPS's 3M to facilitate its perception regarding different load distribution. An eighth waste, also described in Table 1, is presented by many authors, including Liker (1997) that sees untapped human talent as a waste to be considered.

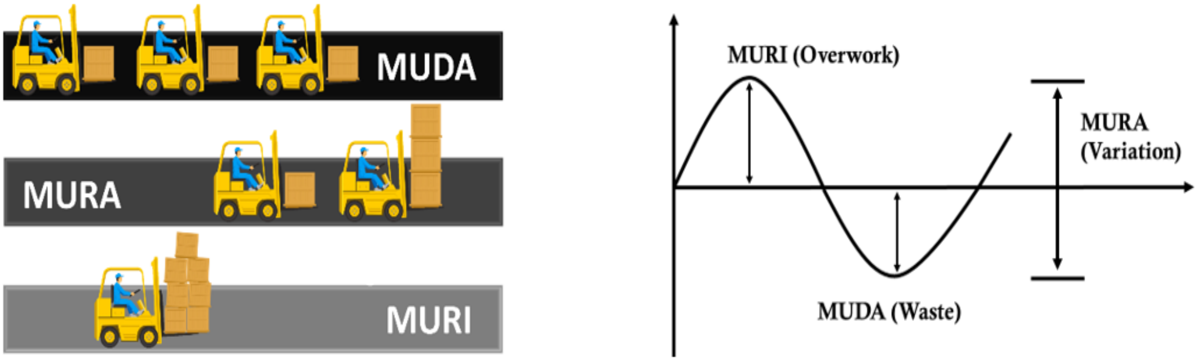


Figure 7 - TPS Mudas and Conceptual image of Muda, Mura, and Muri (Adapted from Osterman, 2017, p. 33)

All eight wastes express what customers are not willing to pay for, simply because they add no value to the expected outcome. The delay in product or service delivery is directly proportional to the total waste present within businesses. Lean philosophy educates the whole organization on how to continuously identify and eliminate wastes and getting closer to perfection (George, 2003).

Table 1 - Manufacturing and service wastes

Waste	Service/Hospital Context	Manufacturing Context
Transportation	Unnecessary transportation for obtaining virtual or face-to-face information turns into Customer dissatisfaction (George, 2003). Centralized departments correspond to transportation bottlenecks in healthcare (Weiss et al., 2017).	Unnecessary movements of materials result in increased production defects and poor quality. Inefficient transport causes delays in the delivery of parts (El-namrouty & Abushaaban, 2013).
Example	*Patient and medicine transportation* (Weiss et al., 2017)	*Material transportation* (El-namrouty & Abushaaban, 2013)
Inventory	It is the result of doing more than expected by the customer (George, 2003). In the health area, patients waiting for service due to bureaucracy and the fact that health professionals have to complete activities that could be performed by others (Weiss et al., 2017).	Stock of raw materials much higher than the need to meet the demand resulting in unnecessary finished products. Stocked products may lose quality (El-namrouty & Abushaaban, 2013).
Example	*Patient waiting for unnecessary documents* (Weiss et al., 2017)	*High level of raw materials and finished goods* (El-namrouty & Abushaaban, 2013)
Motion	Time spent in movements that can be avoided adds no value for customers and are difficult to measure in the service sector (George, 2003). In hospitals, a poorly engineered layout result in time loss for caregivers (Weiss et al., 2017).	Lack of standardized motions and the presence of untrained employees in the working area culminates in longer production time (El-namrouty & Abushaaban, 2013).
Example	*Health professionals looking for supplies* (Weiss et al., 2017)	*Non-standardized jobs* (El-namrouty & Abushaaban, 2013)
Waiting	It is related to the time spent waiting for the previous activity to be ready for the process to continue. Value stream mapping is a useful technique to expose process delays (George, 2003). In healthcare, the hierarchical system results in long waits for authorization from superiors (Weiss et al., 2017).	Responsible for the retraction of the flow, idle machines, and idle workforces increase the work in progress and the chances of defects (El-namrouty & Abushaaban, 2013).
Example	*Patients and doctors waiting for exam results* (Weiss et al., 2017)	*Operators waiting for material* (El-namrouty & Abushaaban, 2013)
Overprocessing	It means performing more work than necessary to please the customer, which causes the price increase. Patients experience unsatisfying episodes in a hospital due to redundant procedures (Weiss et al., 2017).	It causes overproduction, given that machines work full time to reduce cost per machine time (El-namrouty & Abushaaban, 2013).
Example	*Perform duplicate tests unnecessarily* (Weiss et al., 2017)	*The variation between operators* (El-namrouty & Abushaaban, 2013)
Overproduction	Exist when companies execute more services than customers need. It means excess on service performed (George, 2003). In the health sector, overproduction is experienced when patients are scheduled beyond the service capacity (Petersson et al., 2010).	Produce more than necessary. It causes an increase in inventory, in motion, in defects, in transportation, in workers and machines motion, which results in machine breakdown increasing waiting time (El-namrouty & Abushaaban, 2013).
Example	*Perform unnecessary patient radiological images* (Weiss et al., 2017)	*Ample space used for inventory* (El-namrouty & Abushaaban, 2013)
Defects	Service performed out of line with customer needs. The added value in defect elimination is not limited to reducing rework costs, but to captivating and offering customers a high quality-service (George, 2003). In the health sector, defects can endanger the health of patients in case of infections caused by poor hygiene (Petersson et al., 2010).	Its directly related to rework and is responsible for other wastes through the production process, which consequently increases the cost for the final consumer (El-namrouty & Abushaaban, 2013).
Example	*Patient being wrongly medicated* (Weiss et al., 2017)	*Customer complaints* (El-namrouty & Abushaaban, 2013)
Talent	This waste refers to the lack of importance given to the training of workers in solving problems and the lack of incentive for them to put their imagination into practice. This loss of human potential results in unmotivated workers and loss of opportunity to reduce costs (Weiss et al., 2017).	The untapped human potential for improving the production process (Liker, 1997).
Example	*Qualified professionals performing simple activities* (Weiss et al., 2017)	*Using human resources to perform a task below their competence* (Liker, 1997)

The participation of customers (patients) in the healthcare service is fundamental for value creation. In order to improve the waste identification and facilitate the application of Lean principles in the service sector, Dinis-Carvalho et al. (2017) developed, through a case study conducted in a Portuguese public hospital, an article where the seven waste types classified in the TPS are adapted for this service context. Table 2 represents the new classification for service waste types identified in the case study including its relationship with TPS classification.

Table 2 - A terminology proposal for service waste types (Dinis-Carvalho et al., 2017)

Traditional Waste Types (Onho, 1988)	Services Provider/User
Over-production	Too much information or material
Inventory	Information or material waiting
Transportation	Transport of Information or material
Motion	People motion
Waiting	People waiting
Over-processing	Complex and redundant processes
Defects	Defects

2.3.4 Lean Tools and Techniques in Service Operations

Lean implementation is supported by a toolkit to ensure that value will be identified and integrated into the product or service. Lean tools emphasize the importance of continuous waste elimination and make the Lean process more robust to respond to customers' takt time (Melton, 2005). According to Gupta and Sharma (2016), for a well-established Lean implementation, a cultural change is necessary alongside the strict tools selection. For authors the philosophical element present on Lean principles between Lean production and Lean service are equivalent, but tools and practices must be customized for the service sector. Liker (2015) submits that tools and technologies that do not empower employees and do not support the process can probably work as a disruptive acquisition.

Sorooshian and Fen (2017) accomplished quantitative and qualitative research to rank the applicability of Lean tools in the service industry. The result obtained reveals that among twenty-five tools, 5s, Work Balancing, Waste Elimination, Kaizen, and JIT are the 5 most applicable tools in service operations. Another pertinent analysis research of twenty-five tools was realized by Leite and Vieira (2015), in which the most commonly Lean tools used in the service industry were identified. Table 3 summarizes the identification work and classifies each tool from both types of research based on its importance for the service industry.

The 5 most important tools from both types of research are highlighted in Table 3. and described below:

1. *5S:* Besides propitiating relevant improvements when practiced in the service sector, can assist the management practice in creating a neat, comfortable, and secure working atmosphere (Song et al.,

2009). Leite and Vieira (2015) pinpoint that the 5S tool, used in the service industry, can collude to generate a stable base present at the TPS house. The authors also underline the strong connection of the 5S tool with TPS's pillars, which should be in the mind of Lean facilitators for the whole process. Figure 8 illustrates the 5S tools and their S's meaning.

Table 3 - Lean tools ranking table

SERVICE LEAN TOOLS APPLICABILITY	WEIGHT (%)	SERVICE LEAN TOOLS RELEVANCE	WEIGHT (%)
5S	12,65	Value Stream Map	8,79
Work Balancing	10,74	Just-in-time (JIT)	6,59
Elimination of Wastes (Muda)	9,34	Heijunka	6,59
Kaizen (Continuous Improvement)	8,57	Standardization	6,59
Just-in-time (JIT)	7,77	5S	6,59
Continuous Flow	6,81	Multitask	5,49
Check Points and Control Points	6,01	Layout Improvements	5,49
Poka-Yoke	5,23	Set up Reduction	4,40
Value Stream Map	4,54	Training	4,40
Six Sigma	4,03	Problem Solution	4,40
Standardization	3,46	Takt Time	3,30
Quality-Function Deployment (QFD)	3,00	Kaizen (Continuous Improvement)	3,30
Statistical Process Control (SPC)	2,68	Pull System	3,30
Root Cause Analysis	2,32	Zero Defects	3,30
Plan-Do-Check-Act (PDCA)	2,02	Elimination of Wastes (Muda)	3,30
One-Piece Flow	1,84	Automation	3,30
Visual Management	1,49	Visual Management	3,30
Kanban (Pull System)	1,37	Continuous Flow	2,20
Hoshin Kanri (Policy Deployment)	1,13	Value Chain Orientation	2,20
Gemba (The Real Place)	1,12	Consumption Map	2,20
Andon	1,00	Inventory Reduction	2,20
Autonomation/Jidoka	0,89	Kanban (Pull System)	2,20
Failure Mode and Effects Analysis (FMEA)	0,70	Vertical Information System	2,20
Takt Time	0,64	Preventive Maintenance	2,20
Chaku-Chaku	0,63	Poka-Yoke	2,20
TOTAL	100	TOTAL	100

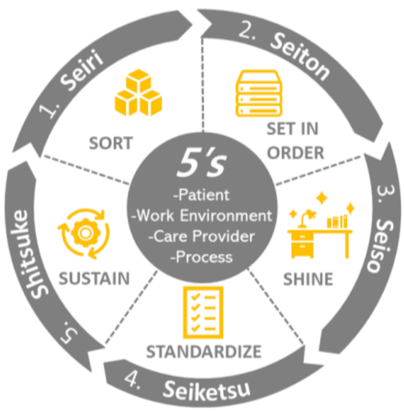


Figure 8 - The 5S process tool (Adapted from Leming-Lee et al., 2019, p. 57)

2. *Working Balance:* This tool can be used to diminish staff's stress and reduce customer's waiting time in the service sector (Swank, 2003), it can also assist the achievement of a smooth workflow (Song et al., 2009). According to Keim (2019), working balancing has to be implemented after non-value-added activities elimination.

3. *Elimination of Wastes (Muda):* In services, Lean sees as waste the unnecessary waiting time spent by the customer, the poor-quality service, lack of ergonomic workspace design, and irrelevant bureaucracy for information exchange. The main idea behind this concept is to expand activities that add value and eliminate those that do not add value to the consumer (Song et al., 2009). Waste occurs from the operational method of the process and its identification has no endpoint (Emiliani, 1998).
4. *Kaizen*: It is a mandatory principle in a Lean system (Liker, 2015). In healthcare, Kaizen culture is responsible for people development inside organizations, workers become self-confident on problem-solving, configuring in a high-level autonomy team. Kaizen concept works as a mindset changer tool, able to implement a continuous improvement culture based on mutual cooperation and constant learning routine for a common target: the patient and caregiver satisfaction (Suárez-Barraza & Miguel-Davila, 2020).
5. *Just in Time (JIT):* As a consequence of workload leveling, JIT can reduce cost and decrease the load exerted on the equipment, facilities, and workers resulting in service response time improvement. This tool is designated to respond to customers' demands, delivering the expected solution at the expected moment without unnecessary bureaucracy (Leite & Vieira, 2015).
6. *Value Stream Management (VSM):* In Lean manufacturing value stream mapping (VSM) is responsible for visually representing the ongoing and the expected process state, allowing the organization to better identify its weaknesses and strengths, focusing attention especially on wasteful situations (Simeonova & Nedyalkov, 2020). Service-oriented, VSM can larger expose the service process and, with the same intention as VSM, support waste points identification through mapping the current state of the process in parallel with the customer value proposition. On the other hand, the expected process state works as a motivating pill for the whole team, since it virtually represents a "future state map" with real potential to be performed (Song et al., 2009, p. 8). Leite and Vieira (2015) also assent with the similarity present on the mapping process between the production and service sectors, given the service's close relation with the development process.
7. *Heijunka:* According to Leite and Vieira (2015), *Heijunka* enables delay reduction in the service sector. The authors cite, as an example of *Heijunka* applied in hospitals, the possibility of ensuring patients flow while shortening waiting time. This tool is used to standardize processes through a leveled workload and a leveled order flow (Liker, 2015)
8. *Standardization:* Stands for procedure documentation including the necessary completing time for each task, what will regulate the processing time (time spent performing each procedure). It can be

also described as best practice guidance to shape a baseline for future improvement to ensure process flow even when staff turnover and absenteeism are part of the organizational routine (Song et al., 2009).

Two extra tools, *Six Sigma and Continuous Flow,* will be also explained due to their relevance conferred by prominent authors related to the health sector. These tools may be described as following:

9. *Six Sigma:* The use of this tool, directed to the health system, is in increasing applicability. Six Sigma can contribute to different departments within hospitals, such as finance, backlog, IT solutions, inpatient, and outpatient clinics. Six Sigma is based on statistical analysis over precise data collection for process variation reduction. This methodology is used, both in the manufacturing and health sector, for greater customer and staff satisfaction through service and product improved quality (Cima et al., 2011).
10. *Continuous Flow:* Flow is the third Lean principle and means no buffer (or minimum buffer) in the production line. In the service sector, flow implies that the rendered service runs smoothly continuously from the beginning to the conclusion in the value stream (Piercy & Rich, 2009). Malmbrandt and Åhlström (2013) declare that redesigning work practices and the presence of a link between all participant sectors can boost the process flow by reducing waiting times and avoiding unexpected interruption of service to be delivered. According to Kollberg and Dahlgaard (2007), level scheduling, multi-skilled teams and, JIT are relevant techniques to achieve continuous flow in the service industry.

2.4 Performance Indicators

Total Productive Maintenance (TPM), developed in Japan and introduced in 1971, is a relevant technique applied within the Lean philosophy to reduce machine downtime and production lead time (Ramakrishnan & Nallusamy, 2017) and has to be addressed in this dissertation. According to Venkatesh (2007), TPM is an evolved approach to implement an improved maintenance program in organizations' equipment and plants. The author stresses that the TPM's purpose is to considerably boost the manufacturing production through higher employee involvement in machinery care and maintenance to enhance staff esteem and satisfaction with the work performed. For Venkatesh, TPM can perform as a medicinal science for all organization's equipment.

In view of the TPM's ability to reduce waste by removing the variation that occurs due to machinery failure, TPM is a prominent asset for the practice of Lean philosophy (Haddad, 2012). Among all TPM quantitative metrics, OEE is the most relevant aspect to measure the TPM implementation program's success (Jeong & Phillips, 2001). The TPM implementation, in an adapted way with top management commitment, in the service providers organizations, such as hospitals, is considered a powerful tool for an upgraded maintenance system (Haddad, 2012). Haddad observed, through a case study research, that the TPM implementation generated considerable operational improvements, in terms of employees' commitment and higher value productivity in the workspace, in a high-size hospital in Jordan.

Since TPM stands for minimize not scheduled and emergency machine maintenance, this technique can highly contribute to waste and cost reduction by prioritizing quality and safety within companies (Venkatesh, 2007). According to the author there are 4 types of maintenance, breakdown maintenance, performed when equipment fails; preventive maintenance, which includes daily routine such as cleaning and lubrification, and more complex maintenance such as parts replacement; corrective maintenance, performed to upgrade equipment and its parts for a more reliable later preventive maintenance; predictive maintenance, which is a study performed to uncover current equipment fragility or to assist in new equipment development.

Ramakrishnan and Nallusamy (2017) defend that a TPM practice can, in addition to fostering a culture of greater employees' involvement, collaborate to the implementation of autonomous and planned maintenance, and reduce equipment downtime due to breakdowns. On other hand, Salata et al. (2014) state that the lack of a reliable maintenance program can increase the expenses associated with the equipment maintenance as well as, in the case of the health industry, exposing users and patients to risks due to vulnerable security. In this sense, the authors affirm that a reliability approach, with the implementation of a preventive maintenance system, has the function of maximizing the efficiency of the equipment throughout the whole production process.

The reliability approach is based on the parameter indicating the time interval in which a machine is not available, this indicator is the MTTR (Mean Time to Repair) and serves to assess the maintenance services' effectiveness (Salata et al., 2014). In parallel with the MTTR reliability indicator, there is the MTBF (Mean Time Between Failure) indicator that serves to inform about equipment reliability. Both indicators are calculated by using corrective and preventive maintenance data (Camila et al., 2015). The authors reinforce the need for a strategic plan for monitoring and analyzing these indicators for a proper start in the management of medical equipment.

Given the need for scientific evidence, mathematical expressions (1) and (2) are used to calculate MTBF and MTTR respectively.

$$MTBF = \frac{\sum TBF}{N} \quad (1)$$

$$MTTR = \frac{\sum TTR}{N} \quad (2)$$

where *TBF* stands for the time between failures, *TTR* for the time to repair, and *N* for the number of repairs (Camila et al., 2015).

In possession of these two indicators, it is possible to measure the equipment availability (Av) through equation (3), to comprehend the equipment working time percentage.

$$Av\ (\%) = \frac{MTBF}{MTTR+MTBF}\ x\ 100 \quad (3)$$

According to Tarawneh and El-Sharo (2009), the availability can be distinguished in seven different classes: excellent (95–100%), very good (90 to 94.9%), good (80 to 89.9%), medium (70 to 79.9%), low (60 to 69.9%) and very low (<60%). Mwanza and Mbohwa (2015) concluded from quantitative and qualitative research that the practice of an effective and suitable maintenance program with the monitoring of relevant performance indicators within the healthcare organizations can, by increasing equipment reliability and availability, add value to the service provided by the hospital.

Since OEE is a key performance indicator for measuring productivity (Souza et al., 2020), a detailed description including its calculation method is presented below. Overall Equipment Effectiveness is a global performance indicator able to identify losses while measuring the effectiveness of production equipment implemented in the manufacturing industry as practices of total productive maintenance (TPM), in which the increase in productivity, quality, and effectiveness is part of the department integration process. The OEE calculation is performed by identifying three classes of losses (Availability losses, Performance losses, and Quality losses) as shown in Figure 9. To obtain these classes of losses it is necessary to calculate the availability of the equipment by the ratio between the Total Time Scheduled (TTS) and the Total Time Available (TTA), the equipment performance by the ratio between the Total Time Used (TTU) and the TTS, and the quality of the equipment by the ratio between the Total Time of Added Value (TTAV) and the TTU. To acquire the overall equipment effectiveness, the availability, performance, and quality indicators are multiplied. OEE can be also determined by the ratio between the TTAV and the TTA measures (Souza, 2019). The authors conducted an exploratory study and proposed an adaptation of the name Overall Equipment Effectiveness (OEE) to Operating Room Effectiveness (ORE) since the study was applied in a surgical center to measure the effectiveness of the hospital's operating room.

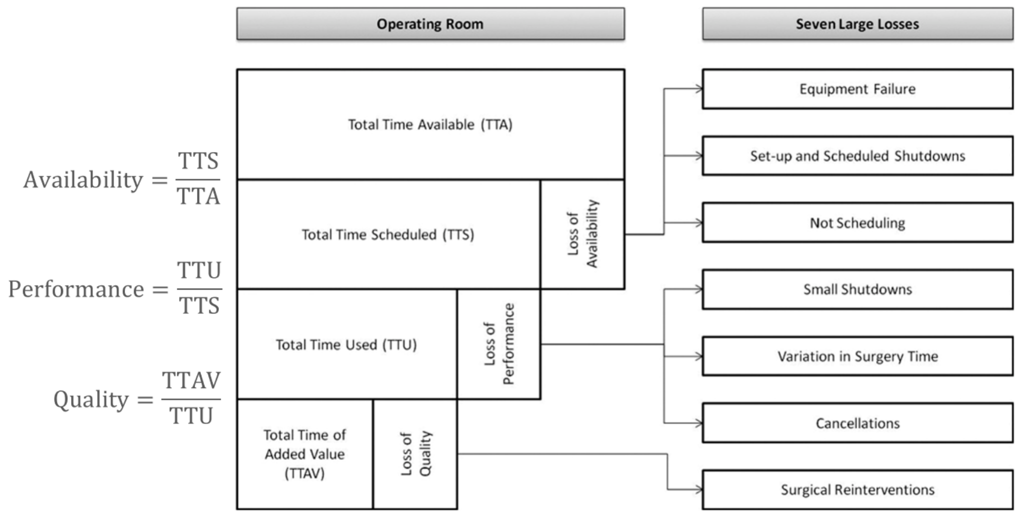


Figure 9 - Operating room variables and losses (Adapted from Souza, 2019, p. 8)

2.5 Lean Implementation

There is no single definition for Lean, some authors define Lean as a way to add value to the customer by reducing waste, while other authors see Lean as a methodology to recognize the customer as the main asset. Some others include also employees together with customers as the focus of Lean's attention, but a definition that recognizes Lean as a practical philosophy to be embedded in the organizations' core summarizes previous definitions (Gupta & Sharma, 2016). The authors recognize divergences between Lean in manufacturing and Lean in services, anyhow they admit that the philosophical basis remains the same in both areas. They also emphasize that tools and techniques applied in the production sector must be customized for the service sector so that Lean can become valuable as a specific problem-solving tool or as a cultural designer for the entire service company, as it has been used in the manufacturing field.

The relevance of the Lean concept is because it represents a philosophy that associates a wide understanding and a high commitment to analysis and troubleshooting. For long-term positive results, dedicated management and external support are crucial to assist the Lean implementation. The external support is responsible to meddle, during the initial implementation process, with a vision totally free of cultural blockages that may exist within organizations, while the management group is responsible to engage the whole team in the transition process. Since Lean correspond to continuous development, external support cannot become a key part of the smooth running of the organization, if a dependency is being diagnosed in relation to external assistance, it can be a sign of implementation failure. Anyhow, lean cannot be implemented in the short-range, as the positive transformation of organizational culture relies on slow and determined steps, focused on limitations and opportunities, and based on frameworks supported by techniques and tools that ensure the process flow (Petersson et al., 2010).

Dinis-Carvalho (2020, p. 1) stresses the importance of high-quality teaching and training on Lean philosophy. The author manifests, based on other relevant authors, that Lean training and education have a similar weight to managers' commitment and employees' engagement as a successful aspect of Lean implementation. Dinis perceive, as a reason for the failures in Lean education, the lack of perception of Lean educators about the intrinsic respect for the human factor present in the Lean concept, also called "the invisible side of Lean". Lean philosophy can provide vast benefits when, implemented holistically and instructed as a mutually beneficial strategy (Hallam & Contreras, 2017; Waring & Bishop, 2010).

2.5.1 Benefits of Lean Implementation

Taking into account the manufacturing sector, Melton (2005) emphasizes customer lead time reduction, inventory and rework minimization, efficiency, management knowledge improvements, and monetary savings as the main advantages acquired with Lean implementation.

In the service area, a highly relevant benefit associated with customer satisfaction that Lean implementation enables is the reduction of customer sacrifice through a more efficient consumption chain, resulting in an improved customer experience (Leite & Vieira, 2015). The authors conclude that Lean practices applied to services can provide similar results experienced in Lean manufacturing, such as more altruistic people behavior and financial savings. Andrés-lópez et al. (2015) reached a similar conclusion through a Lean reassessment study, recognizing the importance of deeply understanding the intrinsic characteristics of the service to be contemplated with the Lean philosophy and the fundamental role of value perception in the customer's perspective to increase the possibilities of serving the customer in an integrated way, creating memorable experiences through a robust methodology that empowers clients to be part of the value co-creation process.

Sharing the same idea and adding to the benefits mentioned in this chapter, Gupta and Sharma (2016) support the concept that Lean can contribute to improving organizations' eco-efficiency, minimizing the environmental footprint by extending waste elimination beyond the chain of goods and services associated with a given organization. Giving greater emphasis to the health sector, Leite and Vieira (2015) recognize hospitals as organizations with large space for service quality improvement, once hospitals are companies that provide varied services, from clinical care, pharmacy and surgery centers to restaurants, distribution centers, safety rooms and so on.

Petersson et al. (2010), Westwood et al. (2007), and Melton (2005) manifest similar benefits both in increasing efficiency through standardization of processes and in the organization's cultural development with a significant increase in employees' soft skills and self-esteem.

2.5.2 Challenges of Lean Implementation

The Lean philosophy is an analogy to performance improvement in the industrial sector, even so, its implementation is not a complication-free process (Jadhav et al., 2015, p. 333 - 336). Table 4 represents what authors consider as the main challenges of Lean implementation in the production field.

Table 4 - Challenges of Lean Implementation (Adapted from Jadhav et al., 2015)

Lean Implementation Challenges	**Description**
Lack of top management commitment and support	Lean implementation requires changes from cultural behavior to the basics necessary for the correct business operation. Leaders who are afraid to leave their comfort zone hinder the Lean implementation process. Most leaders with this profile abandon the implementation of Lean concepts long before achieving positive results (Jadhav et al., 2015).
Lack of training and education	Leaders and workers have to be aware of what Lean implementation stands for and its long-term benefits (Jadhav et al., 2015). Dinis-Carvalho (2020) sees the lack of perception of Lean educators about the intrinsic respect for the human factor, present in the Lean concept, as a reason for Lean education failure.
Financial constraints	Experienced more often by small and medium-sized companies, lack of skilled workforce and lack of innovative solutions represent a considerable reason for the failure to implement any improvement project, including the Lean philosophy (Jadhav et al., 2015).
Employees resistance	Employees with low knowledge of the Lean concept can misinterpret Lean as a process whose main objective is to eliminate job positions. This distrust culminates in a lack of enthusiasm from employees, turning into a barrier for successful implementation (Jadhav et al., 2015).
Poor facility planning and layout	*Just in time* production system requires a flexible factory layout in order to quickly adapt to the constant demand variations. Tightened layouts result in equipment and staff overload and also high inventory levels (Jadhav et al., 2015).
Lack of perseverance	Lack of workers' properly training and education about the Lean principles together with a poor monitoring and control system results in employees' demotivation when difficulties arise from procedural changes (Jadhav et al., 2015).
Organizational cultural difference	In the same way that some leaders fear leaving their comfort zone, employees tend to resist drastic changes. Cultural change is a difficult barrier to overcome due to the lack of a standard model of Lean implementation, giving that each organization is unique in cultural aspects (Jadhav et al., 2015).
Absence of a sound action or planning system	Leaders' knowledge about the whole process is fundamental for Lean implementation and to produce and deliver what the customer expects to receive at the moment he or she needs with maximum quality. A flexible layout itself is not able to keep up with demand fluctuations, an effective action plan is crucial to minimize the total cost of the production process and respond to the customers' takt time (Jadhav et al., 2015).
Lack of information sharing	Poorly transmitted information among stakeholders, from consumer perceived value to suppliers' knowledge about small changes in demand can become disastrous in the manufacturing process. Lean philosophy requires an open and real-time information exchange system (Jadhav et al., 2015).
Cross-functional conflict	Multidisciplinary teams are essential for a Lean high performance. Anyhow, if the team members have no clear perception of the team's importance, function, and structure, there is a big chance for Lean implementation failure. Proper information sharing plays an important role in this aspect (Jadhav et al., 2015).
Slow response to market	A robust facility planning and a flexible layout provide managers the ability for faster response to the market changes regarding demand volume, product mix, and product design. Organizations without the capacity to quickly adapt to the market may easily lose great opportunities (Jadhav et al., 2015).
Poor sales forecasting	A powerful forecast system supports leaders to better respond to market fluctuations. Without adequate forecasting, leaders depend on luck to satisfy customers (Jadhav et al., 2015).

According to Gupta and Sharma (2016), the fear that the identification of waste and inefficiency may negatively interfere with the service, and the lack of knowledge of the possible benefits obtained with Lean philosophy are the initial challenges of Lean implementation in the service sector. They claim the need for a standard framework on Lean service-oriented application as well as a Lean service common definition for an uncomplicated Lean service progression.

George (2003) also considers waste recognition as the biggest challenge in the service sector. According to the author, the reason is due to the fact that it is much more complicated to identify processes in services if compared to the manufacturing sector, in other words, processes are more apparent in the production sector. George sees the employees' autonomy level on controlling their tasks structure as a reason why processes identification is harder within the service sector, they are resistant to accepting a standard work system because they believe they can lose this autonomy. He defends that workers have to understand that they can have more freedom and empowerment by working through standardized processes because it eliminates misperception of each employees' duty.

Amran et al. (2020) diagnosed, from an exploratory study applying a quantitative approach in an Asian hospital, similar barriers found in the manufacturing sector as main obstacles for Lean healthcare implementation. The authors highlight the presence of the right perception of the underlying philosophical principles behind Lean philosophy as a fundamental aspect responsible for a successful Lean implementation. Detected barriers are exposed in Table 5.

Table 5 - Barriers in Lean Healthcare implementation in a Hospital (Amran et al., 2020)

Barriers	**Aspects**
People and Management	Lack of managerial skills Professional skills in healthcare Lack of human resources Financial resources constraints Regulation in healthcare
Organization Management and System	Hierarchy and management resistance Variation of organization culture and style Lack of qualified people in healthcare to guide about lean Lack of facilitator that experts in lean
Process Strategic Planning and Operation	Strategy and purposes Resistance to change Unclear vision Cross departmental
Information & Knowledge of Lean	Perception (lack of lean philosophy) Terminology Variation in defining waste
Organizational Process Variability	Numerous target Various process variability
Skills and Expertise	Inadequate training and education Lack of involvement (commitment and participation) of professionals
Organizational Planning	Organizational Silos Absence of sufficient time allocate for
Human Perspective	Lack of clear focus on customer

2.5.3 Lean Criticisms

Lean implementation has demonstrated, through research and practical applications, be a powerful methodology in processes improvement, such as an eco-efficiency progress achieved by organizations that extend waste elimination beyond goods and services chain, leading to a minimized environmental footprint, mentioned by Gupta and Sharma (2016) as relevant benefits of Lean philosophy. However, there are studies criticizing the Lean concept. According to Womack et al. (1990), workers faced a new reality within Lean organizations, a reality that forced them to be part of improvement processes, thus being responsible for the development and implementation of improvements. On the other hand, companies have been forced to lay off excess labor or unnecessary workstations as a result of the transition from mass production to a continuous improvement process from Lean production (Womack et al., 1991).

According to Mehri (2006), it was asserted by Parker and Slaughter (1988), in the book "Choosing Sides: Unions and the Team Concept" that Lean does not fully consider the human side within organizations. The authors accuse the Lean concept of adopting a stressful management style. Mehri (2006) defends that the Lean concept implemented in the US automotive industry was primarily concerned with cost and time reduction within the shop floor, rather than workers' wellbeing. The author's justification is related to a wrong assumption from west researchers about the Toyota Production System from Japan. Mehri believes that renowned Lean authors, such as Womack, Jones, and Roos reached conclusions, from TPS studies, based only on numbers instead of including the human damage associated with the Lean implementation. Wickens (1993) postulates that Lean progress requires Lean professionals who are, from heart and soul, engaged in human development. In other words, people who are impassioned about people.

Changing the focus to the service sector, the low number of evidence about Lean service positive advantages can be the reason for doubts about achieved improvements and its relation with Lean implementation in the service industry (Arfmann & Barbe, 2014). For the authors, believing that a Lean model can be easily adapted from the manufacturing field to the service area is an illusion that culminates in susceptible failures. The criticisms surrounding Lean healthcare are related to the barriers existing in Lean implementation in hospitals. According to Drotz and Poksinska (2014), studies focusing on the process itself are rare in the health field, what prevails are comparisons between the previous and after state from a Lean intervention, resulting in a hazy investigation stemmed from a fragile implementation where aspects of extreme importance as leadership, work attributes, employees' performance, role, and commitment are neglected. The lack of engagement, by health professionals, in value perception from patient's eyes is another significant gap that receives criticism from researchers in the Lean healthcare area. (Radnor et al., 2012).

Arfmann and Barbe (2014) argue that an important aspect to be considered in the service sector is the Lean ability to enable consumers to directly interact in the value co-creation process. The authors also highlight the present gap among scholars and Lean professionals in realizing the real value that Lean can add to the service sector. For Hines et al. (2020), a multi-skilled team, including people with a higher level of emotional intelligence, compassion, and behavioral awareness, normally present in human resources departments, can assist Lean professionals to develop a more humanized approach. The authors concluded, from a case study, that a successful Lean implementation relies on a well-established implementation plan focused in develop a renovated culture that benefits both sides, employees, and employers.

2.6 Lean Healthcare

Considering that healthcare sector requirements are growing faster than resources, a "new set of skills focused on value, system design, and shared decision making in a fully informed population" is needed (Gray, 2017, p. 2). As the health system involves customers that demand much more from healthcare professionals, it compels a modern approach based on ethical decision-making models, considering priority levels to respond to the current challenges arising due to the increase in life expectancy and the crescent changing on pathologies patterns (Andreu-Perez et al., 2015; Yaeger et al., 2019).

Lean healthcare stands for practicing Lean principles in clinics and hospitals to improve any process in order to satisfy the patient's needs by reducing costs and waiting time, resulting in organizations' financial benefits (Amran et al., 2020), and patients improved experiences (Jiang & Malkin, 2016).

Taking into account the Lean philosophy proposal to maximize the added value through standard works and smooth patient flow within the healthcare service and considering that this dissertation was developed in a period of worldwide epidemic dissemination, this section addresses the health service value-based topic and an overview on how Lean philosophy behaves in times of pandemic crisis.

2.6.1 Value-Based Lean Healthcare

Given that the purpose of many organizations, including the health services, is to eliminate non-value-added activities, and that a value-based healthcare approach foments continuous and sustainable improvement in healthcare, perceive what consumers really value through the patient journey is an unclear desired knowledge expressed by health organizations (Kuuru et al., 2020; Falivena & Palozzi, 2020). Karimi-Dehkordi et al. (2019) justify the difficulty in identifying what patients really value due to the lack of appropriated tools, due to patients' insecurity in manifesting their values, and the patients' lack of knowledge about their own emotions. The authors also defend that nurses and physicians must have a deep knowledge of the patients' value concept to assist the patient's health and deliver a value-based service.

Regarding the improvement and adaptation of lean concepts, the healthcare industry still represents immature progress in contrast with the automotive manufacturing industry. The current Lean healthcare evolution scenario can be correlated to the 1990s, phase in which Lean transition in manufacturing was passing through a struggling process between shop-floor tools execution and process improvement (Hasle et al., 2016; Radnor et al., 2012). Table 6 represents the Lean development phases in the manufacturing sector (Hines et al., 2004, p. 1002).

Table 6 - The development of a contingent evolved lean approach (Hines et al., 2004, p. 1002)

	1980-1990 Cell and line	1990-mid 1990 Shop-floor	Mid 1990-1999 Value stream	2000 + Value system
Prescription / contingency	Highly prescriptive tool-based approach	Highly prescriptive best practice approach	Lean principles Value stream mapping Prescriptive "one best way"; Toyota is best"	Contingency involving: customer value, policy deployment, size, industry, technology
Organizational learning	Knowing organization Single loop learning Management by objectives	Understanding organization Single loop learning Management by objectives	Thinking organization Single (and some often ineffective double) loop learning Management by fact	Learning organization Double-loop (and some Deutero learning) Management by fact

Lean healthcare implementation seems to be complex and with a slow pace of development, especially when applied as a toolkit in isolated work cells Mazzocato et al. (2010). However, Leggat et al. (2015) found, through a systematic review, effective results when hospital managers include employees on decision making in parallel with an integrated approach between Lean philosophy and human resource management. Among the differences between lean concepts application in other service industries such as insurance or financial services and healthcare service, Hasle et al. (2016) emphasizes two complications, the first is Lean limitation on engaging the core processes of organizations and the second is the silo mentality. They also expound three supposed arguments for these events: (1) low lean maturity, (2) process and operations complexity, and (3) different value interpretations among workers (doctors, nurses, and managers).

Keeping a focus on the customer perceived value importance, after a brief explanation about the two first arguments, a deep further analysis will be addressed to the third argument, which is the different value interpretation between health professionals. According to Hasle et al. (2016), the Lean healthcare immaturity will not be fixed over the years of practice and application of already existing Lean manufacturing tools, a process of restructuring and developing custom tools is required. Regarding the complexity level of Lean manufacturing adaptation in healthcare organizations, the biggest impacting factor is the health professionals' inability to predict what results will be obtained in the intervention of each treatment and what will be the patient reaction.

Among other aspects, for instance, the fact that each patient can be exposed to different professionals, such as doctors, nurses, and management professionals, and that each class of professionals has a different perception of value for the patient, are also relevant components that represent the complexity of healthcare sector. These aspects, plus the fact that the presence of a common value perception by the entire organizational team is a key factor for a successful implementation of Lean philosophy, indicate that deep integration of the present value system is needed, given that the team perception does not always meet patients expectation (Hasle et al., 2016; Flynn, 2016).

Young and McClean (2008) assert that distinct individual's value different experiences, and indicated the existence of at least three relevant dimensions associated with value within the healthcare network:

- Clinical value: Focused on positive patient outcomes.
- Operational value: Related to cost-effectiveness matters.
- Experiential value: Customer perceived value.

This recognition is relevant for Lean implementation in the healthcare sector, since the classes concerned about the clinical value are nurses' and doctors' responsibility, whereas the operational value is covered by the management classes (Hasle et al., 2016). Young and McClean (2008) expose, as a conclusion of a literature review, that Lean healthcare is broadly focused on the operational value, making it difficult for doctors and nurses to embrace it as a beneficial cause to increase clinical and experiential value, what belong to their core activities. Hasle et al. (2016) also addressed the necessity of a straight patient involvement Lean approach in hospitals, in order to break down the stigma assumed by doctors and nurses that Lean covers especially the operational value. The authors also highlighted the importance of a smooth and professional Lean initiation, so as not to invade doctors' and nurses' authority sense. Anyhow, it is the responsibility of the Lean manager to ensure that all prerequisites are met before Lean implementation.

According to Radnor et al. (2012), the implementation of lean techniques in the service background is not the main obstacle, it is the public sector singularity that represents the higher adversity. They expose the progress of Lean healthcare as a similar pathway trodden by Lean manufacturing, in other words, Lean healthcare must go through steps like designing its own tools and enhancing Lean foundation until its elemental assumptions are recognized. The authors reinforce that there is no shortcut to a complete form of application and acceptance of Lean philosophy. Hasle et al. (2016) and Radnor et al. (2012) stress the necessity in clarifying and reaching a common value definition between customers when identified, and hospital professionals, and also a shared value system among doctors, nurses, and managers.

Anyway, healthcare is a system that requires a modern approach to respond to the current challenges arising due to the increase in life expectancy and the crescent changing on pathologies patterns (Andreu-Perez et al., 2015; Yaeger et al., 2019). Lopez et al. (2019) affirm that managing the continuum of health and disease, applying technological solutions, contributes to achieving a memorable patient experience. Lining up technology and healthcare on the development of new patient-centered medical products or projects facilitates the transparent and permanent monitoring of the health status of each human being. By making it possible for patients to be monitored, in a secure way, with access to their data, shows that healthcare providers are concerned in delivering patient-centric care, treating people and not their illness process (Andreu-Perez et al., 2015; Yaeger et al., 2019).

2.6.2 Lean Healthcare in Epidemic Crises

The behavior of Lean philosophy within health organizations during pandemic times was already investigated in 2009, during the H1N1 pandemic. According to Isaac-Renton et al. (2012), the 2009 epidemic accentuated the necessity for a continuous improvement process in the health sector. The authors stressed that the Lean concept was implemented for a fast response regarding the high demand for detection tests to combat the H1N1 virus in public Canadian laboratories. Through academic research to identify the response of Lean philosophy in the pandemic scenario, the authors claim that the standardization of repetitive processes, the implementation of flow cells, equipment leveling, and computer process modeling resulted in substantial improvements with respect to the response time in the detection tests.

In another research developed by Tortorella et al. (2020) to identify the effect caused by the COVID-19 epidemic on service business, it was observed that service provider organizations that had already implemented, in a structured way, the Lean service philosophy had lesser impacts related to the economic crisis caused by the pandemic, thus achieving superior performance through the provision of services with high quality. Reshad et al. (2020) suggest, from research developed within health organizations during the COVID-19 pandemic, that for a Lean philosophy implementation to become beneficial for all stakeholders, all health professionals involved must be engaged in the process and they have to believe in the solution.

In a more critical perspective, Mcgovern (2020) also defends that Lean concepts can provide a more assertive response from health organizations in times of pandemic, but according to his research about the United States health system response to the pandemic, many errors occurred in processes that became evidence of waste in the attack against the virus. Among the procedures he calls *unlean*, are highlighted the lack of standardized data collection on the part of all North American states and unnecessary work, such as the existing states competition on buying individual protection equipment and the independent development of applications that are intended for the same purpose in different states, which translates into a waste of effort. For Martichenko (2020), the COVID-19 pandemic brought out the importance of the role of supply chain management as a thinking system, in other words, a system integrated from a broader perspective and based on Lean principles.

Mcgovern (2020) reinforces the need for more responsible Lean implementation in the health area with higher management engagement, adequate capital allocation, staff continuous training, and the existence of autonomous teams for improvement implementation.

2.7 Hospital Operations Management

Operation management (OM) aims attention at the logical structure of product or service production, what demands a complete analysis of the whole process (planning, supplying, scheduling, control, and transformation activities), and general knowledge regarding the costs associated with the overall functioning of the production system (Souza & Lima, 2020). Castle and Jacobs (2011) declare that OM approaches are suitable for the healthcare area and can bring huge benefits, in terms of quality standards and process agility, as it is providing in the manufacturing field.

Service operations management translates the managers' activities, choices, and duties within service companies. Since hospital managers realized the importance of improving hospital operations in order to achieve patients' satisfaction and waste reduction, Hospital Operations Management (HOM) is currently standing out among health service providers (Souza & Lima, 2020).

From an extensive research work made by Dobrzykowski et al. (2014), where the authors analyzed the existing research about supply chain and operations management applied in the healthcare organizations, it is possible to deduce that hospitals can, through OM, reduce waste and increase earnings by implementing OM methods among the entire healthcare service delivery process to guarantee a smoothly patient, materials and information flow.

The mix between Lean philosophy and OM is beneficial for process analysis and improvement because the tools developed from Lean manufacturing can help to enlarge the system's robustness while adding value to the service process (Kleindorfer et al., 2005). According to Souza and Lima (2020), the connection between HOM and Lean principles is important to reduce/prevent the "silos" mentality present in the health industry.

Galetsi et al. (2020) stress that a robust data analytics system can provide improvements in services performed by health organizations while shortening associated risks, lowering unnecessary expenses, and seizing new opportunities.

3. HOSPITAL CONTEXT

This research was developed in a Portuguese public hospital context. This chapter describes the studied hospital with a greater emphasis on the imaging service, including the scheduling model used by this sector.

3.1 Hospital History

Since 2014 the hospital is considered one of the best Portuguese hospitals for achieving high global results on clinical excellence in its reference group in the national health assessment system. The hospital has a collaboration of more than 2900 employees and provides medical assistance to approximately 1.2 million people. To complement clinical diagnosis, the hospital imaging service has the capacity to perform many different exams, such as Ultrasound; X-ray; Mammography; Densitometry; Orthopantomography; Biplanar Angiography; Computerized Axial Tomography (CAT); Hemodynamic Angiography; Magnetic Resonance Imaging (MRI).

This hospital assumes in its mission and values, its commitment to serve the population with health care excellence, and has also implemented an integrated quality, environment, and safety management system, being one of the pillars of its strategic plan. This approach represents the intention of the administration of this hospital to comply with the requirements imposed by the Portuguese NHS, thus characterized as an example to be followed in the national territory. In any case, this hospital does not meet all NHS expectations due to the lack of sufficient resources to meet the high demand with an acceptable response time.

With regard to the practice of Lean philosophy adapted to health services, this hospital is at a very early stage with attempts to implement it in different areas. In the past, this hospital had the presence of a consulting company for a more comprehensive implementation of the Lean philosophy, with the creation of a small team responsible for identifying opportunities for improvement within the hospital, but this project ended when the administration was changed years later.

One of the reasons for the difficulty in implementing the Lean philosophy within the under-study public hospital may be due to the lack of interest on the part of state bodies, a kind of adversity by Lean concepts, making the dissemination of Lean philosophy somewhat complex within the public Portuguese hospitals. For a better perception, the hospital's imaging service and the exam scheduling model are described below.

3.2 Imaging Service

The imaging service has specific rooms for each specialty, being three for ultrasound, three for conventional digital X-ray, one for mammography, one for densitometry, one for orthopantomography, one for biplanar angiography, one for hemodynamic angiography one for TAC, and three for MRIs. The exam prescription is submitted, via the Glint computer system, by a specialist doctor who identifies the need for a more accurate diagnosis for a given patient. Given that ultrasound, CAT and MRI are specialties in critical waiting list situations facing similar issues, MRI service is the focus of this study, including neuroradiology and radiology which are subspecialties belonging to MRI diagnosis.

Neuroradiology refers to any MRI performed on the neck and/or head, particularly in the skull, spine, sinuses, ears, and any other area related to ophthalmology. Radiology refers to all MRI exams done in the rest of the body, mainly associated with problems of articulation and mobility.

The exams are performed by technicians trained in operating the MRI machines. For both neuroradiology and radiology, the MRI specialist doctors are responsible for screening the clinical priority of exams awaiting scheduling by technical assistants. Imaging physicians are also responsible for determining which protocol must be followed and, after the exam has been performed, for uploading the MRI report on the computer platform. The protocols serve to guide MRI technicians so that they have indications about which images should be captured, thus the presence of the doctor during the examination is not mandatory.

3.3 Imaging Service Scheduling Model

The imaging scheduling system at the hospital is partially computerized. In order to request an MRI, the specialist doctor has, during the consultation with the patient, request the exam by stating which images will be necessary to be taken as well as the symptoms presented by the patient. In the sequel, the order is sent via the computer system to the imaging sector, where it is printed and delivered to a radiology or neuroradiology specialist doctor so that he/she can, based on the medical prescription, determine the urgency level and the protocol to be followed.

The mentioned process out of the computer system is present between the urgency level identification and the MRI exam scheduling phase. After specifying the urgency level of the exam, the physical document is filed so that assistants can manually make MRI schedules according to the availability of resources from the imaging services.

The urgency level varies from 1 to 3, while level 3 stands for the least urgent level, and level 1 is the most priority level. The time limit stipulated by the Portuguese government to perform MRI is 90 days from the time of clinical indication, if these deadlines are not met, the patient must be referred to other units of the national health service or to other entities with agreements or conventions. The MRI exams are scheduled by the technical assistants, based on the system capacity, the priority assigned to the exam prescription, and the information related to human resources vacation. The assistants try to schedule exams for a date about 8 to 15 days before the medical appointment that is already scheduled by the specialty that prescribed the MRI exam.

Figure 10 visual represents the MRI scheduling system through the Business Process Modeling Notation (BPMN).

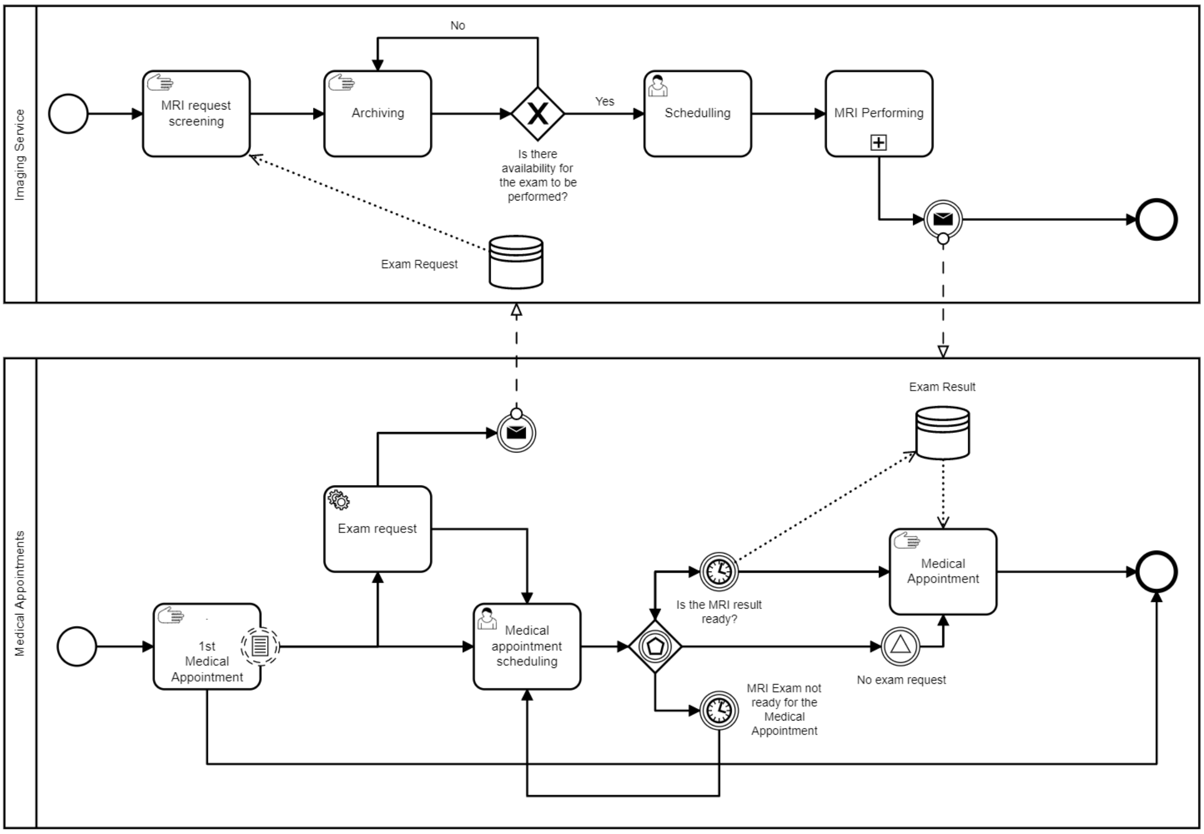


Figure 10 - Business Process Modeling Notation of MRI scheduling system

4. PROBLEM CHARACTERIZATION

In order to comprehend the ongoing status of the hospital, it is necessary to study the way the process is managed. This chapter has the function of clarifying the problems faced by the hospital and precedes the solution formulation phase. The purpose of this study is explanatory and intends to answer the raised research questions about the events covered in the under-study hospital. The exploratory component of this study embodies the search for solutions to the addressed problems.

Given that the main issues addressed in this dissertation have been exposed by the hospital administration, the first step of the action-research process, which is the diagnosis phase, occurred through meetings between the hospital management and the dissertation`s author for the questions to be correctly understood for a later problem definition.

The main issues addressed in this study are the occurrence of ineffective medical appointments, the presence of constraints for MRI capacity planning, and the existence of constraints for monitoring equipment availability. The work related to the problems described in the following sections, and solutions described in the following chapter, have been already published in two different articles (Barretiri et al., 2021a, and Barretiri et al., 2021b).

4.1 Ineffective Medical Appointments

Medical appointments missed due to patient's no-show is a known fact among health organizations. Less known, but also of great relevance, is the occurrence of medical appointments that need to be rescheduled due to the lack of MRI exam results.

With an annual volume of 12000 MRI exams per year, the hospital finds it difficult to reduce the expanding waiting list. In 2019 the number of MRI requests on the waiting list exceeded 9000 patients. The ideal waiting time for different levels of urgency would be 30 days for level 1 exams, 60 days for level 2 exams, and 120 days for level 3 exams, but due to the limitations of the computer system, it was not possible to obtain information about the waiting time for each level of urgency for MRI exams. As the current waiting list management computer system used in the imaging sector of the hospital under study considers the number of patients and not the number of exams requested, when a patient needs to do more than one MRI exam, only one exam will be added to the waiting list. It happens because, in most cases, patients perform the exams in the same appointment, using, depending on the exam’s duration, one or two slots in a row. As updating or changing the computer system is not in the hospital administration's plans, this issue will not be addressed in this work. Currently, the ratio of MRI exams per user is 1.38, which means that some patients execute more than one MRI exam.

Even with recent investments in new equipment, the imaging sector is still unable to respond to the growing demand for MRI exams.. Technological advances and associated benefits with medical diagnosis reflect the high demand for imaging techniques. In Figure 11, it is possible to observe an increasing trend in the annual demand for MRI exams requested between 2017 and 2020.

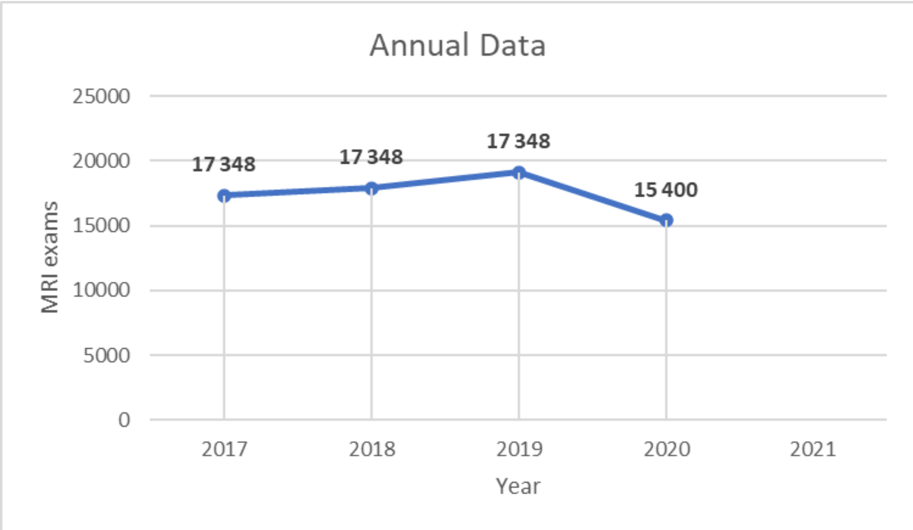


Figure 11 - MRI exams prescribed at the Hospital from 2017 to 2020

In 2020, there was a drop in the requests for these exams due to the new scenario aroused by the restrictions imposed in the first phase of the COVID-19 pandemic. In any case, it is possible to observe in Figure 12, the graph with the analysis of the first semester of the years between 2017 and 2021, in which the increasing trend remains in the hospital under study.

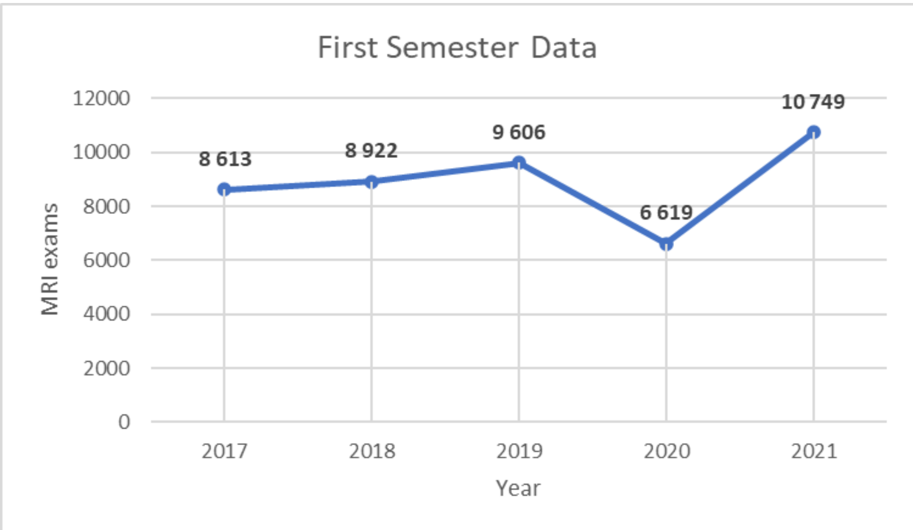


Figure 12 - MRI exams prescribed at the Hospital in the first semester from 2017 to 2021

Due to the large volume of MRI requests and the limited capacity of the imaging services, some exams remain on the waiting list, even though there is a medical appointment related to these exams. Also, the fact that the MRI exam schedule stage is not performed in a computerized system, some medical appointments may not be properly identified, which results in scheduling exams with a date after the medical appointment. Both cases lead to unnecessary motion of the patient to the hospital, and also the loss of the doctor's time in caring for the patient without the result of the respective MRI examination, resulting in an ineffective medical appointment that has to be rescheduled.

Another current possibility of failure due to the hand-operated process of scheduling MRI exams is the loss of physical requests containing the priority level of MRI and the accomplishment protocol. The hospital administration confirmed the occurrence of this type of failure, but it could not be quantified. Given the document is the only source of information used by assistants when scheduling MRI exams, by losing physical requests consequently leads to the non-scheduling of the respective examination which are consequence of the lack of an end-to-end computerized system. The proposed alerting tool can contribute to the imaging sector to identify MRI exams that have not been scheduled by enabling data to cross between medical appointments and requested MRI exams.

The fact that the urgency level screening and the determination of the protocol to be followed are manually classified and filed in physical form, on the one hand, it entails the impossibility of obtaining statistical data so that the existing percentage of MRI exams for each level can be calculated. On the other hand, the lack of a centralized computer system culminates in the inability of hospital management to identify the scheduling of medical appointments for the analysis of MRI results that are scheduled for a date prior to the exam date, which also causes unneeded motion by the patient to the hospital so that the requesting physician finds out that the MRI exam has not yet been performed.

Besides causing great waste of time and resources for the hospital, these circumstances represent a negative experience for patients who attend the hospital without any progress regarding the diagnosis of their clinical condition. An algorithmic model capable of crossing the data referring to the scheduled appointments with the scheduled MRI exams data has the potential to function as an alert indicating appointments that will happen before the corresponding exam is carried out or even if the exam is not scheduled due to lack of imaging sector capacity or due to data loss.

For a better understanding of the problem faced by the under-study hospital, Figure 13 visually describes it. D1 is the starting event and represents the first medical appointment that generates one or more MRI requests. D3 represents the subsequent medical appointment that depends on the MRI result. D3 is scheduled by the medical doctor on D1, without knowing the MRI possible dates. In this scenario describing the problem, at least one exam will be scheduled on a date after D3, in this case, represented by D4. It may happen that some other exams will be scheduled before D3, in this case, illustrated by D2.

Thus, the problem presented by the hospital management occurs when an MRI exam is, due to lack of capacity or by human error, performed on a date after D3. Delayed MRI examination(s) requires that D3 be performed again on a date after D4, which makes the appointment scheduled at D3 to be an ineffective medical appointment.

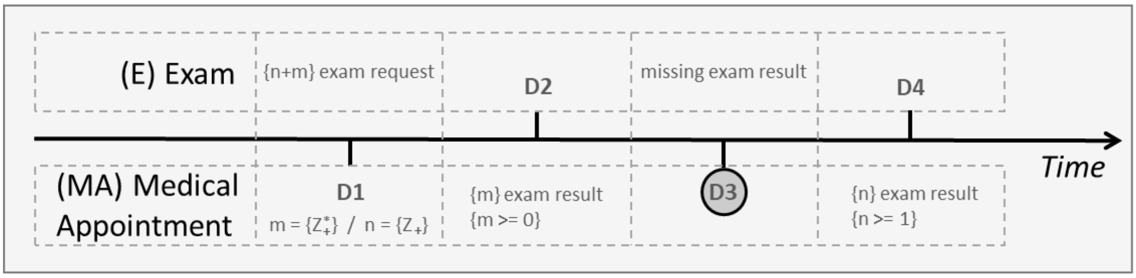


Figure 13 - - Ineffective Medical Appointment Occurrence

At the beginning of the project, hospital management indicated that in most cases of ineffective medical appointments occurrence, the medical request for the MRI exam is in a non-traceable waiting list, since the MRI requests containing the necessary information for scheduling the exams exist only in physical form.

Aware of the limited data available for the development of the study, and as it is a hospital unit that must guarantee the protection of data and the privacy of patients, it was perceived the need for a quick and effective intervention to reduce the existing waste resulting from ineffective medical appointments. Aiming for a fast and low cost response action, it was developed the Anomaly Detection Algorithm (ADA) by utilizing the databases provided by the imaging service without adding the need to acquire external resources. As the hospital has in a computer system data regarding scheduled appointments and about scheduled magnetic resonance exams, this is enough data for the algorithm to identify ineffective medical appointments, as the process that is still done manually does not interfere with the result obtained, since exams that are still in the queue and have not been scheduled are considered late exams by the algorithm.

It was identified, in a first analysis of retrospective data over a one-year period, that 16% of subsequent medical appointments that were scheduled to analyse MRI exam results were ineffective, which equates to a financial loss of € 99.580. The data referring to this analysis are graphically represented in Figure 14. The versatility feature present in this tool is an outstanding differential, given that the algorithm can be replicated among other hospital sectors experiencing similar inefficacies.

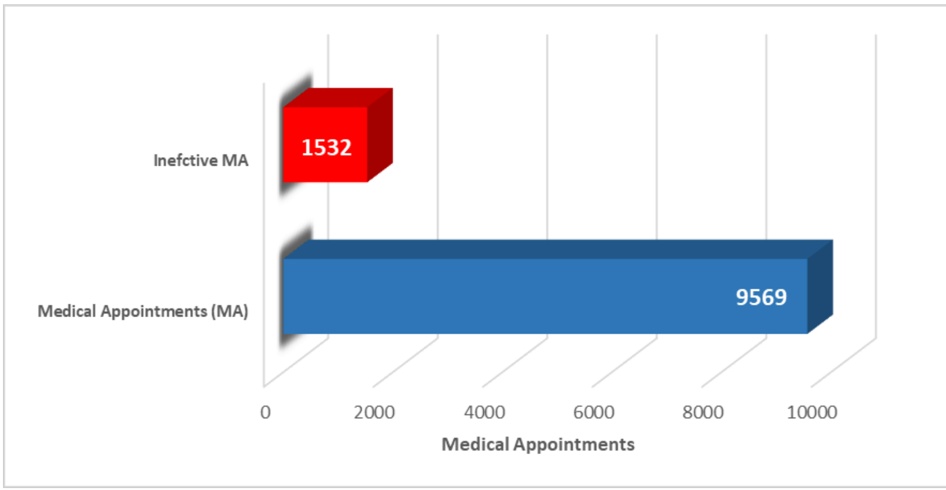


Figure 14 - Ineffective Medical Appointments (one-year retroactive analysys)

4.2 Capacity Planning Constraints

As mentioned in the literature review, the hospital patient scheduling system plays an important role in the healthcare organization's overall performance and patient flow (Conforti et al., 2008). In the national Portuguese public health service, the rate of MRI equipment per habitant is low and does not allow all medical diagnosis that requires imaging exams to be made using the MRI technique. In an attempt to relieve the public sectors of imaging that perform MRI exams, the Portuguese Health National Service prioritizes, when possible and in case of non-urgency, the use of other resources, such as X-ray, ultrasound, and CAT for diagnostic imaging. Anyway, the demand for this image capture technique through a magnetic field is much higher than the internal production capacity of Portuguese hospitals.

This section of the dissertation is the result of a one-year (Feb 2020 – Feb 2021) research and was developed in a large Portuguese public hospital in which the imaging sector works every business day from 8:00 to 20:00. The average number of monthly requests for MRI exams is, during the study period, equal to 1550, against an internal capacity, considering days worked as weekdays, of 840 MRI exams per month.

The imaging department works with the possibility of running overtime during the weekdays and at the weekends, making it possible for the internal production to reach maximum average production of 1480 MRIs per month, which would bring the average monthly internal production closer to the demand. By internal production, this article refers to all MRI scans performed on weekdays and overtime, including weekends. The data referring to monthly internal production and monthly demand for MRI exams is presented in Figure 15.

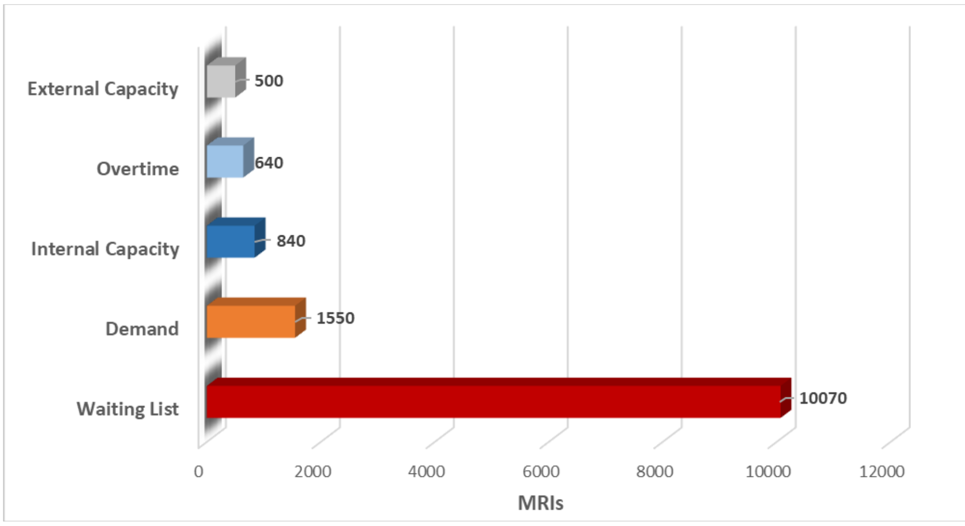


Figure 15 - Monthly Demand and Monthly Productive Capacity

Considering that the current waiting list for MRI exams is 10070, the average response time for MRI scans is 6.8 months. If only the weekdays are considered, with an average production of 840 MRIs per month, the response time goes up to 11.9 months, which means that a patient in need of medical diagnosis through MRI exam, with a low priority level, may have to wait for almost a year for this exam to be performed.

The priority levels in the imaging sector of the concerned hospital can differ from high, medium, and low priority. The Portuguese government stipulated that 90 days is the time limit for patients to wait, in case of no urgency, for MRI exams to be performed, taking into account the date of doctor requisition (Ministério da Saúde, 2017).

If the hospital is unable to meet this deadline, the patient has to be routed to other national health service entities or private units with agreements or conventions. However, the possibility of referring patients to another public entity is unlikely since they are also unable to respond to internal demand and the outsourcing to private units represents a high cost to public coffers.

The fact that capacity restrictions, at the under-study hospital, are currently calculated using annual averages, implies that results are presented in a non-absolute form, which can be interpreted in an ambiguous way. Another particularity is the fact that the number of holidays and working days varies monthly and from year to year, implying variations that significantly alter the results obtained. Also, the fact that the personnel vacation period (July 15th to September 15th) indicates, due to the lack of professionals, the impossibility for overtime MRI performing during this period, is a restriction that, if not considered, results in misinterpretation of results.

This ambiguous interpretation can lead to wrong decisions from the hospital management, considering that it is based only on average data, which may represent an unreal scenario. Early investment in equipment or mistaken planning of future budgets, wrong personnel scheduling, and unnecessary outsourcing of services, are standing out among erroneous decisions that can be taken by the hospital administrative sector due to lack of precision in the information provided with respect to the response time for waiting list reduction.

The use of a mathematical model capable of calculating the ideal monthly internal and external production for cost reduction aims to mitigate this problem.

Due to the high cost associated with performing MRI, these errors can lead to high financial losses for the health organizations. In the hospital where this work was carried out, the possibility of reducing the long waiting list for MRIs is in the out contracting of the service for one external supplier selected through public tender. Because of the budget constraints, this externalization has a maximum monthly limit (500 MRIs) that makes it impossible to carry out a high number of MRIs by the external supplier.

For the patients, the poor operational management and the budgetary constraints are converted into a long waiting time to obtain adequate medical treatment through high-quality imaging exams. This late treatment is reflected in a worsening of the patient's clinical condition, thus eliminating the possibility of preventive treatment, and consequently moving to corrective care. This consequence makes patients dissatisfied with the services provided by the hospital given that they do not have efficient low-cost alternatives.

Currently, the monitoring of the waiting list management for MRI exams is done in an Excel spreadsheet with limited functionalities. In these circumstances, relevant data such as the internal and external average monthly production quantities, need to be manually inserted. As this Excel spreadsheet does not operate dynamically, this is a time-consuming activity and does not guarantee a reliable result, given that this procedure does not consider the working days' variation in each month of the year neither the monthly holidays nor the personal vacation.

4.3 Equipment Availability Monitoring Constraints

The hospital object of study of this dissertation does not have a TPM system implemented for the maintenance of the 20 equipment in the imaging sector. TPM is a pertinent technique applied within the Lean philosophy to reduce machine downtime, production lead time (Ramakrishnan & Nallusamy, 2017), and to reduce waste by removing the variation that occurs due to machinery failure (Haddad, 2012). In view of the hospital's intention to implement a Lean healthcare culture, the lack of such a holistic methodology represents for the hospital a failure to be revised.

Since the imaging sector was, during this project development, only controlling preventive maintenance, the hospital administration expressed their intention to analyze and control indicators of reliability, corrective and preventive maintenance time, availability, and effectiveness of all imaging sector's equipment. Considering Jeong and Phillips's (2001) statement about the OEE's functionality to measure the TPM implementation success, identifying the real productive time of the imaging sector through the implementation of the OEE measurement practice was the first research intention.

Maintenance planning must be based on relevant and reliable information. In the hospital imaging sector, there is newer and older equipment, some have already gone through parts replacements, some may have suffered accidents and others may have an advanced useful life. One machine may have had the same problem three times in a month, while another never stopped for that same reason.

Control and monitor the complete maintenance history of all equipment is a strategic approach missing in the hospital. The starting point of planning must consider this history so that the manager can define how to distribute the team's efforts and keep the equipment working. If a stop to change a part is expected, it must be programmed so that this occurs before the break, preferably in a period outside the work cycle of that sector. This type of control is also part of international standards of management and quality assurance, such as the ISO9001 quality certificate, under which the hospital under study is certified.

The imaging sector understands the need to obtain maintenance indicators that represent a mirror of the company's recent past, with regard to the health of imaging equipment. Through it, it is possible to understand what the best strategies are to prevent mistakes from recurring and optimize the technicians' work.

Because of the limitations imposed by the Portuguese government due to the covid-19 pandemic, the author of this dissertation was not authorized to develop in-person work at the hospital, making it impossible to obtain data such as setup time, equipment failures, unscheduled stops, exam variation time, among others, which are relevant data for the calculation of the OEE. There were attempts to obtain some data directly from the equipment since it is a more reliable way of analyzing data, but it was not possible for the fact that the machines do not record the mentioned data in a discriminated way.

5. Improvement Proposal

Through the development of specific tools, the achievements expected from the resulting solution can benefit patients, doctors, and the health organization once hospital management can take action by having information otherwise not available regarding the system's inefficacy. The proposed tools are presented below.

5.1 Ineffective Medical Appointment Alerting Tool

The solution development was based on the central issue presented by the hospital during the project progress, which is the occurrence of medical appointments without the respective result of a previously requested MRI exam.

Incorporating a centralized computer system is an option to create communication between sectors, which depends on financial investment, and a long adaptation time. As interactions between sectors are complex and the monetary resources are limited in public organizations, a computer algorithm has the function of economically and quickly solving problems that depend on mechanical steps to analyze a high volume of data. Implementing the study outcomes into the imaging sector of the hospital in question has the function of preventing the occurrence of ineffective medical appointments and promote superior patient satisfaction.

Focused on finding a plausible solution with the available resources, the developed model was structured to identify ineffective future medical appointments, due to a not performed imaging service requested by the same specialist (by the time of the consult appointment), so that the hospital administration can try to manage to anticipate the delayed MRI exam so it is performed before the medical appointment (an unlikely action due to lack of capacity of the imaging service) or reschedules the medical appointment. A delayed MRI means an MRI that will not be ready for the medical appointment that was requested, which is normally associated with scheduling problems in the imaging service due to lack of production capacity or human error.

The proposed solution analyzes both data from subsequent medical appointments and the MRI appointments waiting list to detect when a subsequent medical appointment (that requested an MRI exam) will occur before the MRI exam be performed (meaning, an ineffective medical appointment due to lack of MRI results). For a better perception of the developed tool, a brief definition of VBA will be presented before the description of how the data is automatically treated and on the tool's operation.

5.1.1 Data Collection and Cleaning

The main component addressed by this research is the identification, by using the hospital's existing resources, of the reasons for the occurrence of scheduled medical appointments (with prescribed exams) dated before the date of the respective MRI exam. This study then suggests a solution capable of alerting about the existence of this problem, also alerting about the most relevant case, which are medical appointments that will occur without the existence of an appointment for the requested exam.

The hospital management sector provided encrypted data for a retroactive period of one year (2017 – 2018): medical appointments database and MRI exams database. These databases were used for the development phase and validation phase, and also to identify the percentage of delayed MRI exams that occurred in that period of time. This allowed developing an algorithm to analyze planned MRI exams and planned medical appointments to alert the occurrence of ineffective medical appointments.

The medical appointment database (Figure 16) consists of data type (Consultation or Exam), a process number, which corresponds to the patient identification number in the hospital's computer system, the date for which the subsequent medical appointment was scheduled, and information about which service is responsible for the appointment scheduling. The database includes both medical appointments requesting MRI exams and also medical appointments without requests for MRI exams. The algorithm correlates data from the medical appointments and from MRI exams databases, based on the type of appointment, and also based on the key database fields, which are the process number, the exam prescription date, and the prescribing service.

Type	Process Number	Prescription Date	Prescribing Service
C	30000054	09/11/2141	20
C	30000075	23/08/2141	4
C	30000162	13/08/2141	3
C	30000162	03/12/2141	3
C	30000183	11/08/2141	25
C	30000186	27/08/2141	9
C	30000222	22/09/2141	21

Figure 16 - Medical Appointment Database (encrypted data sample)

The MRI exams database (Figure 17) provides similar information as the medical appointment database, consisting of type, the process number, the exam prescription date, the performing date of the exam, the prescribing service, the episode number, which corresponds to a global count of performed exams at the hospital and the performing service, which can, for example, be radiology or neuroradiology and the number of the episode. The key MRI exam database fields are the process number, the prescribing service, the scheduled date of the exam, and the exam prescription date.

Type	Process Number	Prescription Date	Performing Date	Prescribing Service	Episode	Performing Service
E	297051423	04/02/2140	25/11/4637	3	927238545	AA
E	297050619	11/10/2140	25/11/4637	28	927220854	DD
E	297050529	06/11/2137	25/11/4637	3	927188820	BB
E	297050205	12/05/2140	25/11/4637	3	927184911	AA
E	297049329	03/08/2138	25/11/4637	3	927159414	CC
E	297049128	20/05/2139	25/11/4637	3	927154878	AA
E	297049089	23/05/2141	25/11/4637	26	927144846	EE

Figure 17 - MRI Exams Database (encrypted data sample)

The anomaly detection algorithm runs under Excel VBA, where the external data is obtained through a *power query* connection. In addition to making the data selection and organization process error-proof, the benefits of using the *power query* function translate into reducing the effort spent on programming language and consequently reducing the execution time. In summary, the function of the query in this study is to extract the necessary data from the existing database, clean, remodel, add new data and merge the two databases so that a new Excel table is generated for the algorithm analysis. These functions allowed to eliminate repeated data, reordering, and changing table structure, and adding a new column with the type of appointment.

Figure 18 represents, through the flowchart, the data collection, and cleaning process that happens just before the VBA language starts. Part of the *power query* formulation can be seen on Appendix II – Power Query.

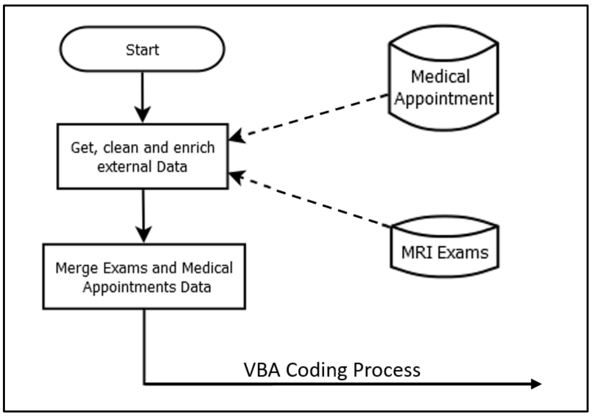


Figure 18 – Power Query Flowchart

5.1.2 Anomaly Detection Algorithm

In this section, the ADA developed for the identification of ineffective medical appointment occurrence, including its decision parameters as well as its main purpose, is described. The first part of the algorithm is related to the organization of the data of the two databases (medical appointments and MRI exams) and was developed with Excel *power queries*. The second part of the algorithm is dedicated to the identification of ineffective medical appointments and was developed with Excel VBA. The details of these parts are described below, and the general organization of the algorithm is represented in the flowchart of Figure 19.

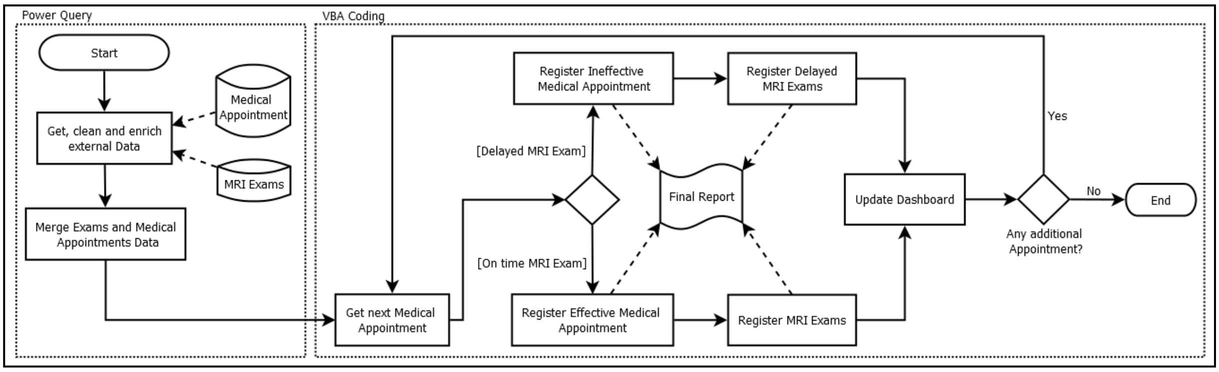


Figure 19 - Algorithm Flowchart

The resulting spreadsheet (Figure 20) from the *power query* contains both the data for medical appointments and MRI exams for a given period. On the databases merging phase, the power query sorts multiple columns respecting to the following order: (1) process number in ascending order; (2) prescription date in ascending order; (3) episode type in ascending order. This reorganization ensures that the data on each patient is grouped in the spreadsheet. Therefore, it ensures that each group of patient data is organized by date, and finally, with the ordering of the type of episode, it ensures that medical appointments with a date equal to the date of the MRI exam prescription are placed in rows preceding the exam data since it refers to the medical appointments that prescribed the exam, these rows will not be marked as ineffective.

Type	Process Number	Prescription Date	Performing Date	Prescribing Service	Episode	Performing Service
C	349536	06/06/2138		27		
E	349563	20/06/2136	04/07/2138	19	922286943	BB
C	349563	21/08/2136		19		
E	349566	11/11/2135	12/06/2138	25	918109791	BB
C	349571	20/11/2137		19		
C	349588	04/06/2138		19		
C	349620	03/07/2137		5		

Figure 20 - Merged Data (encrypted data sample)

Considering that each row of the table generated by the *power query* is previously structured so that the algorithm can easily identify the ineffective medical appointments, the fact that the MRI exam prescription date and the medical appointment date are placed on the same column, and that this column is the second priority on the multiple column sorting, it guarantees that medical appointments with a date after the date of the respective MRI exam will be placed in a subsequent row within the spreadsheet table for the top to bottom analyses run in a proper way.

In the case of a retrospective database, the designed algorithm is capable of crossing the medical appointments database and MRI exams database in order to identify the failed exams and the consequent ineffective medical appointment, based on the patient process numbers, on the prescribing service and comparing the medical appointment date with the exam performing date. Failed exams correspond to exams that occurred on a date equal to or later than the medical appointments.

In the case of a database related to future medical appointments, the function of the algorithm is to alert the occurrence of ineffective medical appointments, including cases in which the exam date has not yet been scheduled. The algorithm is designed to present a general summary that indicates the percentage of failed MRI exams as well as the percentage of ineffective medical appointments that will occur in the analyzed period.

In this overview, more detailed information (detailed by service) is numerically and graphically represented (Figure 21) within the dashboard spreadsheet section. The dashboard contains controller buttons for the user to *run* the algorithm through the VBA language, *refresh* the external data, and *save reports* (separated by service) with detailed information about all ineffective medical appointments.

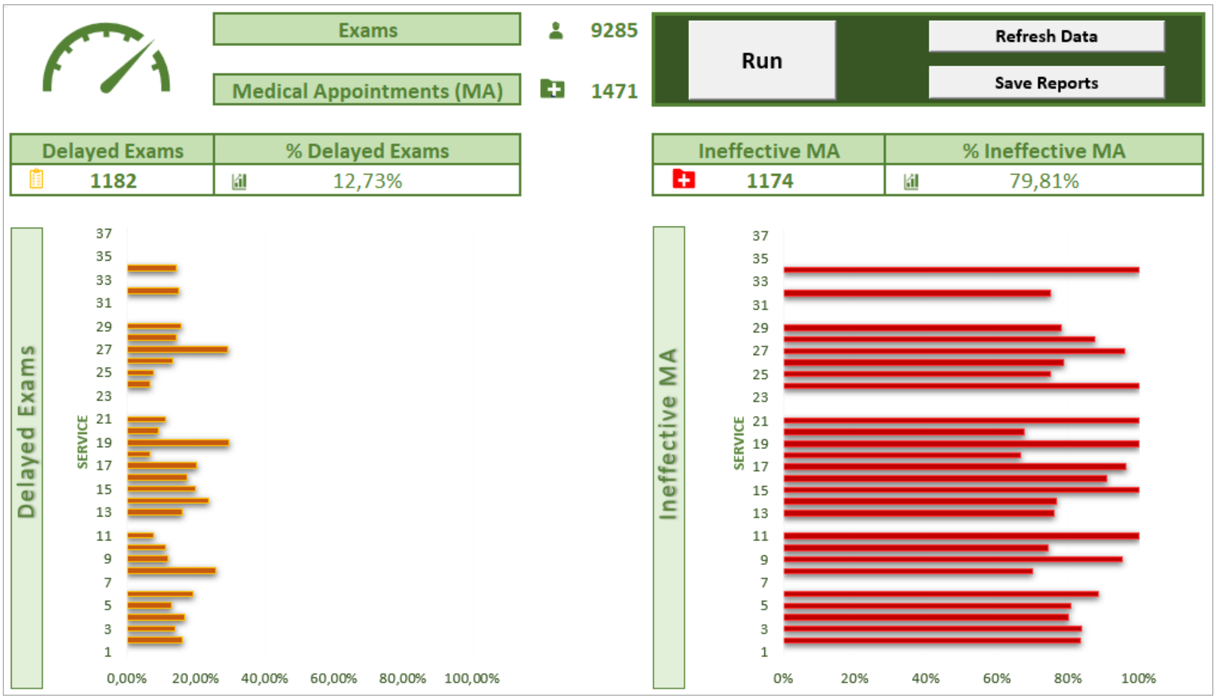


Figure 21 - Anomaly Detection Algorithm General Summary

This information is extremely important for the imaging management department to monitor the evolution and recurrence of ineffective medical appointment cases as well as the percentage of failed MRI exams so that they can intervene to reduce waste related to non-effective medical appointments. Such detailed information may be sent to the hospital services, so they become informed about the coming ineffective medical appointments.

This detailed information is grouped by hospital service in separated documents for ease of use by the respective hospital services (and also each hospital service receives only its respective information). Such information contains all the needed data for a proper traceability procedure, so the hospital services are able to identify the upcoming ineffective medical appointments (and the to-fail MRI that is causing it) and may take action to avoid it.

Considering the data structure referred to in 5.1 and displayed in Figure 17, the algorithm first searches in the merged data spreadsheet for an MRI exam in the column that contains the type of episode by applying a top-down analysis. As soon as it finds one, a verification is made on the following rows as long as there is information about medical appointments for the same patient, that is, with the same process number. Only one ineffective medical appointment is enough for the MRI exam under analysis to be marked as delayed.

The algorithm also checks if the medical appointment comes from the same service presented in the MRI exam data. If these data match, the algorithm checks whether the medical appointment date is equal to or less than the exam date. If this scenario is identified, the model marks the medical appointment as ineffective and counts that failure for the respective service. The looping process continues until a different process number be found.

To represent a more detailed results dashboard, including percentages of effective and ineffective medical appointments, all MRI exams are identified and counted by service. The algorithm also generates a final report containing the data previously described for each ineffective medical appointment. The final algorithm function is to activate the power queries that aim to filter and create separate sheets containing the list of ineffective medical appointments broke down by service. Unscheduled MRI exams are automatically highlighted through the final power query process so that the imaging sector and the requesting services can directly identify and manage it.

The final report (Figure 22), grouped by hospital service, is generated containing key information both from MA and from MRI exams, where each report row represents an ineffective medical appointment, with the following fields of information: process number; prescribing service; exam prescription date; exam scheduled date; subsequent medical appointment date; the incidence of ineffective medical appointments; the amount of scheduled ineffective medical appointments.

Process Number	Prescribing Service	Prescription Date (MRI exam)	Performing Date (MRI exam)	MA Performing Date	Ineffective MA Incidence	Scheduled MA
342057	7	23/08/2136	13/03/2139	29/10/2138	2	1
345810	7	24/07/2138	12/09/2138	08/06/2138	0	1
366684	7	07/10/2137	15/04/2138		1	
377022	7	08/06/2137	24/05/2138	01/03/2138	0	1
380928	7	28/02/2138	04/01/2139	19/12/2138	0	1
386265	7	26/07/2138	24/05/2139		2	
418302	7	30/07/2137	25/06/2138	06/04/2138	3	2

Figure 22 - Services Related Final Report (encrypted data sample)

The "ineffective medical appointment incidence" and the "scheduled medical appointment" field are of utmost importance for the hospital management team in the decision-making to identify the most critical cases of patients waiting for MRI scans. Patients with a high number of ineffective medical appointments can be prioritized if the hospital administration understands that there is this need. Regarding the field of already scheduled medical appointments, if the cell is highlighted in red, it indicates the absence of a medical appointment to analyze the results of MRI exams. In contrast, a high number of scheduled medical appointments for the same patient can represent a failure in the medical appointments scheduling system, which can increase the general medical appointment waiting list, thus affecting other patients.

From the algorithm user's perspective, this computer application can perform several complex tasks with the push of a button. In custody of the databases referring to the medical appointments and expected MRI exams, the algorithm user must rename both files to a pre-established default name and then move these files to a folder previously set as the default. When opening the excel file containing the algorithm, the external data is automatically obtained and sorted by the *power queries*. Thus, after the data processing phase that takes an average of 0.93xseconds per information line, when the "run" button is pressed, all the algorithm operations described in this chapter are performed automatically in an average time of 1.84x seconds per information line.

For a global sense of the algorithm processing time, during the analyzes of the period of 1 year (2018 - 2019) of a general database (MRI exams and medical appointments) containing 461.451 lines, the whole process was completed in approximately 128 seconds. It was not possible to quantify and compare the time spent by the hospital management to manually uncover future ineffective medical appointments, as this process was not even performed due to the large volume of MRI exam requests.

After this quick process, the hospital has at its disposal a dashboard including an ABC analysis diagram (Figure 23) containing relevant information to identify which services are most critical. The dashboard also displays an overview table with information on the amount, per service, of late MRI exams and ineffective medical appointments. The final report is generated in parallel with the dashboard and has the function of feeding the individual reports for each service, which allows the hospital to make future decisions based on evident data about ineffective medical appointment occurrences.

For a better understanding of the complexity of the developed algorithm, the most relevant part of the VBA coding for data analyzes from MRI exams and scheduled medical appointments is presented in Appendix I – VBA Codding.

Service	Individual %	Accumulated %	Classification
3	29,8%	30%	A
5	17,5%	47%	A
20	16,6%	64%	A
26	6,6%	71%	B
9	5,2%	76%	B
13	3,0%	79%	B
14	2,8%	82%	B
10	2,7%	84%	B
6	2,6%	87%	B
29	2,1%	89%	B
17	2,1%	91%	B
27	2,0%	93%	B
28	1,8%	95%	C
16	0,9%	96%	C
18	0,7%	97%	C
8	0,6%	97%	C
32	0,5%	98%	C
25	0,5%	98%	C
19	0,4%	99%	C
2	0,4%	99%	C
4	0,3%	99%	C
34	0,3%	100%	C
11	0,1%	100%	C
15	0,1%	100%	C
21	0,1%	100%	C
24	0,1%	100%	C
35	0,0%	100%	C
36	0,0%	100%	C
33	0,0%	100%	C
37	0,0%	100%	C
31	0,0%	100%	C
1	0,0%	100%	C
12	0,0%	100%	C
7	0,0%	100%	C
30	0,0%	100%	C
23	0,0%	100%	C
22	0,0%	100%	C

Class	Breakdown	Services Ratio	Value Ratio
A	80%	8%	64%
B	95%	24%	29%
C	100%	68%	7%

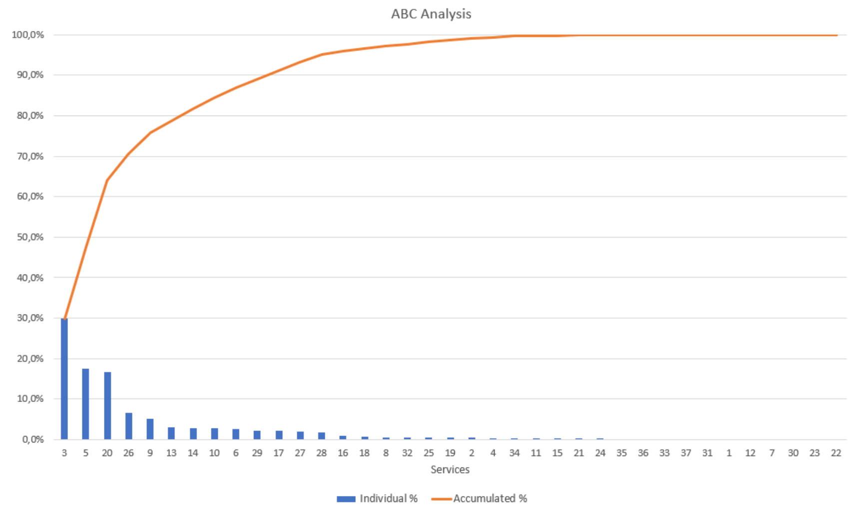


Figure 23 - ABC Analyses Diagram

5.2 Capacity Planning Optimization Model

The imaging sector of the hospital where the project was developed needs to manage the capacity of internal and external production to reduce the waiting list. Thus, this work aims to implement an optimization model capable of maximizing internal production by minimizing monthly costs in order to reduce the waiting list.

Based on an already existent and non-automated spreadsheet table used by the hospital imaging sector to analyze the response time variation in accordance with internal and external production capacity variation and in parallel with the hospital management contribution in the data analysis process, an optimization model capable of maximizing the internal production by minimizing monthly cost and by considering capacity restrictions and the relevant parameters in order to reach defined objectives was developed.

Before presenting the optimization model a brief description on mathematical modeling is presented next.

5.2.1 Optimization Model

To better understanding how the developed linear optimization model works, this section describes the problem modeling. The objective is to reach and maintain the waiting list close to the pre-stipulated 90 days by guaranteeing the minimum MRI external production, thus ensuring that internal production is maximized, with priority for the weekdays and, if possible, without practicing over time.

Among all the problem constraints, the monthly capacity constraint is the one that varies every month, simply because the number of working days on each month of the year is not constant. Also, during the holiday period, there are restrictions that influence the final result of the monthly production capacity.

Bearing in mind that the hospital has the objective of reducing the waiting list as quickly as possible, the optimization is done globally (three years period), but the initial months are prioritized through algorithms by considering all internal and external capacity constraints.

In short, the system restrictions are, monthly capacity constraints, with variations in production quantities from weekdays to weekends. There are also restrictions on specific holidays when the imaging sector does not work (Good Friday, Easter, Christmas, and New Year's Eve).

The model aims to assist the hospital in reducing the waiting list by maximizing internal production before contracting external service in case of a waiting list higher than 90 days. In this sense, the model was developed to work dynamically in the data relationship between different months through algorithm inclusion.

Another aspect is the constraints imposed by the annual vacation period, which, in July and September, reduces the overtime weekdays and weekends production capacity to 50% and, in August, reduces the overtime production by 100%. These restrictions are automatically imposed through an algorithm that identifies and restricts to zero the amount of production in extraordinary hours in the period from 15 July to 15 August.

A relevant feature of this tool is the fact that it dynamically generates the monthly tables (three years period from the starting month) so that the optimization model can distribute, based on the financial cost, the optimal quantity to be internally produced on each day of the month and also the optimal quantity to be externally produced if necessary. Thus, the algorithms' function is to automatically generate the existing constraints, according to each month's conditions, conditions that can vary according to the month length, the existence of holidays in each month, and the possibility of a reduction in production due to staff vacations.

Another restriction that is automatically generated by another algorithm is the minimum quantity to be produced in each month. This algorithm calculates, based on demand, in the waiting list, and in the maximum waiting time pre-stipulated objective, the minimum production quantity for each month. The same algorithm also considers, through the dynamic tables, the number of working days of each month, taking into account the holidays that the imaging sector does not work.

Thus, the proposed mathematical model, combined with all developed algorithms, can minimize the monthly production cost, since the unit cost per MRI internally performed is considerably lower than the external cost production.

With the maximization of the internal MRI production, the hospital can gradually reduce the waiting list until reaching an average response time of three months. After reaching this goal, the model must, based on the monthly demand, establish monthly production capable of sustaining the waiting list near to the limit stipulated by the Portuguese NHS.

As it is an optimization problem within the operational research area, the mathematical notation of the parameters, the decision variables, the objective function, and the problem constraints must be defined. Thus, the mathematical notation is characterized next:

Parameters:

The parameters are of 3 types:

1 - To indicate the cost of each MRI produced:

$\mathbf{WV}_{\boldsymbol{j}}$ (weekday value): during the business days in month j.

$\mathbf{OV}_{\boldsymbol{j}}$ (overtime value): in overtime in month j.

$\mathbf{SV}_{\boldsymbol{j}}$ (Saturday value): on Saturdays in month j.

$\mathbf{CV}_{\boldsymbol{j}}$ (Sunday value): on Sundays in month j.

$\mathbf{EV}_{\boldsymbol{j}}$ (external value): externally produced on a specific month j.

2 - To indicate the quantity of MRIs that can be produced:

$\mathbf{WC}_{\boldsymbol{j}}$ (weekday capacity): during the business days in month j.

$\mathbf{OC}_{\boldsymbol{j}}$ (overtime capacity): in overtime in month j.

$\mathbf{SC}_{\boldsymbol{j}}$ (Saturday capacity): on Saturdays in month j.

$\mathbf{CC}_{\boldsymbol{j}}$ (Sunday capacity): on Sundays in month j.

$\mathbf{EC}_{\boldsymbol{j}}$ (external capacity): externally produced in month j.

3 -To indicate the necessary monthly production:

$\mathbf{MD}_{j}$ (month demand): in a specific month j.

The $\mathbf{MD}_{j}$ parameter is calculated by the algorithm that determines the minimum quantity to be produced in each month based on the beginning of the month Waiting List (WL), in the average monthly Demand (D), which is calculated based on the production of the previous year, in the Monthly Production (MP) capacity, that is automatically calculated independently for each month, and in the desired Response Time (RT).

Indexes:

i = weekdays $\{1, number\ of\ business\ days\ in\ month\ j\}$ (4)

j = months $\{1, 36\}$ (5)

k = Saturdays $\{1, number\ of\ Saturdays\ in\ month\ j\}$ (6)

l = Sundays $\{1, number\ of\ Sundays\ in\ month\ j\}$ (7)

Decision variables:

x_{ij} = number of exams performed on weekday i in month j. (8)

y_{ij} = number of exams overtime performed on weekday i in month j. (9)

s_{kj} = number of exams performed on Saturday k in month j. (10)

c_{lj} = number of exams performed on Sunday l in month j. (11)

ep_{j} = number of exams outsourced performed in month j. (12)

$x_{ij}, y_{ij}, s_{kj}, c_{lj}, ep_{j} \geq 0$ (13)

Objective Function:

The objective function minimizes the cost of analyzed period production, as expressed by equation (14):

$$Z = Min \sum_{j=1}^{36} \left[\sum_{i=1}^{m} \left(x_{ij} \times \mathrm{WV}_{j} + y_{ij} \times \mathrm{OV}_{j} \right) + \sum_{k=1}^{n} \left(\mathrm{s_{kj}} \times \mathrm{SV}_{j} \right) + \sum_{l=1}^{t} \left(\mathrm{c_{lj}} \times \mathrm{CV}_{j} \right) + \mathrm{ep_{j}} \times \mathrm{EV}_{j} \right] \quad (14)$$

m = number of business days in month j. (15)

n = number of Saturdays in month j. (16)

t = number of Sundays in month j. (17)

$m \in \{1, number\ of\ business\ days\}$ (18)

$n \in \{1, number\ of\ Saturdays\}$ (19)

$t \in \{1, number\ of\ Sundays\}$ (20)

Constraints:

$$\sum_{i=1}^{\mathrm{m}} x_{ij} \leq WC_j \tag{21}$$

$$\sum_{i=1}^{\mathrm{n}} y_{ij} \leq OC_j \tag{22}$$

$$\sum_{i=1}^{\mathrm{k}} s_{kj} \leq SC_j \tag{23}$$

$$\sum_{i=1}^{\mathrm{l}} c_{ij} \leq CC_j \tag{24}$$

$$ep_j \leq EC_j \tag{25}$$

$$\sum_{i=1}^{\mathrm{m}} x_{ij} + \sum_{i=1}^{\mathrm{n}} y_{ij} + \sum_{i=1}^{\mathrm{k}} s_{kj} + \sum_{i=1}^{\mathrm{l}} c_{ij} + ep_j \geq MD_j \tag{26}$$

$$WC_j, OC_j, SC_j, CC_j, EC_j \geq 0 \ \forall \ j \ \in \{1, 36\} \tag{27}$$

The model is constrained by the weekday production capacity (7), by the overtime capacity (8), the Saturday capacity (9), the Sunday capacity (10), by the external capacity (11), and by the monthly demand (12). The research results are presented and discussed in section 6.

5.3 Equipment Availability Monitoring Tool

Taking into account Salata et al. (2014) assertation on the importance of implementing a reliable maintenance program in hospitals to reduce the expenses associated with equipment maintenance and to guarantee the security of users and patients, the development of a preventive and corrective maintenance control table was firstly proposed since the imaging sector of the hospital under-study did not have any maintenance control system. Due to the need for a tool, capable to efficiently analyze the data obtained through the maintenance control table and also capable of representing effectively, the results obtained in the form of indicators, a maintenance management spreadsheet for the automatic calculation of MTBF, MTTR, and equipment availability was developed.

To that end, a maintenance control table and a spreadsheet for analyzing the data obtained, through this control table, were developed as part of the project.

5.3.1 Maintenance Control Table

This section describes the table developed for the control of preventive and corrective maintenance. It is a simple table created in Microsoft Excel that contains six columns to be filled in by the responsible person designated for that purpose.

The first column refers to the equipment being tracked in relation to the occurrence of preventive or corrective maintenance. The way of including the equipment is facilitated with the inclusion of a list containing all 20 pieces of equipment. The second column is for information on the type of maintenance to be performed, which can be preventive or corrective, also facilitated by filling in list form. The third column stands for the starting date of the maintenance, the fourth column for the starting time, the fifth column for the ending date, and the sixth column for the ending time of the maintenance. In this table, each line corresponds to one maintenance to specific equipment. From the third to the sixth column the data must be manually entered.

Due to the lack of Microsoft Excel software on the computers used by those responsible for machines in the imaging sector, the spreadsheet was created to be used in the Excel online application present in Microsoft's OneDrive cloud storage service. This feature allows the document to be accessed and changed by all users who have permission to do so, the auto-save function ensures that data is not lost, and allows all changes made to be tracked through each user's Microsoft account. For a better understanding of the structure of the maintenance control table. Figure 24 represents a simulation made to validate the table operation.

Equipment	Maintenance Type	Start Date	Start Time	End Date	End Time
Angiografia	Corrective	27/12/2020	07:00:00	05/01/2021	21:00:00
Densitometria	Corrective	01/02/2021	08:00:00	20/02/2021	10:00:00
RM Phillips	Preventive	26/02/2021	07:00:00	02/03/2021	19:00:00
Litotritor	Preventive	23/02/2021	15:00:00	24/02/2021	09:00:00
Mamografo	Corrective	23/02/2021	07:00:00	27/02/2021	22:00:00
Ortopantomografo	Corrective	24/02/2021	09:00:00	25/02/2021	09:00:00
TC Urgência	Preventive	01/02/2021	13:00:00	02/02/2021	13:00:00

Figure 24 - Maintenance Control Table Layout

5.3.2 Performance Indicators Spreadsheet

One of the features of this spreadsheet is to calculate the time that preventive or corrective maintenance interferes with the production time of each machine in the imaging sector. Given that the operating hours are not fixed for all equipment, and that, with the exception of machines selected to work full time for the emergency cases, different machines can operate on different days depending on the specialty to which it is intended. For a better perception of the days and hours worked for each machine, Table 7 summarizes the operating schedule of all equipment.

Table 7 – Operational Schedule for Imaging Equipment

Equipment	From	To	Working Days
Angiografia	08:00	20:00	Monday to Friday
Densitometria	08:00	14:00	Friday
Eco 1	08:00	20:00	Monday to Friday
Eco 2	08:00	20:00	Monday to Friday
Eco 3	08:00	20:00	Monday to Friday
Litotritor	08:00	14:00	Thursday
Mamografo	14:00	20:00	Monday to Friday
Ortopantomografo	14:00	17:00	Monday to Friday
RM Phillips	08:00	20:00	Monday to Friday
RM Siemens	08:00	20:00	Monday to Friday
RX Bloco 1	08:00	20:00	Monday to Friday
RX Bloco 2	08:00	20:00	Monday to Friday
RX Bloco 3	08:00	20:00	Monday to Friday
RX Bloco 4	08:00	20:00	Monday to Friday
RX Portátil 1	08:00	20:00	Monday to Friday
RX Portátil 2	08:00	20:00	Monday to Friday
Rx Portátil 3	00:00	23:59	Every day
Rx Portátil 4	00:00	23:59	Every day
TC Central	08:00	20:00	Monday to Friday
TC Urgência	00:00	23:59	Every day

Thus, based on information obtained from the maintenance control table, the performance indicators spreadsheet calculates, through an algorithm, the exact amount of time that each machine is inoperable due to the occurrence of preventive and corrective maintenance. The algorithm was designed to take into account the hours and days of operation of each piece of equipment, as well as the days when the imaging sector does not work due to national and international holidays.

In order for the algorithm to calculate the equipment downtime correctly, it is necessary that the information obtained from the maintenance control table regarding the start and end dates and times are concatenated in just two columns, one containing the starting date and the starting time, and another column containing the ending date and the ending time of the maintenance operation.

In this way, the spreadsheet that calculates the performance indicators contains a table inserted in a separate sheet to calculate all machines' downtime. This table is composed of 10 columns, being the first 6 columns the same present in the maintenance control table and the remaining columns being the starting date and the starting time of the maintenance, the ending date and ending time of the maintenance, the global downtime, and the specific downtime in a given period. The necessary data for filling in the first 6 columns and for the calculation of equipment downtime is automatically obtained from external data (maintenance control table) through the *power query* function of Microsoft Excel.

The algorithms that calculate the global downtime for each piece of equipment and the specific downtime for each equipment are present in the last two columns and use the data present in Table 9, with information on days and hours of operation of each equipment and the data obtained from the maintenance control table for the calculation of equipment downtime. The algorithm on the column of specific downtime considers the period of time chosen by the user for its calculation.

Figure 25 displays the mentioned table containing the algorithms with a simulation made to validate the table operation. It is important to clarify that in this simulation displayed in Figure 20, the period chosen for data analysis was from 01/01/2021 until 28/02/2021, which explains the fact that the *Angiografia* and the *RM Philips equipment* global downtime differs from the specific downtime for both types of equipment.

Equipment	Maintenance Type	Start Date	Start Time	End Date	End Time	Starting Date + Time	Ending Date + Time	Global Downtime	Specific Downtime
Angiografia	Corrective	27/12/2020	07:00:00	05/01/2021	21:00:00	27/12/20 7:00	05/01/21 21:00	72:00:00	36:00:00
Densitometria	Corrective	01/02/2021	08:00:00	20/02/2021	10:00:00	01/02/21 8:00	20/02/21 10:00	18:00:00	18:00:00
RM Phillips	Preventive	26/02/2021	07:00:00	02/03/2021	19:00:00	26/02/21 7:00	02/03/21 19:00	35:00:00	35:00:00
Litotritor	Preventive	23/02/2021	15:00:00	24/02/2021	09:00:00	23/02/21 15:00	24/02/21 9:00	0:00:00	0:00:00
Mamografo	Corrective	23/02/2021	07:00:00	27/02/2021	22:00:00	23/02/21 7:00	27/02/21 22:00	24:00:00	24:00:00
Ortopantomografo	Corrective	24/02/2021	09:00:00	25/02/2021	09:00:00	24/02/21 9:00	25/02/21 9:00	3:00:00	3:00:00
TC Urgência	Preventive	01/02/2021	13:00:00	02/02/2021	13:00:00	01/02/21 13:00	02/02/21 13:00	24:00:00	24:00:00

Figure 25 – Equipment Downtimetime Calculation (simulation sample)

The MTBF and MTTR are calculated on the same spreadsheet but on another sheet that contains the fields for the user to fill in the start date and the end date of the period to be analyzed, a table of MTBF, MTTR, and availability goals also to be filled by the user, a graph representing the availability of each equipment in the chosen period, and a table containing detailed information on each indicator.

This table contains the calculation, distinguished by equipment, of MTBF and MTTR of corrective maintenance, MTTR of preventive maintenance, global MTTR, and the availability of each equipment. The MTBF of preventive maintenance is not calculated as it refers to scheduled maintenance where there is no equipment failure to be repaired. In the same table, a general calculation of all the mentioned indicators is made for an overview of the availability of all equipment in the imaging sector. The calculation of these indicators is done automatically, also by algorithms, by utilizing information from the table responsible for the equipment downtime calculation. Figure 26 displays the mentioned table containing results obtained from a simulation made to validate the table operation.

	Corrective Maintenance			Preventive Maintenance		Global Maintenance	
Equipment	MTBF	MTTR	Availability	MTTR	Availability	MTTR	Availability
Angiografia	540:00	60:00	90%	0:00	100%	60:00	90%
Densitometria	57:00	3:00	95%	0:00	100%	3:00	95%
Eco 1	594:00	6:00	99%	5:00	99%	5:30	98%
Eco 2	540:00	60:00	90%	180:00	70%	120:00	60%
Eco 3	588:00	12:00	98%	120:00	80%	66:00	78%
Litotritor	58:00	2:00	97%	18:00	70%	10:00	67%
Rx Portátil 3	1703:59	0:00	100%	0:00	100%	0:00	100%
Rx Portátil 4	1703:59	0:00	100%	0:00	100%	0:00	100%
Mamografo	300:00	0:00	100%	0:00	100%	0:00	100%
Ortopantomografo	150:00	0:00	100%	30:00	80%	30:00	80%
RM Phillips	589:00	11:00	98%	11:00	98%	11:00	96%
RM Siemens	599:00	1:00	100%	49:00	92%	25:00	92%
RX Bloco 1	496:00	104:00	83%	128:00	79%	116:00	61%
RX Bloco 2	588:00	12:00	98%	0:00	100%	12:00	98%
RX Bloco 3	599:00	1:00	100%	13:00	98%	7:00	98%
RX Bloco 4	497:00	103:00	83%	36:00	94%	69:30	77%
TC Central	547:00	53:00	91%	5:00	99%	29:00	90%
TC Urgência	1415:59	288:00	83%	96:00	94%	192:00	77%
RX Portátil 1	593:00	7:00	99%	12:00	98%	9:30	97%
RX Portátil 2	553:00	47:00	92%	24:00	96%	35:30	88%
General	-	-	-	-	-	49:54	91%

Figure 26 – MTBF, MTTR and Availability Calculation (sample table)

The third sheet present in the calculation of the indicators' spreadsheet refers to a dashboard where the data contained in the MTB, MTTR, and availability calculation table are visually represented in the form of graphs so that the hospital management can easily analyze and take appropriate decisions. These graphs with results obtained from a simulation made to validate the tool are presented in Appendix III – Equipment Performance Monitoring Graphics (simulation sample).

6. Results and Discussion

In this section, the results obtained by using the developed tools are presented through analysis made with the data provided by the imaging sector of the hospital in question. First of all, the results obtained through the anomaly detection alerting tool are presented in detail with a distinction of analysis made with retroactive and future data. The objective of analyzing retroactive data is to identify the percentage of ineffective medical appointments that occurred over a period of one year (2018 – 2019). Bearing in mind that the MRI exams are scheduled for a period of one month ahead, the future analysis made by the algorithm was based on the month of November 2020.

The second topic addressed in this section is the analysis of MRI waiting list behavior during the 3-years (2021 – 2023) period exposed after the capacity planning process has been optimized through the developed optimization model. The third topic covered in this section refers to the maintenance control tool for all equipment in the imaging sector with the exposure of important indicators such as MTBF, MTTR, and the global availability of the equipment. Bearing in mind that this type of control was absent in the imaging sector of the hospital in question, the tool was developed for the control of preventive and corrective maintenance, but due to lack of prior control, at the moment there are no data regarding these maintenances to be inserted in the equipment availability monitoring tool for results analysis.

As this dissertation is based on the Lean healthcare philosophy, from the Lean principles presented in the literature review, search for perfection in the flow of processes and value through the elimination of restrictions (waste), are the Lean principles addressed in this dissertation. Value, flow, and perfection because are relevant principles on the chase for patient satisfaction. Among the Lean tools covered in the literature review, the ones that were used during this project are waste elimination, continuous flow, TPM, and continuous improvement.

Since in Lean healthcare, patients waiting for medical appointments and exam realization are considered wastes, the waste eliminations tool was extremely important for the quality of the service to improve with a focus on delivering greater value to the patient. From the Lean wastes in the service area, from Dinis-Carvalho et al. (2017), presented in the literature review, the main wastes addressed in the developed practical solution were people motion, people waiting, information waiting, defects, and complex processes with room for improvement.

In the case of ineffective medical appointments, the wastes addressed are: people motion, when patients attend for a medical appointment without exam results; people waiting, when patients need to wait for medical appointments that could be carried out in advance if ineffective consultations did not exist; complex process, when redundant processes for the realization of exams and medical appointments affect the quality of services provided to patients; information waiting, when the lack of a flown process affects patients in a negative way due to lack of information flow; defect, when patients are served with a service of a lower quality than the hospital is able to provide with existing resources.

In the case of existence of constraints for monitoring equipment availability and the presence of constraints for MRI capacity planning, the wastes addressed are: people waiting, when patients need to wait for MRI exam realization due to lack of an effective capacity planning and maintenance control of all equipment; information waiting, when required MRI exams cannot be performed due to lack of an effective capacity planning and maintenance control of all equipment; defects, when patients are served with a service of a lower quality than the hospital is able to provide with existing resources.

The continuous flow concepts were also very relevant, given that a smooth patient flow can enhance the patient experience. The TPM concept has not been fully implemented, but the inclusion of a availability monitoring tool represents a significant improvement on the road to calculate the OEE in the imaging sector. Continuous improvement approach served to emphasize the importance of a continuous cycle of analysis and validation of the developed tools. The results obtained from the implementation of the developed tools are presented and discussed below.

6.1 Anomaly Detection Algorithm

Most of the text of this section was previously published in an article (Barretiri et al., 2021a). This study analyzed data obtained from the imaging service process of a Portuguese hospital in the event of ineffective medical appointments and its relationship with divergences between consultation scheduling and performing dates of MRI scans.

The research criteria are to uncover the percentage of ineffective medical appointments that took place in a retrospective period analyzed, and with greater relevance, to identify future medical appointments that will occur without the corresponding MRI report.

6.1.1 Retrospective Analysis

In retrospective analysis over a period of one year (2018 - 2019), 12526 MRI exams and 448925 medical appointments have been processed through the algorithm and graphically represented in Figure 27. From these, 9569 medical appointments were depending on MRI results to become effective. From the algorithm analyses, 16.01% of these medical appointments were identified as ineffective, which corresponds to 1532 medical appointments that required rescheduling in a second attempt to obtain the MRI report on the expected date. The percentage of delayed MRI exams presented by the algorithm was 12.2%, corresponding to 1538 exams, a result that raised management concern in optimizing internal processes to maximize the imaging sector production.

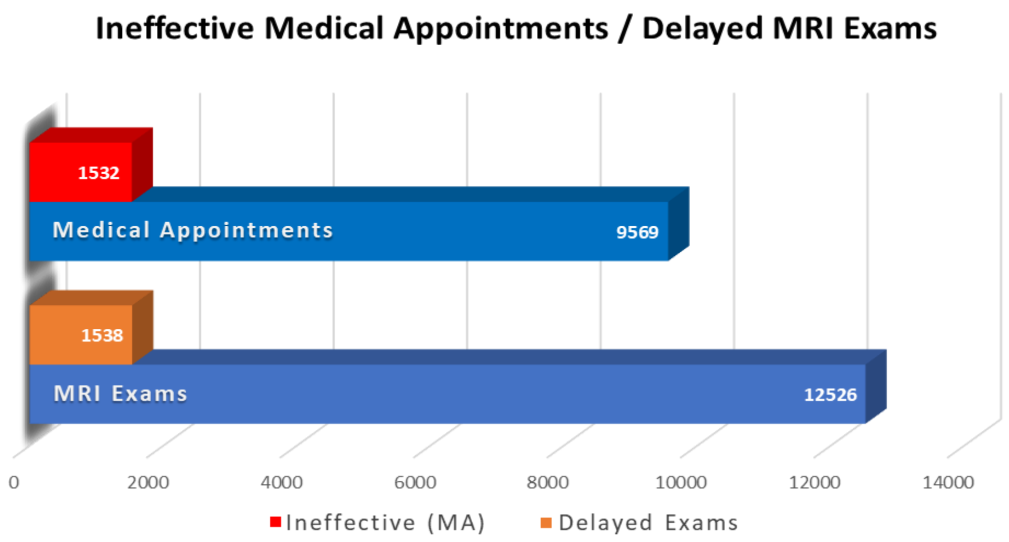


Figure 27 - One-year retroactive ADA analysis

The occurrence of a higher number of delayed MRI exams (1538) in relation to the number of ineffective medical appointments (1532) is due to the fact that a single patient may receive two MRI requests, one for radiology and the other for neuroradiology, requested by the same physician.

For cost analysis, in Portugal, the national health service is managed by the Ministry of Health, a government department whose task is to define and conduct national health policy, ensuring a sustainable application and use of resources with the evaluation of results. Given that the occurrence of ineffective medical appointments is the focus of this study, the cost of subsequent medical appointments represents a monetary waste associated with these occurrences.

For a uniform distribution of funds available for public health, Portuguese hospital entities are separated, according to the complexity of the services provided, into 6 different financing groups. Each group of hospitals has a maximum limit of subsequent medical appointments (subsequent medical appointment index) for each medical appointment performed for the first time in a particular specialty. The index works as a promoter of efficiency and an inducer of the implementation of clinical practices compatible with the monitoring of patients at the most appropriate level of care.

The hospital object of this research was inserted, during the analyzed period, to a group with an index of 2.37 subsequent medical appointments to be paid by the Portuguese Ministry of Health, in which every subsequent medical visit represents a cost of €65 to public funds. Hospitals belonging to the same group with an average number of subsequent annual medical appointments higher than the pre-established index must bear the expenses arising from subsequent medical appointments. In this study, we assumed that these expenses have costs equal to those stipulated by the Portuguese NHS. Therefore, with the implementation of monthly analyzes by the proposed algorithm, the hospital can reduce the number of ineffective medical appointments that, in the year analyzed, represented an associated cost of €99,580.

6.1.2 Future Analysis

In order to identify medical appointments that will occur without the corresponding MRI report, a future analysis was required by using the same database structure. The difference lies in the fact that the algorithm identifies medical appointments without scheduled MRI exams and those that have an MRI scheduled with a date after the date on which the subsequent appointment is scheduled.

In a future analysis performed for a period of one month (11/2020), 9285 MRI exams and 36067 subsequent medical appointments have been processed through the algorithm and graphically represented in Figure 28. In this analysis, all medical appointments scheduled for the month of November 2020 were correlated with all pending MRI exams, including those that have already been scheduled and those that are on the waiting list.

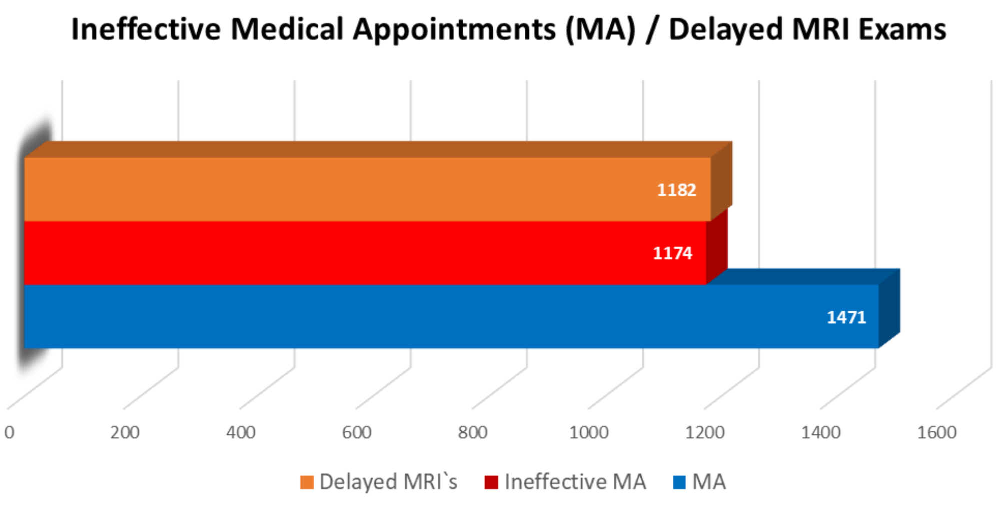


Figure 28 - One-month future ADA analysis

The algorithm revealed that 1471 medical appointments were depending on MRI results to become effective. From these, 79.8% were identified as ineffective appointments, which corresponds to 1174 medical appointments that require rescheduling to obtain the MRI report on the expected date. The percentage of delayed MRI exams presented by the algorithm was 12.7%, corresponding to 1182 exams from the 9285 MRI exams waiting to be scheduled.

The algorithm outcome, in addition to preventing patients from unnecessarily visiting the hospital, can provide monthly savings of around €76,310 for the health organization and consequently for the public coffers. Compared with the retrospective analysis, this value is much higher than expected for monthly values, considering that the annual loss was around €99,000 between 2018 and 2019 due to ineffective medical appointment occurrence. These values were contested with the hospital administration who, after revalidating the tool through sampling analyses, confirmed the values veracity and justified this excessive number of delayed MRI exams due to a lack of capacity on the part of the external MRI services provider to meet the demand for MRI requests sent by the hospital's imaging service. Table 8 summarizes the results obtained from the algorithm.

Table 8 - Results summary

	MRI Exams (Waiting List)	Medical Appointment (MA)	MA depending on MRI results	Ineffective MA	% Ineffective MA	Delayed MRI Exams	% Delayed MRI	Monetary Loss
Retrospective Analysis (one year)	12 526	448 925	9 569	**1 532**	16,01%	**1 538**	12,20%	99 580 €
Future Analysis (one month)	9 285	36 067	1 471	**1 174**	79,80%	**1 182**	12,70%	76 310 €

The crescent need for MRI exams within the hospital under-study aligned with the limited capacity in the imaging sector that makes it impossible to meet, in the expected time, all MRI requests from different hospital sectors. Being aware of budgetary limitations and the urgency to reduce waste that hinders the maximum use of existing resources, the available data from future consultation and exam appointments was used to introduce a bilateral communication theretofore nonexistent between the imaging sector and other services of the hospital. Thus, the main objective of this research was to measure the current scenario and analyze the problem pre-identified by the hospital management to develop, test, and validate a quick fix algorithm able to merge the existing data to detect and preventively alert future occurrences of ineffective medical appointments.

Developing a solution in a hospital environment with the absence of a centralized computer system, where internal service requests occur without a knowledge of the service provider's availability to perform the task and also where several sectors depend on others but work independently, is a scenario that requires practical and effective intervention.

Due to the high volume of data and pre-established processes that cannot be changed and adjusted in a simple and fast way, the developed model helps to improve the level of service provided to patients with a significant reduction of waste and associated costs for the organization. Thus, the algorithm does not prevent the scheduling of ineffective medical appointments but prevents them from happening. In this context, the way the algorithm performs the data crossing is not trivial, given that hospital units do not communicate with each other.

The usefulness of this tool goes beyond alerting the existence of ineffective medical appointments in retrospective and future analyzes or quantifying retrospective ineffective appointments related to the imaging sector. Combined with the fact that the whole process happens with the activation of a single button, the algorithm outcomes (dashboard and final report) are quickly generated, if compared to a manual sorting and analyzes process, which makes the model a synonym for agility in the management of hospital services such as the imaging sector.

This tool can be implemented in other hospital sectors experiencing similar problems or even in hospital environments where the management team is unaware of ineffective appointments' existence. In health organizations facing internal issues due to the lack of a centralized system, this algorithm can work as an alert capable of crossing data from different sectors to compare these data and acknowledge the existence of divergences in future appointments that require exams or clinical analysis results.

Therefore, in hospitals where problems related to the occurrence of ineffective medical appointment are not evident, this tool has the potential to confirm the effectiveness of future medical appointments or, in the event of unidentifiable ineffective medical appointments, bring to light improvement opportunities through waste reduction.

This focus on ineffective appointments is directly related to the growing willingness to maximize the use of existing resources as mentioned by Conforti et al. (2008), which is a consequence of the need of eliminating waste valuing sustainable development with improved customers experience. By taking responsibility for existing failure in the occurrence of missed or ineffective medical appointments, health organizations can easier inspect causes and the associated factors for effective problem-solving framework development.

From the patient's point of view and as designated by Dinis-Carvalho et al. (2017) as people motion waste, the act of moving from home, from the workplace, or from any possible location to attend a medical appointment that culminates in unnecessary movement, can become a negative experience where the patient's perception of their own clinical condition remains the same, due to the lack of the result of a previously requested MRI examination, what can generate frustration in the patient and worsening his/her clinical condition.

This is an aspect that should be taken into consideration by hospital management in order to provide an improved service and achieve the medical appointment objective, which is clarifying patients' perception about their clinical condition and recommend future actions if the results obtained from clinical exams or analysis reflect this need.

In this context and concerning Amran et al. (2020) and Jiang and Malkin (2016) statement about Lean principles adapted for clinics and hospitals to improve any process in order to deliver greater value to patients in the service provided, the developed ADA can be adapted and replicated to other sectors within the hospital where the model was developed or practically directly applied in any hospital that aims to implement a waste reduction culture and improve the patient experience.

Answering the first research question:

How does the identification of delayed MRI exams impact the reduction on ineffective medical appointments occurrence within health organizations?

The identification of medical appointments scheduled, for exam results analysis, that will occur without the result of previously required exams allows the hospital's administration, upon knowing that there are late exams, to make decisions so that these medical appointments cease to be ineffective or that they happen at a later date of the respective exam.

6.2 Capacity Planning Optimization Model

Most of the text of this section was previously published in an article (Barretiri et al., 2021b). Following the premise of Rechel et al. (2010) about benefits obtained from improved operations management through relevant approaches, such as "lean philosophy" adapted to the health industry to assist in the implementation of a culture of continuous improvement for improved management focused on patient flow, the purpose was to develop a model to make waiting list control and capacity planning a simpler process for the imaging sector management.

By using a Microsoft Excel spreadsheet, all information necessary to parameterize and solve the problem was organized. The OpenSolver tool with the Simplex method was used as an optimization engine.

The model parameters data are presented in Table 9:

Table 9 - Problem Parameters

Model Parameters					
$\mathbf{WV}_j$	Weekday Value	1 x V (EUR)	$\mathbf{WC}_j$	Weekday Capacity	40 (MRIs)
$\mathbf{OV}_j$	Overtime Value	4 x V (EUR)	$\mathbf{OC}_j$	Overtime Capacity	15 (MRIs)
$\mathbf{SV}_j$	Saturday Value	4 x V (EUR)	$\mathbf{SC}_j$	Saturday Capacity	45 (MRIs)
$\mathbf{CV}_j$	Sunday Value	4 x V (EUR)	$\mathbf{CC}_j$	Sunday Capacity	45 (MRIs)
$\mathbf{EV}_j$	External Value	6 x V (EUR)	$\mathbf{EC}_j$	External Capacity	500 (MRIs)
$\mathbf{MD}_j$	Month Demand	Algorithmically Calculated (MRIs)			

Month Demand Algorithm Parameters		
WL	Waiting List	10070 (MRIs)
D	Demand	1550 (MRIs)
RT	Response Time	3 (months)
MP	Month Production	Varies Monthly (MRIs)

The actual costs of performing MRIs were not reported. The only information provided about the costs is related to the occasion when the exam is performed. Thus, performing MRI internally on business days represents the lowest cost. As for the same exam, the cost is four times higher if executed in overtime and on weekends, and six times higher if externally performed. With this information, we use fictitious values to find the optimal solution, however, a cost analysis will not be displayed in this study.

Posterior to data collection and to the analysis of the current scenario at the under-study hospital imaging sector, the model exposed that even using the maximum external production that is limited to 500 MRIs per month, it is necessary 17 months (Jan 2021 – May 2022) of maximum internal and external production for the waiting list to reach, in June, the response time of 90 days stipulated by the Portuguese health ministry.

The model additionally exposes that will be possible to reduce external production by 62,1% in the remaining 19 months (Jun 2022 – Dec 2023) of the analysis and still maintaining the queue close to the expected limit. The model also shows that the weekend production can be also reduced in some months that external production is not needed. Table 10 displays detailed information from the capacity planning model regarding necessary MRIs production during the three years analyzed period.

Table 10 - Capacity Planning Table

2021	MRI - Capacity Planning											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Waiting List (MRIs)	10070	9570	9160	8585	8165	7610	7145	6970	7140	6965	6410	5890
Business Days	800	800	920	840	840	840	880	880	880	840	880	920
Overtime	300	300	345	315	315	315	165	0	165	315	330	345
Weekends	450	360	360	315	450	360	180	0	180	450	360	315
External	500	500	500	500	500	500	500	500	500	500	500	500
Total	2050	1960	2125	1970	2105	2015	1725	1380	1725	2105	2070	2080
Waiting List Length (Months)	**11,39**	**10,90**	**10,22**	**9,72**	**9,06**	**8,51**	**8,30**	**8,50**	**8,29**	**7,63**	**7,01**	**6,38**

2022	MRI - Capacity Planning											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Waiting List (MRIs)	5360	4850	4440	3865	3455	2890	2520	2520	2760	2640	2520	2640
Business Days	840	800	920	800	880	840	840	920	880	840	880	880
Overtime	315	300	345	300	330	315	165	0	165	315	330	330
Weekends	405	360	360	360	405	360	180	0	180	450	220	340
External	500	500	500	500	500	405	365	390	445	65	0	0
Total	2060	1960	2125	1960	2115	1920	1550	1310	1670	1670	1430	1550
Waiting List Length (Months)	**5,77**	**5,29**	**4,60**	**4,11**	**3,44**	**3,00**	**3,00**	**3,29**	**3,14**	**3,00**	**3,14**	**3,14**

2023	MRI - Capacity Planning											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Waiting List (MRIs)	2640	2640	2400	2760	2360	2760	2640	2520	2650	2485	2530	2530
Business Days	880	800	920	760	920	880	840	920	840	880	880	680
Overtime	330	300	270	285	230	330	150	0	150	330	330	88
Weekends	340	360	0	405	0	315	225	0	225	295	340	200
External	0	330	0	500	0	145	455	500	500	0	0	0
Total	1550	1790	1190	1950	1150	1670	1670	1420	1715	1505	1550	968
Waiting List Length (Months)	**3,14**	**2,86**	**3,29**	**2,81**	**3,29**	**3,14**	**3,00**	**3,29**	**3,09**	**3,14**	**3,14**	**2,86**

For a global understanding of results presented by the model, Figure 29 graphically exposes the necessary MRIs production during the period of three years in analysis.

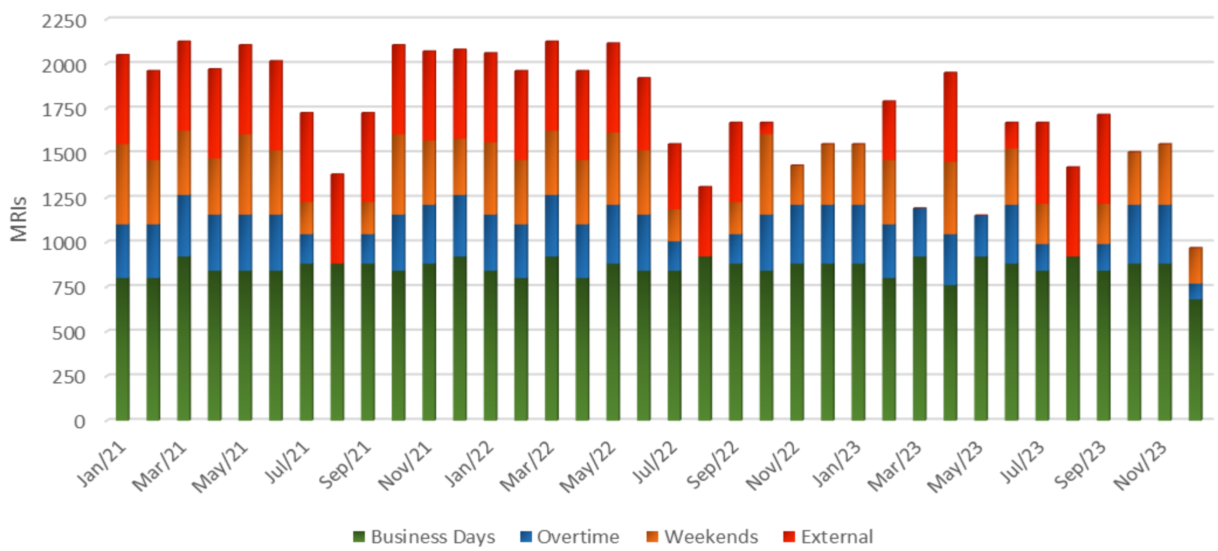


Figure 29 - Required MRIs Production

To better comprehend how it will impact the response time, Figure 30 displays the waiting list behavior in the analyzed period. The orange line in the graph represents the hospital's target (in months) for the waiting list.

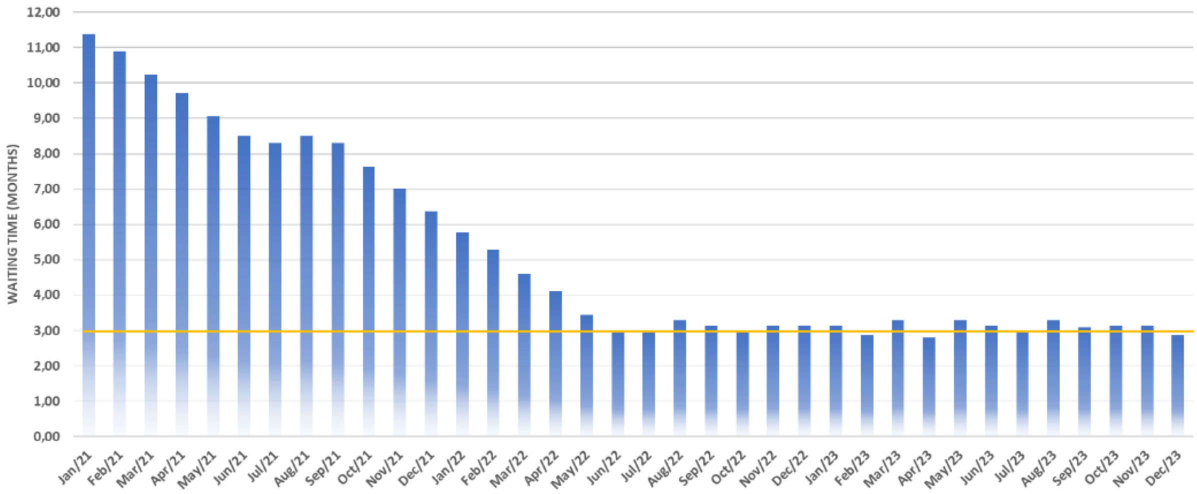


Figure 30 - Waiting List Behavior

It is also possible to use the model to analyze the impact that hiring more technicians, or the acquisition of a new MRI machine can generate in the internal production and consequently in the reduction of the waiting list. Other scenarios can also be analyzed by changing the decision variables, for instance, increasing or decreasing the number of overtime hours or by changing the monthly demand, which reinforces Langabeer II and Helton (2015) allegation that health organizations can enhance organizational efficiency and effectiveness by utilizing their current management and operational assets.

As mentioned by Emery et al. (2009), an improved waiting list management suggests a different proposal for waiting list reduction. The capacity planning problem presented, reinforced by the lack of tools such as a model with a greater level of detail and that performs dynamically the waiting list control, brings to light the challenges faced by hospital managers, planners, and physicians (Rechel et al., 2010). The presence of industrial managers in the health area indicates that the need for operations management and a robust capacity planning system was perceived by the hospital's administration, the point is that these managers are, most of the time, focused on resolving urgent problems, not having availability for general issues that end up being postponed due to managers' lack of time.

One of the possible reasons for this condition is related to the fact that the capital available to health service providers is more controlled than before (Rechel et al., 2010). This factor, associated with a greater concern on the part of citizens regarding health, causes overcrowding in health units that do not have sufficient resources.

Following the perception of Farughi et al. (2020) on the concept of optimization models within the healthcare design system to reduce operating costs and increase coverage capacity, the developed model makes the waiting list control and the capacity planning process simpler for the imaging sector management. The dynamism of this tool makes it unlimited in a matter of future dates to be analyzed with a view that automatically presents three years ahead based on the month chosen as initial.

Thus, with the fulfillment of the decision variables, the algorithms present in the Excel tables calculate the minimum quantities to be monthly produced so that the optimization model can distribute the production, with a lower cost priority and respecting the constraints, among business days, overtime, weekends, and external production to achieve the goal of reducing the waiting list efficiently.

Answering the second research question:

How does the implementation of a capacity planning optimization model can contribute to reducing patients' waiting time in the hospital imaging sector?

It is possible to understand by analyzing Figure 30 that the response time for MRI exams tends to reduce since the model maximizes internal production and, when necessary, external production so that the waiting list is gradually reduced. So, considering that the hospital did not have a system for capacity planning to maximize the use of internal resources, which meant that the waiting list always remained at a high level, the implementation of a capacity planning optimization model can assist the hospital management to reduce waiting lists for MRI exams.

6.3 Equipment Availability Monitoring Tool

One of the objectives of this project was to implement a hitherto non-existent system for recording corrective and preventive maintenance to monitor the availability of all equipment in the imaging sector of the hospital under-study. In this regard, a maintenance control table was developed and implemented. Also, a spreadsheet for analyzing the data in the maintenance control table was developed in Microsoft Excel with the ability to automatically obtain the external data to dynamically present the main performance indicators mentioned in the literature review.

According to Mwanza and Mbohwa (2015), the practice of an effective and suitable maintenance program within the healthcare organizations can, by increasing equipment reliability and availability, add value to the service provided by the hospital. In order to start the implementation of a maintenance control within the under-study hospital, the calculated indicators are MTBF, MTTR, and availability.

As there was, until the present moment of this study, no type of maintenance control in relation to the absolute time to carry out preventive and corrective maintenance, it was not possible to calculate which is the current MTBF, MTTR, and the availability of all equipment used in the realization of exams with imaging techniques.

Currently, the hospital only has a scheduling control for future preventive maintenance with an estimated duration, that does not always correspond to the reality, of maintenance for each piece of equipment. Bearing in mind that imaging exams cannot be performed during any type of maintenance on the machine intended for the type of exam, the main function of this preventive maintenance control is to block future appointments for equipment that has scheduled preventive maintenance, having no functionality to calculate the imaging sector equipment performance.

The hospital administration informed that the present system for blocking the appointment of exams, for equipment with scheduled preventive maintenance, is not 100% reliable, so they intend to adapt the developed maintenance control table to solve this issue through the cloud operation option. Since the calculation of OEE in the imaging sector was an objective that had to be postponed in this study, the availability monitoring tool represents an important step for the hospital to maximize the use of resources and to uncover waste existence.

Answering the third research question:

How the implementation of an availability analysis system, by using performance indicators, turns into an important step to obtain the Overall Equipment Effectiveness (OEE) of the hospital's imaging sector?

The developed equipment availability monitoring tool is a relevant step to the OEE calculation because this will make it possible for the hospital administration to obtain essential indicators about production time losses, which until then were not monitored, such as downtime due to failures and downtime for preventive maintenance.

7. Conclusions

The importance of improving hospital operations in order to achieve patients satisfaction and waste reduction has been perceived by hospital managers (Lima et al., 2020). The fusion between Lean concepts and operations management is beneficial for the improvement of processes since the tools developed from lean manufacturing can be adapted to provide added value to the service process (Kleindorfer et al., 2005).

This research work explored the possibility to provide process improvements within a hospital imaging service in a Portuguese public hospital through advanced operations management techniques aligned with the Lean healthcare concepts. The developed tools were designed to solve issues previously identified by the imaging sector of the hospital under-study. The issues addressed in this dissertation are the occurrence of ineffective medical appointments, the lack of an MRI capacity planning, and the lack of a maintenance control system for all imaging sector equipment.

The methodology used was action research, in which the problems to be solved were diagnosed in the first phase, with the collaboration of the imaging sector management. Even with the limitations experienced due to the restrictions imposed by the Portuguese government because of the pandemic of covid-19, this phase occurred productively with a regular collaboration through online meetings with the hospital.

In the second phase, which is the action planning phase, a massive literature review was made so that studies based on the Lean philosophy carried out in hospitals were identified. As Lean concepts are already being applied in hospitals, it was not difficult to find relevant materials with Lean healthcare approaches.

In the third phase, the possible solutions found were presented and selected with the participation of the hospital management. This phase ran smoothly due to the experience of the research team in hospital operations management.

The fourth phase was probably the most exhaustive, where the possible results to be obtained with the application of the chosen solutions were analyzed. Exhaustive because the hospital does not have a practical system for obtaining large amounts of data, which sometimes made the process of analyzing results time-consuming, which delayed the validation of the developed tools.

The last phase of the action research, the results presentation phase, was the most exciting stage of the project due to the hospital's recognition of the importance of the tools developed for relevant improvements implementation. All developed tools were implemented in the imaging sector and the hospital's general administration revealed interest in implementing the ineffective medical appointment alerting tool in different areas of the hospital, such as in the clinical analysis sector.

All processes of the action research methodology were extremely important for the creation of process improvement tools and for the learning of techniques related to the management of operations in a hospital environment. Being aware of the existence of innumerable improvement opportunities in the health industry to provide a service closer to the patients` expectations was the most relevant learning to continue in the practice of improving hospital operations management with a focus on Lean healthcare philosophy.

Restrictions due to the covid-19 pandemic, lack of an implemented Lean healthcare culture, difficulty in obtaining data related to the problems addressed, and lack of Lean manufacturing tools adapted for the health sector are part of the main foreseen challenges that were experienced during the development of this dissertation. These challenges were overcome with the collaboration and interest on the part of the hospital management to obtain necessary data and to implement possible improvements. Also, the use of video communications software to hold weekly online meetings and the use of Microsoft excel for the development of analysis tools through specific features such as *power query* and VBA were applied to surpass the barriers faced during the project progress.

Concerning the occurrence of ineffective medical appointments, two different possibilities have been identified. The first is the case of MRI exams already scheduled for dates after the date of the medical appointment. The second and most recurrent possibility is the non-scheduling of the MRI exam due to the imaging sector's lack of capacity. In response to the research question related to the ineffective medical appointment occurrence, by eliminating ineffective medical appointments resultant from delayed MRI exams, hospital management can reduce the financial impact caused by the associated waste and also assist in providing hospital services with higher quality.

Limited imaging service capacity for MRI exams and lack of a centralized informatics system were identified as the main reasons for ineffective appointments occurrence. An algorithm capable to previously alert this failure episode widely contributes to waste reduction within the hospital's environment.

As the model resulting from this project is able to identify the medical appointments that will occur without the corresponding MRI results, which are paramount for the requesting physician to display a more accurate diagnosis, the hospital has a greater chance of maintaining the agile and quality service provided to users in order to eliminate unpleasant situations experienced by both doctors and users in the case of medical appointments happening before the MRI exam is performed. This reduction in time wasted by medical appointments that happen unnecessarily is reflected in greater use of hospital resources and delivery of services closer to patients' expectations.

The developed algorithm demonstrated to be more than a temporary solution, given that the hospital under-study demonstrated interest in using the algorithm to identify the occurrence of ineffective medical appointments in other hospital sectors. Another feature is that the algorithm can be combined into the computer system so that the root cause is addressed at the time that the hospital administration disposes of available resources to invest in an integrated system, capable of alerting existing divergences in the consultations and exams appointment process.

Regarding the presence of constraints for MRI capacity planning , according to the feedback from the hospital management, the optimization model developed will be of great use as it addresses capacity planning in a useful and dynamic way, expressing exactly what the monthly quantity of internal and external production is, an approach that was not possible before the model implementation.

This tool can positively impact the hospital’s performance in agility for data analysis and to assist decision making based on the expected response time, an aspect that answers the research question related to the presence of constraints for MRI capacity planning production, given that this tool turns the budgetary planning process much more robust for the hospital administration by representing the necessary monthly amount of MRIs that need to be performed internally and externally based on the restrictions present in both resources, what enables the waiting list to be reduced in a programmed way by maximizing internal production to minimize costs.

The outcomes obtained from the proposed model revealed, by meeting all problem constraints, the period of time needed to reach the 90 days waiting list target within the current scenario. Eighteen months is the necessary time for the goal to be achieved, which may be considered a high period regarding patients’ notion of valuable service. Anyway, this is the reality of many hospitals, considering the capacity restrictions, amid intense pressure to reduce monetary expenses.

Besides exposing a long response time by the imaging sector of the under-study hospital, an urgent need for increased production capacity was identified, since the demand for MRI scans tends to continue rising. A quick solution to increase the production would be to invest in other MRI equipment, or alternatively to find a higher level of external service.

Based on this reality, a methodology capable of reducing waste and increase value-added in the service performed by utilizing the existing resources is a credible action for internal improvements that can culminate in faster response time and greater patient satisfaction.

The developed tool represents an initial evolution in terms of improvements, but as the need for a new project is clear, the implementation of the OEE (Souza et al., 2020) to identify the real percentage of each equipment production time and to promote an increase in all imaging sector equipment reliability is of utmost importance. That would be a way for uncovering wastes in the MRI exams performing process, which could then be addressed and reduced to increase the overall effectiveness of MRI equipment.

Since restrictions imposed by the Portuguese government due to the covid-19 pandemic prevented in-person work at the hospital, the implementation of the OEE became unfeasible at this stage of the project. Bearing in mind that the maintenance of the equipment directly interferes with the effectiveness of the equipment and that the hospital's imaging sector does not have any maintenance control system, the creation of a maintenance control tool to accurately identify the availability losses stood out as a priority activity that was possible to be carried out remotely.

Thus, a tool was developed to monitor the availability of equipment used to perform imaging exams. The equipment availability monitoring tool allows the hospital to document the maintenance performed in the imaging sector to monitor and identify the equipment reliability including wastes related to the time of maintenance, which represents an initiation in the implementation of the TPM concept to foster the practice of Lean culture.

Relevant benefits were confirmed in the practical work developed, such as monetary savings, management knowledge improvements, reduction of patient sacrifice, increasing efficiency, and waste reduction. The main contributing factor to the achievement of these benefits is the fact that the reduction or elimination of ineffective medical appointments increases the delivered value to the patient, enhancing the patient experience and reducing wastes, which results in financial savings for the hospital.

Based on the objectives initially presented, it was possible to characterize and analyze the operational processes of the imaging sector for the application of Lean healthcare principles. It was also possible to test, validate and implement the algorithm developed to identify ineffective medical appointments, the capacity planning optimization model to reduce the waiting list, and the equipment availability monitoring tool to measure the availability of all imaging sector equipment.

7.1 Study Limitations and Constraints

Among the constraints experienced by the project team, restrictions on access to the imaging sector due to the occurrence of the covid-19 pandemic and the difficulty in obtaining relevant data are the most prominent.

From the TPS house, mentioned in the literature review, what effectively applies in this practical work is an initiation in implementing continuous improvement through the reduction of waste and the improvement of the flow of patients with the objective of reaching the TPS true north which is customer satisfaction. Regarding the not applied items from the TPS house in this project, the main reason was the lack of a more direct iteration with the hospital administration, which was not possible due to the restrictions imposed by the Portuguese government because of the covid-19 pandemic. This made it impractical to carry out a more detailed analysis regarding the hospital structure for the application of other items present in the TPS house.

There are also study limitations related to the impossibility to compare the solutions obtained with previous tools, due to the inexistence of comparable tools. Thus, there are limitations in quantifying the improvement implemented due to the lack of a pre-existing process for ineffective medical appointments identification. Also, the existence of constraints for monitoring equipment availability in the imaging sector, made it impractical to compare results obtained with the tool developed for this purpose.

Although the research team beliefs in the general characteristic of these problems and the proposed solution, the limitations experienced in this research impose some care regarding the interpretation of the solutions. Nevertheless, most of the approaches may be replicated or used as inspiration to similar problems in different hospitals or in different services of the same hospital.

7.2 Future Work

The high percentage of delayed MRI exams uncovered by the developed ADA and the long response time to achieve the waiting list length objective reveals the need for studies focusing on the optimization of hospital procedures to maximize the use of available resources, thus, a study focusing on the implementation of *heijunka* (leveling) concept for the MRI production can be converted into an improved scheduling system based on an updated demand with a focus on reducing waste to promote processes standardization and patient flow. Studies can also be proceeded on the calculation of the OEE in the imaging sector as an initiation for TPM implementation, also with the intention of adding value to the services provided.

Through the literature review, the lack of a common value perception from the patient's perspective by all health professionals (managers, nurses, and doctors) was identified. The development of a common value perception system with the direct participation of patients is an opportunity for a real perception of what the patient values in health services.

These are opportunities for future work to propitiate timely medical treatment and patient satisfaction, given that the pathway to achieving a hospital`s service improvement starts by maximizing exchange value and assist to maximize the coming value-in-use, preparing and habilitating stakeholders to positively contribute to the continuum of value co-creation.

References

During this research work it was possible to develop two papers already published, one in a journal and the other in a conference:

Barretiri, L., Gonçalves, B. S., Lima, R. M., & Dinis-Carvalho, J. (2021a). Improving hospital operations management to reduce ineffective medical appointments. *Cogent Engineering*, *8*(1). https://doi.org/10.1080/23311916.2021.1904806

Barretiri, L., Gonçalves, B. S., Lima, R. M., & Dinis-Carvalho, J. (2021b). Prioritizing Internal Production on MRI Waiting List Management: An Optimization Model. *International Center for Information Ethics (ICIE)*, 68–78. https://doi.org/https://doi.org/10.1007/978-3-030-78170-5_7

There is the intention to develop a third article that is still under development.

The works cited in this dissertation are listed below.

Ahmed, S., Kemp, K., Johnson, D., Quan, H., & Santana, M. J. (2020). Identifying areas for improvement in paediatric inpatient care using the Child HCAHPS survey. *Paediatrics & Child Health*, *25 (6)*, 365–371. https://doi.org/10.1093/pch/pxz031

Amran, M. D. M., Januddi, F., Nuraina, S., Ikbar, A. W. M., & Khairanum, S. (2020). The Barriers in Lean Healthcare Implementation. *TEST Engineering and Management*, *82*, 1972–1981. http://www.testmagzine.biz/index.php/testmagzine/article/view/1170

Andrés-López, E., González-Requena, I., & Sanz-Lobera, A. (2015). Lean Service : Reassessment of Lean Manufacturing for Service Activities. *Procedia Engineering*, *132*, 23–30. https://doi.org/10.1016/j.proeng.2015.12.463

Andreu-Perez, J., Leff, D. R., Ip, H. M. D., & Yang, G. Z. (2015). From Wearable Sensors to Smart Implants-Toward Pervasive and Personalized Healthcare. *IEEE Transactions on Biomedical Engineering*, *62*(12), 2750–2762. https://doi.org/10.1109/tbme.2015.2422751

Arfmann, D., & Barbe, F. G. T. (2014). *The Value of Lean in the Service Sector : A Critique of Theory & Practice*. *5*(2), 18–24. http://www.ijbssnet.com/journals/Vol_5_No_2_February_2014/3.pdf

Atkinson, P. (2004). Creating and Implementing Lean Strategies. *Management Services*, *48*(2), 18–33. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.198.4743&rep=rep1&type=pdf

Bades, A., Evans, K., Todhunter, J., & Stephen-Haynes, J. A. (2018). Are missed appointments sinking the NHS? *Journal of Community Nursing*, *32*(1), 8–10.

Barretiri, L., Gonçalves, B. S., Lima, R. M., & Dinis-Carvalho, J. (2021a). Improving hospital operations management to reduce ineffective medical appointments. *Cogent Engineering*, *8*(1). https://doi.org/10.1080/23311916.2021.1904806

Barretiri, L., Gonçalves, B. S., Lima, R. M., & Dinis-Carvalho, J. (2021b). Prioritizing Internal Production on MRI Waiting List Management: An Optimization Model. *International Center for Information Ethics (ICIE)*, 68–78. https://doi.org/https://doi.org/10.1007/978-3-030-78170-5_7

Berry, L. L., Carbone, L. P., & Haeckel, S. H. (2002). Managing the Total Customer Experience. *MIT Sloan Management Review*, *43*(3), 85–89. https://www.researchgate.net/profile/Lewis-Carbone/publication/266277275_Managing_the_Total_Customer_Experience_Managing_the_Total_Customer_Experience/links/55929abc08ae16f493ee285f/Managing-the-Total-Customer-Experience-Managing-the-Total-Customer-Experi

Bhamu, J., & Sangwan, K. S. (2014). Lean manufacturing : literature review and research issues. *International Journal of Operations & Production Management*, *37*(7), 876–940. https://doi.org/10.1108/IJOPM-08-2012-0315

Bhasin, S., & Burcher, P. (2006). Lean viewed as a philosophy. *Journal of Manufacturing Technology Management*, *17*(1), 56–72. https://doi.org/10.1108/17410380610639506

Bullinger, H.-J., Fähnrich, K., & Meirena, T. (2003). Service engineering — methodical development of new service products. *Journal of Production Economics*, *85*(3), 275–287. https://doi.org/10.1016/S0925-5273(03)00116-6

Camila, R. S., William, C. A., Renan, F., & Renato, G. (2015). Reliability Indicators in the Medical Equipment Management. In *Jaffray D. (eds) World Congress on Medical Physics and Biomedical Engineering, June 7-12, 2015, Toronto, Canada. IFMBE Proceedings* (Vol. 51). Springer, Cham. https://doi.org/10.1007/978-3-319-19387-8_381

Castle, D., & Jacobs, R. F. (2011). Operations Management Body of Knowledge Framework. In *APICS The Association for Operations Management* (3rd ed.). https://www.coursehero.com/file/31634024/2015-APICS-OMBOKpdf/

Chiarini, A., Baccarani, C., & Mascherpa, V. (2018). Lean production, Toyota Production System and Kaizen philosophy: A conceptual analysis from the perspective of Zen Buddhism. *The TQM Journal*, *30*(4), 425–438. https://doi.org/10.1108/TQM-12-2017-0178

Christl, M., Köppl-turyna, M., & Kucsera, D. (2020). Determinants of Public-Sector Efficiency: Decentralization and Fiscal Rules. *Kyklos*, *73*(2), 253–290. https://doi.org/10.1111/kykl.12224

Cima, R. R., Brown, M. J., Hebl, J. R., Moore, R., Rogers, J. C., Kollengode, A., Amstutz, G. J., Weisbrod, C. A., Narr, B. J., & Deschamps, C. (2011). Use of lean and six sigma methodology to improve operating room efficiency in a high-volume tertiary-care academic medical center. *Journal of the American College of Surgeons*, *213*(1), 83–92. https://doi.org/10.1016/j.jamcollsurg.2011.02.009

Conforti, D., Guerriero, F., & Guido, R. (2008). Optimization models for radiotherapy patient scheduling. *4OR*, *6*(3), 263–278. https://doi.org/10.1007/s10288-007-0050-8

Cornwell, J. (2015). Reframing the work on patient experience improvement. *Patient Experience Journal*, *2*(1), 11–14. https://doi.org/10.35680/2372-0247.1079

Coulter, A. (2015). Time to deliver patient centred care. *The BMJ*. https://doi.org/10.1136/bmj.h530

da Luz Peralta, C. B., Echeveste, E., Lermen, F. H., Marcon, A., & Tortorella, G. (2020). A framework proposition to identify customer value through lean practices. *Journal of Manufacturing Technology Management*, *31*(4), 725–747. https://doi.org/10.1108/JMTM-06-2019-0209

de Jesus, C. M., & Alves, H. M. B. (2019). Consumer experience and the valued elements in the three phases of purchase of a cultural event. *International Review on Public and Nonprofit Marketing*, *16*(2), 173–194. https://doi.org/10.1007/s12208-019-00224-4

de Souza, L. B. (2009). Trends and approaches in lean healthcare. *Leadership in Health Services*, *22*(2), 121–139. https://doi.org/10.1108/17511870910953788

Diário da República. (2016). *Despacho n.º 199/2016, Série II de 2016-01-07* (pp. 569–570). Saúde - Gabinete do Secretário de Estado Adjunto e da Saúde. https://dre.pt/home/-/dre/73046270/details/maximized

Dinis-Carvalho, J. (2020). The role of lean training in lean implementation. *Production Planning and Control*, *32*(6), 441–442. https://doi.org/10.1080/09537287.2020.1742376

Dinis-Carvalho, J., Lima, R. M., Menezes, A., & Amorim, M. (2017). Waste Types in People Processing Services. In *Amorim M., Ferreira C., Vieira Junior M., Prado C. (eds) Engineering Systems and Networks* (Vol. 3). Springer, Cham. https://doi.org/10.1007/978-3-319-45748-2_30

Dobrzykowski, D., Deilami, V. S., Hong, P., & Kim, S. C. (2014). A structured analysis of operations and supply chain management research in healthcare (1982-2011). *International Journal of Production Economics*, *147*(Part B), 514–530. https://doi.org/10.1016/j.ijpe.2013.04.055

Drotz, E., & Poksinska, B. (2014). Lean in healthcare from employees' perspectives. *Journal of Health Organisation and Management*, *28*(2), 177–195. https://doi.org/10.1108/JHOM-03-2013-0066

El-namrouty, K. A., & Abushaaban, M. S. (2013). Seven wastes elimination targeted by lean manufacturing case study "gaza strip manufacturing firms". *International Journal of Economics, Finance and Management Sciences*, *1*(2), 68–80. https://doi.org/10.11648/j.ijefm.20130102.12

Emery, D., Forster, A., Shojania, K., Magnan, S., Tubman, M., & Feasby, T. (2009). Management of MRI Wait Lists in Canada. *Healthcare Policy | Politiques de Santé*, *4*(3), 76–86. https://doi.org/10.12927/hcpol.2009.20537

Emiliani, M. L. (1998). Lean behaviors. *Management Decision*, *36*(9), 615–631. https://doi.org/10.1108/00251749810239504

Evans, C. H. (2016). *The patient experience: effects of employee engagement on patient satisfaction*. http://d-scholarship.pitt.edu/id/eprint/27469

Falivena, C., & Palozzi, G. (2020). Value-Based Healthcare Paradigm for Healthcare Sustainability. In *Brunelli S., Di Carlo E. (eds) Accountability, Ethics and Sustainability of Organizations. Accounting, Finance, Sustainability, Governance & Fraud: Theory and Application*. Springer, Cham. https://doi.org/10.1007/978-3-030-31193-3_7

Farughi, H., Tavana, M., Mostafayi, S., & Santos Arteaga, F. J. (2020). A novel optimization model for designing compact, balanced, and contiguous healthcare districts. *Journal of the Operational Research Society*, *71*(11), 1740–1759. https://doi.org/10.1080/01605682.2019.1621217

Flynn, S. (2016). Who cares? A critical discussion of the value of caring from a patient and healthcare professional perspective. *International Journal of Orthopaedic and Trauma Nursing*, *20*, 28–39. https://doi.org/10.1016/j.ijotn.2015.06.001

Frank, M. L. (1988). Problem Solving and Mathematical Beliefs. *The Arithmetic Teacher*, *35*(5), 32–34. https://doi.org/10.5951/AT.35.5.0032

Freund, L. E., & Spohrer, J. C. (2012). The Human Side of Service Engineering. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *23*(1), 2–10. https://doi.org/10.1002/hfm.20521

Galetsi, P., Katsaliaki, K., & Kumar, S. (2020). Big data analytics in health sector: Theoretical framework, techniques and prospects. *International Journal of Information Management*, *50*, 206–216. https://doi.org/10.1016/j.ijinfomgt.2019.05.003

George, M. L. (2003). *Lean Six Sigma for service: How to use Lean speed and six sigma quality to improve services and transactions* (1st ed.). McGraw-Hill Education. https://doi.org/10.5041/RMMJ.10352

Giordano, L. A., Elliott, M. N., Goldstein, E., Lehrman, W. G., & Spencer, P. A. (2010). Development, Implementation, and Public Reporting of the HCAHPS Survey. *Medical Care Research and Review*, *67*(1), 27–37. https://doi.org/10.1177/1077558709341065

Glickman, S. W., Boulding, W., Manary, M., Staelin, R., Roe, M. T., Wolosin, R. J., Ohman, E. M., Peterson, E. D., & Schulman, K. A. (2010). Patient Satisfaction and Its Relationship With Clinical Myocardial Infarction. *Circulation: Cardiovascular Quality and Outcomes*, *3*(2), 188–195. https://doi.org/10.1161/CIRCOUTCOMES.109.900597

Goolaup, S. (2018). *On Consumer Experiences and the Extraordinary On Consumer Experiences and the Extraordinary* [University of Gothenburg]. https://gupea.ub.gu.se/bitstream/2077/56583/1/gupea_2077_56583_1.pdf

Gray, M. (2017). *Value based healthcare*. *437*, 1–2. https://doi.org/10.1136/bmj.j437

Gupta, S., & Sharma, M. (2016). Lean services: a systematic review. *International Journal of Productivity and Performance Management*, *65*(8), 1025–1056. https://doi.org/10.1108/IJPPM-02-2015-0032

Haddad, T. H. (2012). The Applicability of Total Productive Maintenance for Healthcare Facilities : an Implementation Methodology. *International Journal of Business, Humanities and Technology*, *2*(2), 148–155.

Haji, M., & Darabi, H. (2011). A simulation case study: Reducing outpatient waiting time of otolaryngology care services using VBA. *IEEE International Conference on Automation Science and Engineering*, 525–530. https://doi.org/110.1109/CASE.2011.6042448

Hall, R. W. (2004). Lean and the Toyota Production System. *Target*, *20*(3), 22–27. https://doi.org/10.1016/j.jaubas.2014.07.001

Hall, R. W. (2011). *Handbook of Healthcare System Scheduling* (Vol. 168). New York: Springer Science+ Business Media, LLC. https://doi.org/10.1007/978-1-4614-1734-7

Hallam, C., & Contreras, C. (2018). Lean healthcare: scale, scope and sustainability. *International Journal of Health Care Quality Assurance*, *31*(7), 684–696. https://doi.org/10.1108/IJHCQA-02-2017-0023

Hasle, P., Nielsen, A. P., & Edwards, K. (2016). Application of Lean Manufacturing in Hospitals — the Need to Consider Maturity , Complexity , and the Value Concept. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *26*(4), 430–442. https://doi.org/10.1002/hfm.20668

Hines, P., Holweg, M., & Rich, N. (2004). Learning to Evolve: A Review of Contemporary Lean Thinking. *International Journal of Operations & Production Management*, *24*(10), 997–1011. https://doi.org/10.1108/01443570410558049

Hines, P., Taylor, D., & Walsh, A. (2020). The Lean journey: have we got it wrong? *Total Quality Management and Business Excellence*, *31*(3–4), 389–406. https://doi.org/10.1080/14783363.2018.1429258

Holbrook, M. B., & Hirschman, E. C. (1982). The Experiential Aspects of Consumption: Consumer Fantasies, Feelings, and Fun. *Journal of Consumer Research*, *9*(2), 132. https://doi.org/10.1086/208906

Isaac-Renton, J. L., Chang, Y., Prystajecky, N., Petric, M., Mak, A., Abbott, B., Paris, B., Decker, K. C., Pittenger, L., Guercio, S., Stott, J., & Joseph, D. M. (2012). Use of lean response to improve pandemic influenza surge in public health laboratories. *Emerging Infectious Diseases*, *18*(1), 57–62. https://doi.org/10.3201/eid1801.101485

Jadhav, J. R., Mantha, S. S., & Rane, S. B. (2015). Analysis of interactions among the barriers to JIT production: Interpretive structural modelling approach. *Journal of Industrial Engineering International*, *11*(3), 331–352. https://doi.org/10.1007/s40092-014-0092-4

Jasti, N. V. K., & Kodali, R. (2015). Lean production: literature review and trends. *International Journal of Production Research*, *53*(3), 867–885. https://doi.org/10.1080/00207543.2014.937508

Jeong, K.-Y., & Phillips, D. T. (2001). Operational efficiency and effectiveness measurement. *International Journal of Operations and Production Management*, *21*(11), 1404–1416. https://spmconsultant.co.in/sites/default/files/downloads/Operational efficiency and effectiveness measurement.pdf

Jiang, N., & Malkin, B. D. (2016). Use of Lean and CAHPS Surgical Care Survey to Improve Patients' Experiences with Surgical Care. *Otolaryngology - Head and Neck Surgery*, *155*(5), 743–747. https://doi.org/10.1177/0194599816657051

Jørgensen, F., Matthiesen, R., Nielsen, J., & Johansen, J. (2007). Lean Maturity, Lean Sustainability. In *IFIP — The International Federation for Information Processing* (Vol. 246). Springer, Boston, MA. https://doi.org/10.1007/978-0-387-74157-4_44

Jussen, P., Kuntz, J., Senderek, R., & Moser, B. (2019). Smart Service Engineering. *Procedia CIRP*, *83*, 384–388. https://doi.org/10.1016/j.procir.2019.04.089

Karimi-Dehkordi, M., Spiers, J., & Clark, A. M. (2019). An evolutionary concept analysis of "patients' values". *Nursing Outlook*, *67*(5), 523–539. https://doi.org/10.1016/j.outlook.2019.03.005

Karlsson, C., & Hlström, P. (1996). Assessing changes towards lean production. *International Journal of Operations and Production Management*, *16*(2), 24–41. https://doi.org/10.1108/01443579610109820

Keim, E. M. (2019). Rethinking the basics. *The Journal for Quality and Participation*.

Kim, C. S., Spahlinger, D. A., Kin, J. M., & Billi, J. E. (2006). Lean health care: what can hospitals learn from a world-class automaker? *Journal of Hospital Medicine (Online)*, *1*(3), 191–199. https://doi.org/10.1002/jhm.68

Kim, H. (2009). Service Science for Service Innovation. *Journal of Service Science*, *1*(1), 1–7. https://doi.org/10.1007/s12927-009-0001-3

Kim, H. (2019). Service Science: Past, Present, and Future. *Journal of Service Science Research*, *11*(2), 117–132. https://doi.org/10.1007/s12927-019-0006-5

Kim, S., & Toya, K. (2019). Leadership style required for the transition to servitization in Japan. *Journal of Manufacturing*

Technology Management, *30*(2), 335–352. https://doi.org/10.1108/JMTM-02-2018-0034

Kleindorfer, P. R., Singhal, K., & Van Wassenhove, L. N. (2005). Sustainable Operations Management. *Production and Operations Management*, *14*(4), 482–492. https://doi.org/10.1111/j.1937-5956.2005.tb00235.x

Kollberg, B., & Dahlgaard, J. J. (2007). *Measuring lean initiatives in health care services : issues and findings*. *56*(1), 7–24. https://doi.org/10.1108/17410400710717064

Korpal, P., & Jasielska, A. (2019). Investigating interpreters' empathy: Are emotions in simultaneous interpreting contagious? *Target International Journal of Translation Studies*, *31*(1), 2–24. https://doi.org/10.1075/target.17123.kor

Krafcik, J. F. (1988). Triumph of the lean production system. *Sloan Management Review*, *30*(1), 41–52. https://doi.org/10.1108/01443570911005992

Kucukergin, K. G., & Meydan Uygur, S. (2019). Are emotions contagious? Developing a destination social servicescape model. *Journal of Destination Marketing and Management*, *14*, 100386. https://doi.org/10.1016/j.jdmm.2019.100386

Kumar, V., & Reinartz, W. (2016). Creating Enduring Customer Value. *Journal of Marketing*, *80*(6), 36–68. https://doi.org/10.1509/jm.15.0414

Kuuru, T.-K., Litovuo, L., Aarikka-Stenroos, L., & Helander, N. (2020). Emotions in Customer Experience. In *Society as an Interaction Space* (pp. 247–274). Springer, Singapore.

Langabeer II, J. R., & Helton, J. (2016). *Health Care Operations Management: A Systems Perspective* (2nd ed.). Jones & Bartlett Learning.

Laursen, M. L., Gertsen, F., & Johansen, J. (2003). Applying lean thinking in hospitals – exploring implementation difficulties. In *3rd International Conference on the Management of Healthcare and Medical Technology*.

Leggat, S. G., Bartram, T., Stanton, P., & Bamber, G. J. (2015). Have process redesign methods , such as Lean , been successful in changing care delivery in hospitals ? A systematic review. *Public Money & Management*, *35*(2), 161–168. https://doi.org/10.1080/09540962.2015.1007714

Leite, H. dos R., & Vieira, G. E. (2015). Lean philosophy and its applications in the service industry: A review of the current knowledge. *Production*, *25*(3), 529–541. https://doi.org/10.1590/0103-6513.079012

Leming-Lee, T. S., Polancich, S., & Pilon, B. (2019). The Application of the Toyota Production System LEAN 5S Methodology in the Operating Room Setting. *Nursing Clinics of North America*, *54*(1), 53–79. https://doi.org/10.1016/j.cnur.2018.10.008

Lewis, M. A. (2000). Lean production and sustainable competitive advantage. *International Journal of Operations and Production Management*, *20*(8), 959–978. https://doi.org/10.1108/01443570010332971

Li, X., Zhang, C., Almeev, R. R., & Holtz, F. (2020). GeoBalance: An Excel VBA program for mass balance calculation in geosciences. *Chemie Der Erde*, *80*(2), 125629. https://doi.org/10.1016/j.chemer.2020.125629

Liker, J. K. (1997). *Becoming Lean: Inside Stories of U.S. Manufacturers*. Productivity Press. https://www.routledge.com/Becoming-Lean-Inside-Stories-of-US-Manufacturers/Liker/p/book/9781563271731

Liker, J. K. (2015). *The Toyota Way in Services : The Case of Lean*. *May 2006*. https://doi.org/10.5465/AMP.2006.20591002

Lima, R. M., Dinis-Carvalho, J., Souza, T. A., Vieira, E., & Gonçalves, B. (2020). Implementation of lean in health care environments: an update of systematic reviews. *International Journal of Lean Six Sigma*, *12*(2), 399–431. https://doi.org/10.1108/IJLSS-07-2019-0074

Lin, M. T. Y. (2019). Effects of Experiential Marketing on Experience Value and Customer Satisfaction in Ecotourism. *Ekoloji Dergisi*, *28*(107), 3151–3156. http://www.ekolojidergisi.com/download/effects-of-experiential-marketing-on-experience-value-and-customer-satisfaction-in-ecotourism-5953.pdf

Lopez, M. G., Unibertsitatea, M., Val, E., Unibertsitatea, M., Iriarte, I., & Unibertsitatea, M. (2019). *Gaining patient experience insights : an integrated and multi-leveled framework of information*. *November*. https://doi.org/10.33114/adim.2019.05.253

Major, M. J., & Magalhães, A. (2014). Reestruturação do serviço nacional de saúde em Portugal: balanço da empresarialização dos hospitais públicos portugeses. *Revista de Administração*, *49*(3), 476–490. https://doi.org/10.5700/rausp1162

Maleyeff, J. (2006). Exploration of internal service systems using lean principles. *Management Decision*, *44*(5), 674–689. https://doi.org/10.1108/00251740610668914

Malmbrandt, M., & Åhlström, P. (2013). An instrument for assessing lean service adoption. *International Journal of Operations and Production Management*, *33*(9), 1131–1165. https://doi.org/0.1108/IJOPM-05-2011-0175

Martichenko, R. O. (2020). Post COVID-19 Crisis Supply Chain: A Time to Rise. In *LeanCor Supply Chain Group* (p. 17). https://info.leancor.com/post-covid-19-crisis-supply-chain

Marx, E., Pauli, T., Fielt, E., & Matzner, M. (2020). From services to smart services: Can service engineering methods get smarter as well? *Roceedings of the 15th International Conference on Business Information Systems 2020 "Developments, Opportunities and Challenges of Digitization", WIRTSCHAFTSINFORMATIK 2020*, 1–15. https://doi.org/10.30844/wi_2020_j9-marx

Maurya, A. (2012). *Running Lean: iterate from plan A to a plan that works*. O'Reilly Media, Inc.

Mazzocato, P., Savage, C., Brommels, M., & Thor, J. (2010). Lean thinking in healthcare: a realist review of the literature.

BMJ Quality & Safety, *19*(5), 376–382. https://doi.org/10.1136/qshc.2009.037986
MCDT's - SNS. (2020). https://www.sns.gov.pt/monitorizacao-do-sns/mcdts/
Mcgovern, K. M. P. A. (2020). Lean the Virus: Applying Lean principles to the COVID-19 response. *Northeast Conference on Public Administration: At the Heart of Public Service in America*.
Mehri, D. (2006). The Darker Side of Lean: An Insider's Perspective on the Realities of the Toyota Production System. *Academy of Management Perspectives*, *20*(2), 21–42. https://doi.org/10.5465/AMP.2006.20591003
Melton, T. (2005). The benefits of lean manufacturing: What lean thinking has to offer the process industries. *Chemical Engineering Research and Design*, *83*(6 A), 662–673. https://doi.org/10.1205/cherd.04351
Meyer, C., & Schwager, A. (2007). *Understanding Customer Experience Customer Experience*. *85*(2), 116–126. http://uc.cinepoliscorporativo.com.mx/wbt/cursos/DEyAP/DEyAP2017/ACT DEYAP_UNDERSTANDING CUSTOMER EXPERIENCE-ING_Enfoque en el cliente.pdf
Ministério da Saúde. (2017). *Portaria 153/2017*. Diário da República n.º 86/2017, Série I de 2017-05-04. https://data.dre.pt/eli/port/153/2017/05/04/p/dre/pt/html
Ministério da Saúde. (2018). *Retrato da Saúde, Portugal* (Vol. 25, Issue 8). https://www.sns.gov.pt/retrato-da-saude-2018/
Mittal, S., Schulz, A. S., & Stiller, S. (2014). Robust Appointment Scheduling. *Leibniz International Proceedings in Informatics, LIPICS*, *28*, 356–370. https://doi.org/10.4230/LIPIcs.APPROX-RANDOM.2014.356
Monden, Y. (1983). *Toyota Production System: An Integrated Approach to Just-in-time* (1ª ed.). New York: CRC Press.
Mwanza, B. G., & Mbohwa, C. (2015). An assessment of the effectiveness of equipment maintenance practices in public hospital. *Procedia Manufacturing*, *4*, 307–314. https://doi.org/10.1016/j.promfg.2015.11.045
Nunes, A. M. (2018). Recuperação do Serviço Nacional de Saúde Português: Novas Perspectivas Para a Política de Saúde. *Revista de Gestão Em Sistemas de Saúde*, *7*(1), 16–28. https://doi.org/10.5585/rgss.v7i1.311
Ohno, T. (1988). *Toyota Production System: Beyond Large-Scale Production* (1st ed.). CRC Press.
Ojasalo, J., & Ojasalo, K. (2020). Lean Service Innovation. *Service Science*, *10*(1), 25–39. https://doi.org/10.1287/serv.2017.0194
Osterman, C. (2015). *Towards a lean integration of lean* [Mälardalen University]. https://doi.org/10.13140/RG.2.2.10282.72644
Petersson, P., Olsson, B., Lundström, T., Johansson, O., Broman, M., Blücher, D., Alsterman, H., & Svante, A. (2010). *Lean - Turn Deviations into Success!* Part Media.
Piercy, N., & Rich, N. (2009). Lean transformation in the pure service environment: the case of the call service centre. *International Journal of Operations & Production Management*, *29*(1), 54–76. https://doi.org/10.1108/01443570910925361
Pine, B. J., & Gilmore, J. H. (1998). Welcome to the Experience Economy. *Harvard Business Review*, *76*(4), 97–106. https://go.gale.com/ps/anonymous?id=GALE%7CA20916746&sid=googleScholar&v=2.1&it=r&linkaccess=abs&issn=00178012&p=AONE&sw=w
Poppendieck, M. (2011). Principles of Lean Thinking. *IT Management Select*, *18*, 1–7.
Priyan, S., & Uthayakumar, R. (2016). Operations Research in Healthcare Supply Chain Management Under Fuzzy-Stochastic Environment: Operations Research in Healthcare. In *Stochastic Processes and Models in Operations Research* (pp. 271–314). IGI Global. https://doi.org/10.4018/978-1-5225-0044-5.ch016
Radnor, Z., & Boaden, R. (2008). Editorial: Lean in Public Services—Panacea or Paradox? *Public Money and Management*, *28*(1), 3–7. https://doi.org/10.1111/j.1467-9302.2008.00610.x
Radnor, Z. J., Holweg, M., & Waring, J. (2012). Lean in healthcare: The unfilled promise? *Social Science & Medicine*, *74*(3), 364–371. https://doi.org/10.1016/j.socscimed.2011.02.011
Ramakrishnan, V., & Nallusamy, S. (2017). Implementation of total productive maintenance lean tool to reduce lead time - A case study. *International Journal of Mechanical Engineering and Technology*, *8*(12), 295–306. http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=12
Rechel, B., Wright, S., Barlow, J., & McKee, M. (2010). Hospital capacity planning: from measuring stocks to modelling flows. *Bulletin of the World Health Organization*, *88*(8), 632–636. https://doi.org/10.2471/BLT.09.073361
Repenning, N. P., & Sterman, J. D. (2001). Nobody ever gets credit for fixing problems that never happened: creating and sustaining process improvement. *California Management Review*, *430*(4), 64–88. https://doi.org/10.1109/EMR.2002.1167285
Reshad, A. I., Rahman, M. M., & Chowdhury, N. M. (2020). Improving performance of epidemic healthcare management during covid-19 outbreak using lss dmaic approach: A case study for Bangladesh. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 534–544. http://www.ieomsociety.org/detroit2020/papers/132.pdf
Ribando, R. J. (1998). An Excel/Visual Basic for Applications (VBA) Programming Primer. *Computers in Education Journal*, *8*(2), 38–43. https://www.researchgate.net/publication/294364618_An_ExcelVisual_Basic_for_Applications_VBA_programming_primer

Safdar, K. A., Emrouznejad, A., & Dey, P. K. (2020). An optimized queue management system to improve patient flow in the absence of appointment system. *International Journal of Health Care Quality Assurance*, *33*(7/8), 477–494. https://doi.org/10.1108/IJHCQA-03-2020-0052

Salata, F., De Lieto Vollaro, A., De Lieto Vollaro, R., & Davoli, M. (2014). Plant Reliability in Hospital Facilities. *Energy Procedia*, *45*, 1195–1204. https://doi.org/10.1016/j.egypro.2014.01.125

Schmitt, B. (1999). Experiential Marketing. *Journal of Marketing Management*, *15*(1/3), 53–67. https://doi.org/10.1362/026725799784870496

Sebaa, A., Nouicer, A., Tari, A., Tarik, R., & Abdellah, O. (2017). Decision support system for health care resources allocation. *Electronic Physician*, *9*(6), 4661–4668. https://doi.org/10.19082/4661

Shah, R., & Ward, P. T. (2003). Lean manufacturing: Context, practice bundles, and performance. *Journal of Operations Management*, *21*(2), 129–149. https://doi.org/10.1016/S0272-6963(02)00108-0

Sharifi, S., & Saberi, K. (2014). Capacity planning in hospital management: an overview. *Indian Journal of Fundamental and Applied Life Sciences*, *14*(2), 515–521. https://www.researchgate.net/profile/Kianoush-Saberi/publication/324017698_CAPACITY_PLANNING_IN_HOSPITAL_MANAGEMENT_AN_OVERVIEW/links/5ab94f9c45851515f5a0c8db/CAPACITY-PLANNING-IN-HOSPITAL-MANAGEMENT-AN-OVERVIEW.pdf

Simeonova, A., & Nedyalkov, A. (2020). A priori research on lean tools in business. *58th Annual Scientific Conference of University of Ruse and Union of Scientists*. http://conf.uni-ruse.bg/bg/docs/cp19/bp/bp-7.pdf

Slack, N., Chambers, S., & Johnston, R. (2007). *Operations Management* (5th Editio). Prentice Hall/Financial Times.

Song, W., Tan, K. H., & Baranek, A. (2009). Effective toolbox for lean service implementation. *International Journal of Services and Standards*, *5*(1), 1–16. https://doi.org/10.1504/IJSS.2009.021663

Sorooshian, S., & Fen, T. A. (2017). Applicability of Manufacturing Lean Tools in Service Operations. *International Journal of Mechanical Engineering and Technology (IJMET)*, *8*(7), 53–60. https://www.researchgate.net/publication/319040783_Applicability_of_manufacturing_lean_tools_in_service_operations

Souza, T. A., & Lima, R. M. (2020). Hospital Operations Management: An Exploratory Study from Brazil and Portugal. *Proceedings on 25th International Joint Conference on Industrial Engineering and Operations*, 69–77. https://doi.org/https://doi.org/10.1007/978-3-030-43616-2_8

Souza, T. A., Vaccaro, G. L. R., & Lima, R. M. (2020). Operating room effectiveness: a lean health-care performance indicator. *International Journal of Lean Six Sigma*, *11*(5), 987–1002. https://doi.org/10.1108/IJLSS-12-2017-0141

Spear, S. J., & Bowen, H. K. (1999). Decoding the DNA of the Toyota Production System. *Harvard Business Review*, *77*, 99–106. https://i9y8y5w2.stackpathcdn.com/wp-content/uploads/2015/12/Decoding-DNA-Spear-Bowen.pdf

Spohrer, J., & Kwan, S. K. (2009). Service science, management, engineering, and design (SSMED): An emerging discipline-outline & references. *International Journal of Information Systems in the Service Sector (IJISSS)*, *1*(3), 1–31. https://doi.org/10.4018/jisss.2009070101

Suárez-Barraza, M. F., & Miguel-Davila, J. A. (2020). Kaizen–Kata, a problem-solving approach to public service health care in Mexico. A multiple-case study. *International Journal of Environmental Research and Public Health*, *17*(9), 3297. https://doi.org/10.3390/ijerph17093297

Susman, G., & Evered, R. D. (1978). An assessment of the scientific merits of action research. *Administrative Science Quarterly*, *23*(4), 582–603. https://www.jstor.org/stable/pdf/2392581.pdf

Swank, C. K. (2003). The Lean Service Machine. *Harvard Business Review*, *81*(10), 1–7.

Tarawneh, W., & El-Sharo, S. (2009). Assessment of medical equipment in respect to their down time. *World Congress on Medical Physics and Biomedical Engineering*, *25*(7), 267–270. https://doi.org/10.1007/978-3-642-03885-3_74

Tortorella, G., Narayanamurthy, G., Godinho Filho, M., Portioli Staudacher, A., & Mac Cawley, A. F. (2020). Pandemic's effect on the relationship between lean implementation and service performance. *Journal of Service Theory and Practice*, *31*(2), 203–224. https://doi.org/10.1108/JSTP-07-2020-0182

Towill, D. R. (2010). Industrial engineering the Toyota Production System. *Journal of Management History*, *16*(3), 327–345. https://doi.org/10.1108/17511341011051234

Tsai, W. C., Lee, W. C., Chiang, S. C., Chen, Y. C., & Chen, T. J. (2019). Factors of missed appointments at an academic medical center in Taiwan. *Journal of the Chinese Medical Association*, *82*(5), 436–442. https://doi.org/10.1097/JCMA.0000000000000068

Venkatesh, J. (2007). An Introduction to Total Productive Maintenance (TPM). *The Plant Maintenance Resource Center*, 3–20. http://courseware.cutm.ac.in/wp-content/uploads/2020/06/total-productive-management-pdf.pdf

Waring, J. J., & Bishop, S. (2010). Lean healthcare: Rhetoric, ritual and resistance. *Social Science and Medicine*, *71*(7), 1332–1340. https://doi.org/10.1016/j.socscimed.2010.06.028

Weinstock, D. (2008). Lean healthcare. *Journal of Medical Practice Management: MPM*, *23*(6), 339–341. https://doi.org/10.20396/jihm.v1i1.9305

Weiss, E. N., Jackson, S., English, A., & Stevenson, D. (2017). Lean Tools for Service Business Model Innovation in Healthcare. In *Pfannstiel M., Rasche C. (eds) Service Business Model Innovation in Healthcare and Hospital Management* (pp. 233–

247). Springer, Cham. https://doi.org/10.1007/978-3-319-46412-1_13
Westwood, N., Moore, M. J., & Cooke, M. (2007). Going lean in the NHS: How lean thinking will enable the NHS to get more out of the same resources. In *NHS Institute of Innovation and Improvement* (p. 23). https://www.england.nhs.uk/improvement-hub/wp-content/uploads/sites/44/2017/11/Going-Lean-in-the-NHS.pdf
Wickens, P. D. (1993). Lean Production and Beyond: the System, Its Critics and the Future. *Human Resource Management Journal*, *3*(4), 75–90. https://doi.org/10.1111/j.1748-8583.1993.tb00324.x
Womack, J. P., & Jones, D. T. (1994). From Lean Production to the Lean Enterprise. *Harvard Business Review*, *72*(2), 93–103. http://orca.cf.ac.uk/id/eprint/47687%0A
Womack, J. P., & Jones, D. T. (1997). Lean thinking–banish waste and create wealth in your corporation. *Journal of the Operational Research Society*, *48*(11), 1148–1148. https://doi.org/10.1057/palgrave.jors.2600967
Womack, J. P., & Jones, D. T. (2015). *Lean solutions: how companies and customers can create value and wealth together*. Simon and Schuster. https://books.google.pt/books?hl=pt-PT&lr=&id=-Q1ZCgAAQBAJ&oi=fnd&pg=PA1&dq=+Lean+Solutions+jones+dt&ots=QVtntUQ1d0&sig=F0Im-oV_kjFCnfQuwdNg0UuZ9Sg&redir_esc=y#v=onepage&q&f=false
Womack, J. P., Jones, D. T., Roos, D., & Carpenter, D. S. (1991). *The machine that changed the world:[based on the Massachusetts Institute of Technology 5-million-dollar 5-year study on the future of the automobile]* (1ª ed.). Rawson Associates.
Yaeger, K., Martini, M., Rasouli, J., & Costa, A. (2019). Emerging Blockchain Technology Solutions for Modern Healthcare Infrastructure. *Journal of Scientific Innovation in Medicine*, *2*(1), 1–7. https://doi.org/10.29024/jsim.7
Young, T. P., & McClean, S. I. (2008). A critical look at Lean Thinking in healthcare. *BMJ Quality & Safet*, *17*(5), 382–386. https://doi.org/10.1136/qshc.2006.020131

APPENDIX I – VBA CODDING

```
Sub Run_Macro()

' Macro_Run_Macro

    Dim StartTime As Double
    Dim SecondsElapsed As Double

    Dim answer As Integer
    Dim text As String
    Dim goRun As Integer

    'guarda o tempo de inicio
    StartTime = Timer

        Application.ScreenUpdating = False

    'verifica se dados foram carregados
    Sheets("Dashboard").Select
    Range("A1").Select
    ActiveCell.FormulaR1C1 = _
"=COUNTA(Original_Data_Exams!R[1]C,Original_Data_
Consultations!R[1]C)"
    If (ActiveCell > "0") Then

    '- - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - -
    'criacao da caixa de dialogo

    text = "Run now, are you sure?"
    answer = MsgBox(text, vbYesNo + vbQuestion,
"Ready to Run")

    'guarda o tempo de inicio
    StartTime = Timer

    If answer = vbYes Then

    'mostra worksheet
    Sheets("Check_RN").Visible = True

    'goRun = 0
    goRun = 1
    Range("Q1").Value = ""

    '- - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - -
    'Procura falha de exames/consultas

    If goRun = 1 Then

        With Application
            .Calculation = xlCalculationManual
            .DisplayStatusBar = False
            .EnableEvents = False
        End With

        Sheets("Check_RN").Select
        Range("Combined_data[#Headers]").Select
        Selection.AutoFilter
        Selection.AutoFilter
        Range("I2:I777777").Clear
        Range("J2:J777777").Clear
        Range("K2:K777777").Clear
        Range("L2:L777777").Clear
        Range("Q9:R58").Clear
        Range("S9:S58").ClearFormats
        Range("U9:U58").Clear
        Range("V9:V58").ClearFormats
        Range("X9:X58").Clear
        ActiveSheet.Calculate

        Sheets("ABC Analysis").Select
        Range("ABC_Analysis[#Headers]").Select
        Selection.AutoFilter
        Selection.AutoFilter
        Range("A2:B38").Select
        Selection.ClearContents

        Range("A2").Select
        Sheets("Final Report").Select
        Range("Final_Report[#Headers]").Select
        Selection.AutoFilter
        Selection.AutoFilter
        Range("A2:I2").Select
        Range(Selection,
Selection.End(xlDown)).Select
        Selection.ClearContents
        Range("A1").Select

        '- - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - -

        'Procura exames - 1-a-1

        Sheets("Check_RN").Select

        examesNumber = Range("P1").Value

        Count = 0
        found = 0
        FoundOk = 0
        IndexResult = 2

         For i = 1 To examesNumber

            'Selection.End(xlDown).Select
            Cells(i + 1, 8).Select

            If (ActiveCell.Offset(0, 1).Value =
"") And (ActiveCell.Value <> "") Then

                ActiveCell.Offset(0, 1).Value = 0
'Marca que ja analisou este exame
                ActiveCell.Offset(1,
1).Range("A1").Select
                'incrementa numero de exames deste
tipo na parte dos resultados
                Cells(8 + ActiveCell.Offset(-1, -
4).Value, 17).Value = Cells(8 +
ActiveCell.Offset(-1, -4).Value, 17).Value + 1

                Count = 0
                found = 0
                FoundOk = 0
                'enquanto o ID paciente for o mesmo
e ainda nao tiver encontrado a consulta
correspondente a este exame
                Do While (ActiveCell.Offset(0 +
Count, -7).Value = ActiveCell.Offset(-1, -
7).Value)
                    'se e uma consulta e e o mesmo
servico e a data de realizacao da consulta e menor
ou igual que a data de realizacao do exame
                    If ((ActiveCell.Offset(0 +
Count, -8).Value = "C") And (ActiveCell.Offset(0 +
Count, -4).Value = ActiveCell.Offset(-1, -
4).Value)) And _
                    (ActiveCell.Offset(0 + Count,
-6).Value <= ActiveCell.Offset(-1, -5).Value) Then
                        'contabiliza consulta
falhada apenas se ainda nao foi contabilizada e se
existe uma consulta futura ineficaz para o
respectivo exame
                        If
(ActiveCell.Offset(Count, 0).Value = "") And
(ActiveCell.Offset(Count, -6).Value > Date) And
(ActiveCell.Offset(-1, 3).Value = "") Then
                            Cells(8 +
ActiveCell.Offset(-1, -4).Value, 21).Value =
Cells(8 + ActiveCell.Offset(-1, -4).Value,
21).Value + 1

                                    'copia dados
de consultas falhadas, com respectivos dados dos
exames, para o relatorio final (1 consulta por
exame falhado)
                                    If
(ActiveCell.Offset(-1, 1).Value = "") And
(ActiveCell.Offset(Count, -6).Value > Date) And
(ActiveCell.Offset(-1, 3).Value = "") Then
                                    Sheets("Final
Report").Cells(IndexResult, 1).Value =
ActiveCell.Offset(Count, -7).Value
```

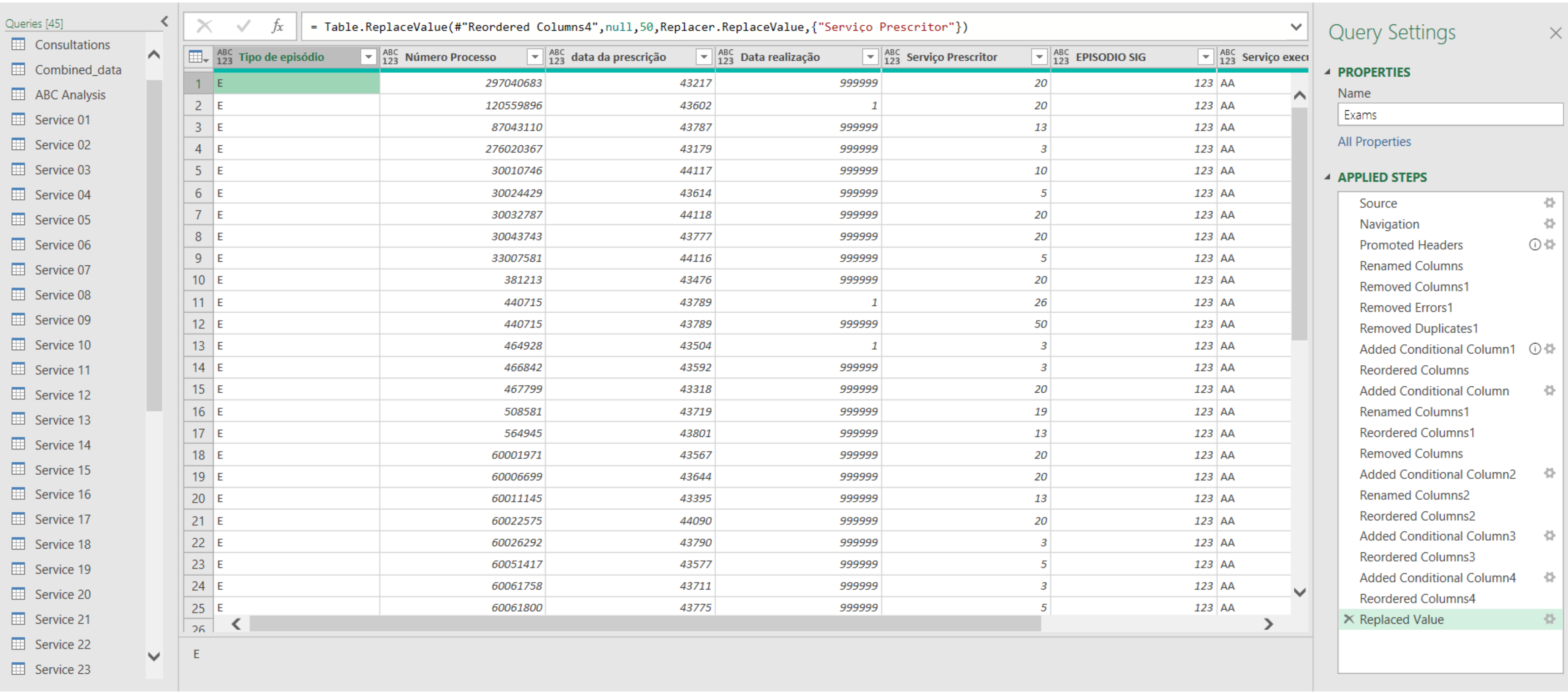
```
                                    Sheets("Final
Report").Cells(IndexResult,       2).Value       =
ActiveCell.Offset(Count, -4).Value
                                    Sheets("Final
Report").Cells(IndexResult,       3).Value       =
ActiveCell.Offset(-1, -3).Value
                                    Sheets("Final
Report").Cells(IndexResult,       4).Value       =
ActiveCell.Offset(-1, -2).Value
                                    Sheets("Final
Report").Cells(IndexResult,       5).Value       =
ActiveCell.Offset(-1, -6).Value
                                    Sheets("Final
Report").Cells(IndexResult,       6).Value       =
ActiveCell.Offset(-1, -5).Value
                                    Sheets("Final
Report").Cells(IndexResult,       7).Value       =
ActiveCell.Offset(Count, -6).Value
                                    IndexResult  =
IndexResult + 1
                                    End If

                        End If

                                    If
(ActiveCell.Offset(-1,   1).Value   =   "")   And
(ActiveCell.Offset(Count, -6).Value <= Date) And
(ActiveCell.Offset(-1, 2).Value = "") Then
                                    Sheets("Final
Report").Cells(IndexResult,       1).Value       =
ActiveCell.Offset(Count, -7).Value
                                    Sheets("Final
Report").Cells(IndexResult,       2).Value       =
ActiveCell.Offset(Count, -4).Value
                                    Sheets("Final
Report").Cells(IndexResult,       3).Value       =
ActiveCell.Offset(-1, -3).Value
                                    Sheets("Final
Report").Cells(IndexResult,       4).Value       =
ActiveCell.Offset(-1, -2).Value
                                    Sheets("Final
Report").Cells(IndexResult,       5).Value       =
ActiveCell.Offset(-1, -6).Value
                                    Sheets("Final
Report").Cells(IndexResult,       6).Value       =
ActiveCell.Offset(-1, -5).Value
                                    Sheets("Final
Report").Cells(IndexResult,       7).Value       =
ActiveCell.Offset(Count, -6).Value
                                    IndexResult  =
IndexResult + 1
                                    End If

                        'marca  como  consulta  sem
exame
                        ActiveCell.Offset(Count,
0).Value = 1

                        'contabiliza   numero   de
consultas ineficazes por exame
                        If  (ActiveCell.Offset(0  +
Count, -6).Value <= Date) Then
                            ActiveCell.Offset(-1,
2).Value = ActiveCell.Offset(-1, 2).Value + 1
                        Else
                            ActiveCell.Offset(-1,
3).Value = ActiveCell.Offset(-1, 3).Value + 1
                        End If

                            'copia    numero    de
consultas  ineficazes  ocorridas  para  exames  sem
consulta agendada para o relatorio final
                            If
(ActiveCell.Offset(Count,  -6).Value  <=  Date)  And
(ActiveCell.Offset(-1,   2).Value   >=   1)   And
(ActiveCell.Offset(-1, 3).Value = "") Then
                            Sheets("Final
Report").Cells(IndexResult   -   1,   8).Value   =
ActiveCell.Offset(-1, 2).Value
                            End If

                                'copia  numero  de
consultas  ineficazes  ocorridas  por  exame  para  o
relatorio final
                                If
(ActiveCell.Offset(Count,  -6).Value  >  Date)  And
(ActiveCell.Offset(-1, 3).Value >= 1) Then
                                Sheets("Final
Report").Cells(IndexResult   -   1,   8).Value   =
ActiveCell.Offset(-1, 2).Value
                                End If

                                    'copia  numero
de consultas ineficazes que irao ocorrer por exame
para o relatorio final
                                    If
(ActiveCell.Offset(Count,  -6).Value  >  Date)  And
(ActiveCell.Offset(-1, 3).Value >= 1) Then
                                    Sheets("Final
Report").Cells(IndexResult   -   1,   9).Value   =
ActiveCell.Offset(-1, 3).Value
                                    End If

                            'contabiliza    exame
falhado apenas se ainda nao foi contabilizado
                            If
(ActiveCell.Offset(-1,   1).Value   =   "")   And
(ActiveCell.Offset(Count, -6).Value > Date) Then
                            Cells(8           +
ActiveCell.Offset(-1,   -4).Value,   18).Value   =
Cells(8    +    ActiveCell.Offset(-1,    -4).Value,
18).Value + 1
                            End If

                        'marca como exame falhado
                        If
ActiveCell.Offset(Count, -6).Value > Date Then
                        ActiveCell.Offset(-1,
1).Value = 1
                        'marca consulta encontrada
                        found = 1
                        End If

                    'se e uma consulta e e o mesmo
servico e a data de realizacao da consulta e maior
que a data de realizacao do exame
                    ElseIf ((ActiveCell.Offset(0 +
Count, -8).Value = "C") And (ActiveCell.Offset(0 +
Count,   -4).Value   =   ActiveCell.Offset(-1,   -
4).Value)) And _
                            (ActiveCell.Offset(0
+  Count,  -6).Value  >  ActiveCell.Offset(-1,  -
5).Value) And FoundOk = 0 Then
                                'contabiliza
consultas  eficazes  (realizadas  com  resultado  de
exames)
                                Cells(8          +
ActiveCell.Offset(-1,   -4).Value,   24).Value   =
Cells(8    +    ActiveCell.Offset(-1,    -4).Value,
24).Value + 1
                                FoundOk = 1

                    End If

                    Count = Count + 1

                Loop
                'ActiveCell.Offset(-2,
0).Range("A1").Select
                'ActiveSheet.Calculate
                'Selection.End(xlUp).Select

            Else
            'Cells(1,   10).Value   =   i   -   1
'confirmacao  de  quantos  episodios/exames  sao
analisados
            'i = examesNumber + 1
            End If

        Next

        '- - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - -
        'Parte  de  formatacao  dos  resultados  -
Exames

        Range("S9:S51").Select
        Selection.FormatConditions.AddColorScale
ColorScaleType:=3

Selection.FormatConditions(Selection.FormatCondit
ions.Count).SetFirstPriority

Selection.FormatConditions(1).ColorScaleCriteria(
1).Type = _
```

```
            xlConditionValueLowestValue
        With
Selection.FormatConditions(1).ColorScaleCriteria(
1).FormatColor
            .Color = 8109667
            .TintAndShade = 0
        End With

Selection.FormatConditions(1).ColorScaleCriteria(
2).Type = _
            xlConditionValuePercentile

Selection.FormatConditions(1).ColorScaleCriteria(
2).Value = 50
        With
Selection.FormatConditions(1).ColorScaleCriteria(
2).FormatColor
            .Color = 8711167
            .TintAndShade = 0
        End With

Selection.FormatConditions(1).ColorScaleCriteria(
3).Type = _
            xlConditionValueHighestValue
        With
Selection.FormatConditions(1).ColorScaleCriteria(
3).FormatColor
            .Color = 7039480
            .TintAndShade = 0
        End With

        Selection.Style = "Percent"
        Selection.NumberFormat = "0.00%"

        '- - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - -
        'Parte de formatacao dos resultados -
Consultas

        Range("V9:V51").Select
        Selection.FormatConditions.AddColorScale
ColorScaleType:=3

Selection.FormatConditions(Selection.FormatCondit
ions.Count).SetFirstPriority

Selection.FormatConditions(1).ColorScaleCriteria(
1).Type = _
            xlConditionValueLowestValue
        With
Selection.FormatConditions(1).ColorScaleCriteria(
1).FormatColor
            .Color = 8109667
            .TintAndShade = 0
        End With

Selection.FormatConditions(1).ColorScaleCriteria(
2).Type = _
            xlConditionValuePercentile

Selection.FormatConditions(1).ColorScaleCriteria(
2).Value = 50
        With
Selection.FormatConditions(1).ColorScaleCriteria(
2).FormatColor
            .Color = 8711167
            .TintAndShade = 0
        End With

Selection.FormatConditions(1).ColorScaleCriteria(
3).Type = _
            xlConditionValueHighestValue
        With
Selection.FormatConditions(1).ColorScaleCriteria(
3).FormatColor
            .Color = 7039480
            .TintAndShade = 0
        End With

        Selection.Style = "Percent"
        Selection.NumberFormat = "0.00%"

        '- - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - -
        'Parte de formatacao dos resultados -
Consultas pelos Exames

        Range("W9:W51").Select
        Selection.FormatConditions.AddColorScale
ColorScaleType:=3

Selection.FormatConditions(Selection.FormatCondit
ions.Count).SetFirstPriority

Selection.FormatConditions(1).ColorScaleCriteria(
1).Type = _
            xlConditionValueLowestValue
        With
Selection.FormatConditions(1).ColorScaleCriteria(
1).FormatColor
            .Color = 8109667
            .TintAndShade = 0
        End With

Selection.FormatConditions(1).ColorScaleCriteria(
2).Type = _
            xlConditionValuePercentile

Selection.FormatConditions(1).ColorScaleCriteria(
2).Value = 50
        With
Selection.FormatConditions(1).ColorScaleCriteria(
2).FormatColor
            .Color = 8711167
            .TintAndShade = 0
        End With

Selection.FormatConditions(1).ColorScaleCriteria(
3).Type = _
            xlConditionValueHighestValue
        With
Selection.FormatConditions(1).ColorScaleCriteria(
3).FormatColor
            .Color = 7039480
            .TintAndShade = 0
        End With

        Selection.Style = "Percent"
        Selection.NumberFormat = "0.00%"

        Range("P1").Select
        ActiveSheet.Calculate

        Range("Q1").Value = "Done"


    'Atualização invidual de relatorio por servico
    ActiveWorkbook.Connections("Query - ABC
Analysis").Refresh
    ActiveWorkbook.Connections("Query - Service
01").Refresh
    ActiveWorkbook.Connections("Query - Service
02").Refresh
    ActiveWorkbook.Connections("Query - Service
03").Refresh
    ActiveWorkbook.Connections("Query - Service
04").Refresh
    ActiveWorkbook.Connections("Query - Service
05").Refresh
    ActiveWorkbook.Connections("Query - Service
06").Refresh
    ActiveWorkbook.Connections("Query - Service
07").Refresh
    ActiveWorkbook.Connections("Query - Service
08").Refresh
    ActiveWorkbook.Connections("Query - Service
09").Refresh
    ActiveWorkbook.Connections("Query - Service
10").Refresh
    ActiveWorkbook.Connections("Query - Service
11").Refresh
    ActiveWorkbook.Connections("Query - Service
12").Refresh
    ActiveWorkbook.Connections("Query - Service
13").Refresh
    ActiveWorkbook.Connections("Query - Service
14").Refresh
    ActiveWorkbook.Connections("Query - Service
15").Refresh
    ActiveWorkbook.Connections("Query - Service
16").Refresh
    ActiveWorkbook.Connections("Query - Service
17").Refresh
    ActiveWorkbook.Connections("Query - Service
18").Refresh
```

```
    ActiveWorkbook.Connections("Query  -  Service
19").Refresh
    ActiveWorkbook.Connections("Query  -  Service
20").Refresh
    ActiveWorkbook.Connections("Query  -  Service
21").Refresh
    ActiveWorkbook.Connections("Query  -  Service
22").Refresh
    ActiveWorkbook.Connections("Query  -  Service
23").Refresh
    ActiveWorkbook.Connections("Query  -  Service
24").Refresh
    ActiveWorkbook.Connections("Query  -  Service
25").Refresh
    ActiveWorkbook.Connections("Query  -  Service
26").Refresh
    ActiveWorkbook.Connections("Query  -  Service
27").Refresh
    ActiveWorkbook.Connections("Query  -  Service
28").Refresh
    ActiveWorkbook.Connections("Query  -  Service
29").Refresh
    ActiveWorkbook.Connections("Query  -  Service
30").Refresh
    ActiveWorkbook.Connections("Query  -  Service
31").Refresh
    ActiveWorkbook.Connections("Query  -  Service
32").Refresh
    ActiveWorkbook.Connections("Query  -  Service
33").Refresh
    ActiveWorkbook.Connections("Query  -  Service
34").Refresh
    ActiveWorkbook.Connections("Query  -  Service
35").Refresh
    ActiveWorkbook.Connections("Query  -  Service
36").Refresh
    ActiveWorkbook.Connections("Query  -  Service
37").Refresh
    ActiveWorkbook.Connections("Query  -  Service
38").Refresh
    ActiveWorkbook.Connections("Query  -  Service
39").Refresh
    ActiveWorkbook.Connections("Query  -  Service
40").Refresh
    ActiveWorkbook.Connections("Query  -  Service
50").Refresh


    'altera colunas para o formato data
    Sheets("Imunoalergologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_01[[#Headers],[Nr
Processo]]").Select

    Sheets("Anestesiologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_02[[#Headers],[Nr
Processo]]").Select

    Sheets("Ortopedia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_03[[#Headers],[Nr
Processo]]").Select

    Sheets("Pneumologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_04[[#Headers],[Nr
Processo]]").Select

    Sheets("Neurologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_05[[#Headers],[Nr
Processo]]").Select

    Sheets("Pediatria").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_06[[#Headers],[Nr
Processo]]").Select

    Sheets("Pedopsiquiatria").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_07[[#Headers],[Nr
Processo]]").Select

    Sheets("Cirurgia Plástica").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_08[[#Headers],[Nr
Processo]]").Select

    Sheets("Otorrinolaringologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_09[[#Headers],[Nr
Processo]]").Select

    Sheets("Gastrenterologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_10[[#Headers],[Nr
Processo]]").Select

    Sheets("Estomatologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_11[[#Headers],[Nr
Processo]]").Select

    Sheets("Imunohemoterapia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_12[[#Headers],[Nr
Processo]]").Select

    Sheets("Endocrinologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_13[[#Headers],[Nr
Processo]]").Select

    Sheets("Oncologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_14[[#Headers],[Nr
Processo]]").Select

    Sheets("Dermatologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_15[[#Headers],[Nr
Processo]]").Select

    Sheets("Ginecologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_16[[#Headers],[Nr
Processo]]").Select

    Sheets("Oftalmologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_17[[#Headers],[Nr
Processo]]").Select

    Sheets("Cardiologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_18[[#Headers],[Nr
Processo]]").Select

    Sheets("Nefrologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_19[[#Headers],[Nr
Processo]]").Select

    Sheets("Neurocirurgia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_20[[#Headers],[Nr
Processo]]").Select

    Sheets("Psiquiatria").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_21[[#Headers],[Nr
Processo]]").Select

    Sheets("Obstetrícia").Select
```

```
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_22[[#Headers],[Nr
Processo]]").Select

    Sheets("Infecciologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_23[[#Headers],[Nr
Processo]]").Select

    Sheets("Cirurgia Pediátrica").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_24[[#Headers],[Nr
Processo]]").Select

    Sheets("Medicina           Fisica           e
Reabilitação").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_25[[#Headers],[Nr
Processo]]").Select

    Sheets("Urologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_26[[#Headers],[Nr
Processo]]").Select

    Sheets("Reumatologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_27[[#Headers],[Nr
Processo]]").Select

    Sheets("Medicina Interna").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_28[[#Headers],[Nr
Processo]]").Select

    Sheets("Cirurgia Geral").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_29[[#Headers],[Nr
Processo]]").Select

    Sheets("Radioterapia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_30[[#Headers],[Nr
Processo]]").Select

    Sheets("Cirurgia Vascular").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_31[[#Headers],[Nr
Processo]]").Select

    Sheets("Cirurgia Maxilofacial").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_32[[#Headers],[Nr
Processo]]").Select

    Sheets("Cardiologia Pediátrica").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_33[[#Headers],[Nr
Processo]]").Select

    Sheets("Neonatologia").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_34[[#Headers],[Nr
Processo]]").Select

    Sheets("Genética Médica").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_35[[#Headers],[Nr
Processo]]").Select

    Sheets("Cuidados Paliativos").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_36[[#Headers],[Nr
Processo]]").Select

    Sheets("Service 37").Select
    Columns("E:G").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_37[[#Headers],[Nr
Processo]]").Select

    Sheets("Exames sem Serviço").Select
    Columns("B:C").Select
    Selection.NumberFormat = "m/d/yyyy"
    Range("Service_50[[#Headers],[Nr
Processo]]").Select

    Sheets("Dashboard").Select
    Range("A1").Select
    Calculate


    Else
        Sheets("Check_RN").Select
        Range("Q1").Value = "No Run"
        'Range("Q1").Select
        Sheets("Dashboard").Select
        Range("A1").Select

    End If

    'Protege todas worsheets
    'For w = 1 To Sheets.Count
    'Sheets(w).Protect                    "hb2020",
DrawingObjects:=True,              Contents:=True,
Scenarios:=True,             AllowSorting:=True,
AllowFiltering:=True
    'Next w

    'oculta worksheet
    Sheets("Check_RN").Visible = False


    Sheets("Dashboard").Select
    Range("A1").Select

    'calcula tempo decorrido
    SecondsElapsed = Round(Timer - StartTime, 2)

    'notifica o utilizador
    MsgBox   "Tempo    de    processamento:    "    &
SecondsElapsed & " segundos", vbInformation

        With Application
            .DisplayStatusBar = True
            .EnableEvents = True
        End With


 'se a resposta for nao
        Else
        'goRun = 0
        Sheets("Dashboard").Select
        Range("A1").Select
        Selection.ClearContents
        End If

      Else
    'goRun = 0
    Sheets("Dashboard").Select
    Range("A1").Select
    Selection.ClearContents
    text = "No data available, press Refresh Data."
    answer = MsgBox(text, vbYes)
    End If


End Sub
```

APPENDIX II – POWER QUERY



APPENDIX III – EQUIPMENT PERFORMANCE MONITORING GRAPHICS (SIMULATION SAMPLE)

DASHBOARD - MTBF / MTTR / UNAVAILABILITY

START 01/01/2021

END 28/02/2021

AVAILABILITY 91%