NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

INÊS ALVIM CARVALHO REBELO PINTO

BSc in Sciences of Industrial Engineering and Management

LEAN SIX SIGMA APPLICATION IN THE HEALTHCARE SECTOR

A CASE STUDY IN A GYNAECOLOGY EXAM ROOM

INTEGRATED MASTER IN INDUSTRIAL ENGINEERING AND MANAGEMENT

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"Não devemos ter medo de nos sentir inquietos,
de pensar que tudo o que possamos fazer não basta.
(...)
Por isso, tende a coragem de substituir os medos pelos sonhos:
não sejam administradores de medos, mas empreendedores de sonhos!"
(Papa Francisco)

Abstract

The healthcare sector plays an important role in the world economy and health institutions have a growing concern about the quality of their services. This means an effective and fast response to achieve a better service quality and a strong response to patient's needs.
This project urges as a need to enlarge the offer and the efficiency of the Cervix and Lower Genital Tract Unit of a Portuguese Hospital to improve the client satisfaction and increase the hospital service levels.
Therefore, the Lean Six Sigma methodology was used recurring to the Define, Measure, Analyse, Improve, Control (DMAIC) cycle in which many different quality tools and techniques were used.
After careful observation of the unit, and data analysis, it was possible to identify some space for improvement. Although two different projects were initially identified, only one of them was implemented.
The project implemented was related to the client experience with the exams performed in this department. The other project identified was related to the registering procedures used at the hospital but it was not possible to proceed with it due to lack of resources.
After the full implementation, it was possible to eliminate 33% of the non-value added activities, reduce the waiting time by an average of 10 minutes by eliminating the sub-waiting moment, reduce the total exam time by an average of 3 minutes, cutting 80 minutes per day in the Front-Office Customer Service Technicians Tasks and an overall restructure of Scheduling System.
In the end, it is expected that the sigma level in this project increases from the current level of 1.7-1.8 to the 2.1-2.2 level.

Keywords: Healthcare, Human Papillomavirus Lean Six Sigma, Process Improvement, DMAIC cycle

Resumo

O setor da saúde desempenha um papel importante na economia mundial e as instituições de saúde têm uma preocupação crescente com a qualidade dos seus serviços. Isto significa eficácia e rapidez de resposta para conseguir uma melhor qualidade de serviço que vai ao encontro das necessidades dos doentes.
Este projeto surge como uma necessidade de aumentar a oferta e a eficiência da Unidade de Colo do Útero e Trato Genital Inferior de um Hospital Português para melhorar a satisfação dos clientes e os níveis de serviço hospitalar.
Para o efeito, foi utilizada a metodologia Lean Six Sigma recorrendo ao ciclo DMAIC no qual foram utilizadas diversas ferramentas e técnicas da qualidade.
Após a observação cuidada da unidade e uma análise de dados, foram tiradas algumas conclusões sobre quais deveriam ser os objectos de melhoria. Apesar de terem sido identificados dois projectos diferentes, apenas um foi objeto de implementação.
O primeiro projeto foi o que foi implementado e estava relacionado com a experiência do cliente ao realizar os exames deste departamento. O segundo projeto identificado estava relacionado com a forma de registos do cliente no hospital e não foi possível avançar devido à falta de recursos.
Após todas as implementações foi possível eliminar 33% das actividades sem valor acrescentado, reduzir o tempo de espera em média 10 minutos através da eliminação do momento de subespera, reduzir o tempo total de exame em média 3 minutos, reduzir 80 minutos por dia nas tarefas dos Técnicos de Atendimento do Front-Office e uma reestruturação global do Sistema de Agendamento.
No final, espera-se que o nível sigma passe do nível atual de 1,7-1,8 para o nível 2,1-2,2 neste projeto.

Palavras-chave: Saúde, Papilloma Virus Humano, Lean Seis Sigma, Melhoria de Processos, Ciclo DMAIC

Contents

Appendices

Annexes

List of Figures

List of Tables

Acronyms

ASCUS	Atypical Squamous Cells of Undetermined Significance
BO	Back-Office
BPMN	Business Process Model Notation
CQI	Continuous Quality Improvement
CSF	Critical Sucess Factors
CST	Customer Service Technician
DMADV	Define, Measure, Analyse, Design, Verify
DMAIC	Define, Measure, Analyse, Improve, Control
DPMO	Defects per Million of Opportunities
EHR	Electronic Health Records
ER	Emergency Room
FO	Front-Office
HPV	Human Papilloma Virus
HSIL	High-Grade Squamous Intraephithelial Lesions
JCI	Joint Commission International
KPI	Key Perfomance Indicators
LOS	Length of Stay
LSD	Least Significant Difference
LSIL	Low-Grade Squamous Intraephithelial Lesions
LSS	Lean Six Sigma
MA	Medical Assistant

NPS Net Promoter Score
NS Not Scheduled

OR Operating Room

PDCA Plan, Do, Check, Act
PDSA Plan, Do, Study, Act

QI Quality Improvement

RPN Risk Priority Number

S Scheduled
SIPOC Suppliers, Inputs, Process, Outputs, Customers
SMART Specific, Measurable, Achievable, Relevant and Time Constrained

TPS Toyota Production System
TQM Total Quality Management

VOC Voice of Customer
VSM Value Stream Mapping

Chapter 1

Introduction

This first chapter aims to contextualise the present dissertation and to confront the problems in analysis with the existing literature.
In the section 1.1, the main reasons for the study being carried out are explained along with the literature previous findings. In the second section 1.2 the main objectives (specific and general ones) are presented. The proposed methodology to perform the study is stated in the 1.3 section. In the last section 1.4, the structure of the following document is described.

1.1 Theoretical Background

The healthcare sector is vital to countries and communities. Governments have shown some concern because this sector has a large impact on a country's socioeconomic component, accounting for 15% of all government expenses in the European Union (Improta et al., 2018).
In health establishments it is necessary a certain level of flexibility and promptness in problem solving to achieve a better service quality and a strong response to patient's needs. For this reason, the health management systems need to be effective and ready to respond to variability of patients demand as well as to the unexpected events like what was experienced through the COVID-19 pandemic. To have a system that can correspond to these needs, it is required that the governance level is increased and also the process control mechanisms are improved, the number of errors occurrence must be diminished by establishing new processes and analysing the roots of what is causing the main problems (Improta et al., 2020).
Knowing that healthcare is experiencing a need for change, Lean Six Sigma (LSS) appears as a methodology that can help accomplish some of the sector needs. Lean Thinking is

already in use since 2002, but the combination of LSS is in use nowadays, also showing its good results (Ahmad Ansari, 2022). LSS has its focus on the end customer value desires, in healthcare the patient, and this is done by a continuous improvement culture eliminating the multiple wastes and the non-value-added activities (O'Mahony et al., 2021).
The LSS methodology combines two compatible methodologies since Lean is used to trace and remove waste and Six Sigma its more indicated to have less process variations (Improta et al., 2018).
The healthcare most common wastes are the abnormal waiting times, unnecessary movement of patients, working areas that require more health professionals' movements around the hospital, wrong labelling, or lack of information. Therefore, the most common improvements upcoming of LSS integration in the healthcare sector are the ones related to patient Length of Stay (LOS), earlier access to diagnostic and treatment processes, reduction of surgical site infections, reduction of time to perform tasks and a better communication between all that are involved in the health caring process like staff, patients, and families (Ahmad Ansari, 2022) (O'Mahony et al., 2021).
Healthcare establishments are experiencing an increase of their demand. Many studies show that healthcare professionals have now looked for guidance in other sectors to improve healthcare quality and patients' satisfaction. It is urgent to implement measures that can improve the health organisations efficiency and turn its focus on the value perceived by the hospital patients (Tlapa et al., 2022) (Schretlen et al., 2021).
The Lean Six Sigma methodology can be defined as a combined use of two methods: Lean Thinking and Six Sigma. Although these methodologies are different, they have a common goal that is to reduce wastes and achieve the most effective and efficient system possible.
In what concerns the Lean thinking methodologies, there are seven distinct types of wastes that can be found, such as transportation, inventory, overprocessing, overproducing, motion, waiting and defects. In the healthcare the several wastes can be specified as (Bharsakade et al., 2021):

- **Transportation** - Unnecessary movements of patients and medication, etc...
- **Inventory** - Excess of material supplies, consumables, equipment, and medication. With medication this is extremely important due to expiration dates. Maintaining patients for more time than necessary can be considered as an excess of inventory too.
- **Overprocessing** - In a doctor view it can appear as taking unnecessary patient history every time, requiring duplication of pathological tests, or in administrative view it can be processing patients' information more times than necessary.
- **Overproducing** - can appear as requesting unnecessary procedures that are not adding value, or ordering more medicines than required.
- **Motion** - This specific waste focuses on unnecessary movements of hospital staff.
- **Waiting** - Defined as the time that the patient is without any activity.

- **Defects** - Defects in healthcare are usually caused due to procedural mistakes, miscommunications, or wrong diagnoses. Defects or errors are more severe as they can lead to the injury or even death of the patients.

This methodology has been initiated in the production industry field by Toyota Motor Corporation, but its use has been increasing in the healthcare industries (Zhu et al., 2020). Six Sigma Methodologies main goal is to reduce the level of defects encountered to less than 3.4 per million of processes. This evaluation is made by the calculation of the sigma level that can be reached through the number of Defects per Million of Opportunities (DPMO), which in a given table states the sigma level that is attributed to a different DPMO number. Most of Six Sigma interventions follow the DMAIC approach (Abid et al., 2020).
The DMAIC cycle aims to identify opportunities for improvement of a certain problem by reducing its variability. By following the DMAIC cycle, a logical path will lead to these conclusions. Each of the five phases has a clear objective. It is mentioned that Six Sigma DMAIC approach can have better results than the usual quality improvement techniques that services have been applied (Shi et al., 2022).
According to the National Program for oncologic diseases in Portugal, from 114.718 women between the age of 20 to 60 years, that performed a cervical cancer screening in 2020, 6% presented a Human Papilloma Virus (HPV) primary positive result (Dinis et al., 2021).
The Portuguese consensus guidelines for the management of abnormal cervical cancer screening tests has determined which are the conducts to perform according to each possible outcome of a colposcopy or a HPV screening (Pedro et al., 2023). In these guidelines it is mentioned that when the HPV test is positive, 3 out of 7 outcomes are to perform a colposcopy, from these colposcopies, when a lesion is confirmed, most of them have to be re-observed in 12 and 24 months. It is estimated that the second most found form of cancer in women between the age of 15 and 44 in Europe is the cervical and in 2017, the Portuguese mortality rate of cervical cancer was 1.25 per 100 000 women (Wojtyla et al., 2020).
Taking these factors into consideration, it is expected an increase in colposcopies demand in the Portuguese population, being this the reason for the study.

1.2 Main goals

The main goal of this dissertation is to demonstrate the significance of applying the LSS Methodology to the area of outpatient exams and appointments as it is already in use for Operating Room (OR) and Hospital Internment areas. This project will help reduce the variability and therefore increase healthcare providers time of care and improve hospital client's experience and optimize the client workflow throughout the hospital. The project will be held in the Cervix and Lower Genital Tract Unit of the Obstetrics and Gynaecology

Department of an Hospital in Lisbon.
To achieve the variability reduction and to improve the sigma level, the specific goals of the dissertation are:

- Achieve a Scheduling Rate of 85%;
- Reduce Variability between doctors performance;
- Elimination of the Non-Value Added Activities;
- Decrease the time in the waiting room.

Through the implementation of various improvement measures it is expected that the sigma level can be increased to 2.
Even though the whole process of exams realization is well designed, the indexed processes like Scheduling, Check-In, Check-Out and everything related to registering can be enhanced and improved. In these processes the project can have a major impact. The changes implemented will help to reach the specific goals defined and hence, the overall goals of variability and client experience.
In the end, the project aims to answer to these questions:
Question 1: What are the main factors that can influence the effectiveness and productivity of an outpatient exam department?
Question 2: In the outpatient exam context, with different doctors performing numerous different procedures, is the variability a factor that should be reduced or accounted has a benefit?

1.3 Proposed Methodology

The methodology proposed is based on the investigation of a particular case study in a private hospital's gynaecology exam rooms.
The case study research methodology is a qualitative research method that involves an in-depth investigation of a person, group, event, or community. It is an established research design that is used in a variety of disciplines and that is good for describing, comparing, evaluating, and understanding different aspects of a research problem. They can be used to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context. Case studies allow critical events, interventions, policy developments, and program-based service to be examined in detail (Crowe et al., 2011; Runeson & Höst, 2009).
This case study was an application of the LSS methodology in the healthcare sector. Therefore it was necessary to proceed on a theoretical investigation about the problems that this methodology is able to solve in the sector as well as to deepen the knowledge about the quality tools used to execute the project. In addition to the theoretical knowledge it was also necessary to have a deep knowledge of the institution and the department staff to better understand the context of the project.
In the first phase, a literature review was performed in two parts. The first one to have

a better view of what could be found in this specific hospital department, a literature review about what has been done with the LSS methodology in the healthcare sector. The second part was to better understand the quality tools being applied and the ones that would be a better fit with the issues being handle. The second phase was to understand the context in which the project was being held. This led to a description of the company owing the hospital and the hospital itself and a characterization of the department and the specific exams being held at the exam room in analysis. The medical focus of the unit is just a brief acknowledgement for contextualization. The third phase was to implement the methodology, the DMAIC cycle, with its five different phases:

- **Define (D)** - defining the main problem or opportunity for improvement and the main goals to be achieved through the project implementation;
- **Measure (M)** - the current level sigma is calculated, and the baseline of the project is established so that a concrete goal can be defined in the future;
- **Analyse (A)** - the causes of defects and errors are inferred;
- **Improve (I) - concrete steps can be named with the goal of a process optimization.**;
- **Control (C) - granting that the improvements made are maintained through time**

The last phase was to conclude about the findings and to propose future investigations in the hospital that can take place in this hospital and that are in line with the present one.

1.4 Dissertation Structure

The following dissertation has six chapters. It is divided in two main parts: the theoretical and the practical.
The theoretical part (Chapter 1, Chapter 2 and Chapter 3), aims to describe the context in which the dissertation was held and the literature review of what has been done in the healthcare sector with the LSS Methodology. This chapter concerns the introduction of the dissertation. The second chapter it is the beginning of the literature review and it is related to the LSS methodology in the healthcare sector and the particular subjects of Waiting Times, and Scheduling Procedures. The Chapter 3, it is for the understanding of the quality tools used in the scope of the dissertation. The second part, starts with Chapter 4, and the Hospital characterization for a better comprehension of the case study. After the hospital characterization, in the fifth chapter, the case study is presented and it's development is explained with the DMAIC cycle evolution. The last chapter it is for the conclusions and the suggestions for future projects that can be implemented. There is also the bibliography and the multiple appendix that support the work presented in the Chapter 5.

Chapter 2

Quality Improvement in the Healthcare Sector

The chapter presented here, aims to overview a few subjects and concepts related with healthcare improvements that are considered to be relevant for the study here implemented.
There will be an overall review of quality in the sector and then a close up to the specific technique used in the project mentioned in the last chapter.

2.1 Quality Improvement

In the dynamic landscape of healthcare, the pursuit of quality improvement is paramount. The concept of quality improvement explores the methodologies, challenges, and strategies associated with enhancing the quality of healthcare services while simultaneously managing costs.

Iterative Cycles and Improvement Models
Knudsen et al. (2019), underscores in his study the significance of iterative cycles, particularly Plan, Do, Study, Act (PDSA) cycles, in quality improvement within the healthcare sector. These cycles borrow principles from industrial management, aligning the improvement process with the scientific method of experimental learning. They facilitate a continuous learning process through iterative testing of changes, a concept pivotal for Quality Improvement (QI) approaches like Total Quality Management (TQM), Continuous Quality Improvement (CQI), Lean, Six Sigma, and the Model for Improvement. The integration of small-scale testing, data collection, and explicit theoretical rationale exemplifies a commitment to quality enhancement.

Patient-Centered Care and Integration

The role of patients in healthcare quality improvement is essential and highlighted in various articles (Mistarihi et al., 2023). The shift towards patient-centered care acknowledges patients as stakeholders in service delivery, planning and improvement. Patient involvement drives better patient experiences, clinical outcomes, and organizational efficiency. However, incorporating patient perspectives into decision-making and designing systems around them instead of with them poses challenges.

Systems Thinking and Organizational Change

The integration of systems thinking and organizational change is vital for effective quality improvement in healthcare, as emphasized by Wackers et al. (2021). Developing comprehensive strategies that align with the organization's objectives, involving strong leadership, engaging stakeholders, and fostering a culture of innovation is essential. The study underscores the importance of clear communication and data-driven decisions within healthcare institutions. Leadership's role in managing the complex interplay of clinical, financial, and operational aspects is crucial for a successful implementation.

Integrated Approaches and Tools

There is a study that highlights the integration of lean tools in healthcare to identify waste and inefficiencies, leading to improved processes (de Barros et al., 2021). The use of tools like DMAIC, Value Stream Mapping (VSM), and 5S underscores the systematic approach toward improving hospital processes. This approach is echoed by Höög et al. (2016), which suggests that systematic monitoring and follow-up processes, along with patient experience data, contribute to continuous quality improvement.

Challenges and Future Directions

Williams and Best (2022) as discussed in his studies the numerous challenges emerge in the pursuit of quality improvement. Leadership, political dynamics, cultural shifts, education, and technological constraints must all be navigated. Achieving patient involvement requires balancing opportunities and openness. It becomes evident that achieving quality improvement is not a linear path but an ongoing endeavor influenced by policy reforms, technological advancements, research, and patient experiences.

Quality improvement in healthcare involves a multifaceted approach that combines iterative cycles, patient-centered care, systems thinking, and the integration of tools and methodologies. Effective implementation necessitates strong leadership, stakeholder engagement, and a supportive organizational culture. While there are numerous challenges, the continuous pursuit of quality enhancement is pivotal for healthcare institutions aiming to provide high-quality care while optimizing resource utilization. The evolving landscape of healthcare demands a relentless commitment to improvement, grounded in evidence-based practices and a patient-centered perspective.

2.2 Lean Six Sigma

LSS has gained significant attention in the healthcare sector as a process improvement methodology aimed at enhancing the quality of care and operational efficiency. In this section various aspects of LSS in healthcare will be highlighted, particularly its relationship with person-centered care, its academic development trajectories, critical success factors, and its integration with digital technologies.
Teeling et al. (2021), explores the interplay between LSS and person-centered care in healthcare. It underlines that LSS is a fusion of Lean and Six Sigma methodologies, which individually focus on waste reduction and data-driven process improvement, respectively. Person-centered care prioritizes patient needs and emphasizes tailoring care to individual requirements. The study's goal is to uncover how LSS education influences healthcare staff's person-centered practice. Through a realist inquiry approach, the research identifies mechanisms and processes by which LSS education influences person-centered care, ultimately contributing to enhancing patient care and organizational cultures.
The Academic Development Trajectories of Lean Production Based on Main Path Analysis Method investigates about the evolution of lean production across various sectors. The study identifies different groups of lean production concepts and applications, including "Lean healthcare concept and application." It highlights how lean thinking and LSS, with their roots in lean production, have been integrated into healthcare practices to improve efficiency and quality. The study also emphasizes the role of lean methodologies in reducing waste and optimizing processes, thus creating value for patients (Lin et al., 2022).
The Critical Sucess Factors (CSF) when implementing LSS projects in healthcare organizations that significantly correlate with project success are identified in the literature as (Abid et al., 2020; Marzagão & Carvalho, 2016; McDermott et al., 2022; Sohal et al., 2022):

1. Readiness factors: A healthcare organization should fulfill certain readiness factors before starting the implementation phase of LSS.
2. Organizational readiness: Factors related to the readiness of the organization, such as culture, structure, and employee engagement, play a significant role in LSS implementation.
3. Leadership commitment: Strong leadership commitment is crucial for the successful implementation of LSS in healthcare organizations.
4. Alignment with strategy: LSS should be aligned with the overall strategy and goals of the healthcare organization.
5. Allocation of resources: Adequate allocation of resources, including people, time and budget, is essential for the successful implementation of LSS.
6. Training and education: Providing training and education to employees on LSS methodologies and tools is important for their effective utilization in healthcare settings.

7. Continuous improvement culture: Creating a culture of continuous improvement and fostering a mindset of problem-solving and innovation are CSF for LSS implementation.
8. Stakeholder engagement: Engaging and involving key stakeholders, including healthcare professionals and staff, in the LSS implementation process can enhance its success.
9. Data-driven decision-making: LSS relies on data analysis and statistical methods, so promoting a data-driven decision-making approach is important.
10. Monitoring and feedback: Regular monitoring of LSS projects and providing feedback to the teams involved can help identify areas for improvement and ensure the effectiveness of the implementation.

These factors underscore the importance of integrating LSS effectively within healthcare environments, aligning with management control mechanisms and organizational goals. The research not only highlights the benefits of LSS implementation but also the need for adapting management accounting systems to support lean practices.
There has been a growth in projects that combine lean interventions with digital technologies on healthcare services. This study acknowledges that lean practices, such as LSS, are used to enhance healthcare quality and efficiency. The integration of digital technologies from Industry 4.0, known as Healthcare 4.0 or Health 4.0, further aids in streamlining processes, improving patient flow, and providing personalized care. The study calls for more research in this area to better understand the dynamics of this dual intervention and its effects on healthcare outcomes (Tlapa et al., 2022).
Overall, Lean Six Sigma as an improvement methodology in healthcare presents its significance and its potential to improve patient-centered care, efficiency, and quality through waste reduction, data-driven decision-making, and integration with digital technologies. The reviewed articles present insights into the application of Lean methodologies in healthcare, particularly within hospital settings. The key points highlighted the value of the significance of Lean principles, their evolution from manufacturing to healthcare, and their positive impact on improving efficiency and patient outcomes.
The global trend of applying Lean principles in healthcare to drive operational efficiencies and improve patient care is emphasized by the examples provided in how Lean methodologies can be tailored to address the challenges within healthcare settings, ultimately leading to enhanced quality of care and better patient experiences.

2.2.1 DMAIC Cycle

The DMAIC Cycle is mentioned by de Barros et al. (2021) as the most used tool when applying LSS in the healthcare sector.
Incorporating the DMAIC cycle in healthcare settings aligns with the broader trend of data-driven decision-making and continuous improvement. By addressing challenges, enhancing processes and focusing on patient outcomes, healthcare organizations can

ensure higher-quality care delivery and improved overall system efficiency.
This is a well-structured and data-driven approach that has five different phases that help to achieve the goal defined by the team in charge when combined. These different phases are the ones shown in the figure 2.1 and explained ahead (Ferreira et al., 2019).

Figure 2.1: Phases of DMAIC cycle

1. Define:
   This phase involves identifying the problem, specifying the goals, and forming a multidisciplinary team to address the challenges. This phase involves identifying the customer, their critical to quality issues, and the core business process involved. It also involves defining the project boundaries and the process to be improved by mapping the process flow.
2. Measure:
   The next step involves quantifying the extent of the problem. This phase involves collecting data on the process, identifying the Key Perfomance Indicators (KPI), and establishing a baseline for the process based on the data collection analysis.
3. Analyze:
   The third phase of the DMAIC cycle is to analyze the data collected in the previous phase. This phase involves identifying the root cause of the problem, determining the factors that contribute to the problem, and developing hypotheses about how to improve the process.
4. Improve:
   Based on the analysis, the multidisciplinary team develops and implements solutions. These improvements are aimed at eliminating non-value-added activities and addressing the root causes of waste.
5. Control:
   The final phase focuses on sustaining the improvements over the long term. This involves establishing controls and monitoring mechanisms to ensure that the changes made are maintained and continue to deliver the desired outcomes. Long-term monitoring and ongoing adjustments are key to preventing regression to previous inefficiencies.

Some of the areas where this methodology has been applied are mentioned below:

- **Reducing Patient Mortality Rates:** Just as the study utilized DMAIC to address high mortality rates in acute myocardial infarction (AMI) cases, healthcare organizations can identify critical areas with higher mortality rates and implement the DMAIC cycle to analyze underlying causes, design interventions, and track improvements over time (Rosa et al., 2023).

- **Enhancing Emergency Department Efficiency:** The DMAIC cycle can be applied to streamline processes in the emergency department, from patient triage to discharge. By defining key metrics like patient wait times and analyzing bottlenecks, hospitals can implement changes to improve patient flow and resource allocation (Mistarihi et al., 2023).
- **Optimizing Medication Management:** Medication errors are a significant concern in healthcare. DMAIC can be used to investigate medication administration processes, identify sources of errors, and implement control measures to reduce mistakes and enhance patient safety (Buestan & Perez, 2022).
- **Improving Surgical Outcomes:** Applying DMAIC to surgical procedures can help identify factors contributing to surgical complications or extended recovery times. By analyzing data on surgical techniques, pre-operative preparation, and post-operative care, hospitals can optimize protocols to improve patient outcomes (Improta et al., 2017).
- **Enhancing Patient Satisfaction:** Patient experience is crucial in healthcare and the DMAIC cycle can be utilized to measure patient satisfaction metrics, analyze feedback, and implement improvements in communication, amenities, and overall care delivery (Tufail et al., 2022).
- **Streamlining Diagnostic Testing:** The diagnostic process often involves multiple steps and potential delays. DMAIC can be employed to analyze the journey from initial consultation to diagnosis, identifying areas where unnecessary delays occur and implementing measures to expedite the process (Shi et al., 2022).
- **Addressing Staff Burnout:** Healthcare staff burnout can impact patient care. The DMAIC cycle can help identify stressors, workload inefficiencies, and workflow issues contributing to burnout. Implementing improvements in staff scheduling, workload distribution, and support systems can positively affect staff well-being and patient care (Buestan & Perez, 2022).
- **Enhancing Electronic Health Records (EHR) Usage:** DMAIC can be applied to optimize the usage of electronic health records. By defining key usability metrics, analyzing user feedback, and improving EHR interfaces, healthcare organizations can ensure that EHR systems enhance rather than hinder clinical workflows (Baek et al., 2018).
- **Reducing Readmission Rates:** High readmission rates can strain healthcare systems. Applying DMAIC to readmission cases can help uncover the reasons for re-admissions, implement interventions to address these issues, and measure the success of these interventions over time (Tipton et al., 2021).
- **Optimizing Telemedicine Services:** With the growing adoption of telemedicine, applying DMAIC to virtual care processes can help identify technical glitches, communication gaps, and patient concerns. This approach ensures that telemedicine services provide a seamless and effective healthcare experience (Tlapa et al., 2022).

The application of the DMAIC cycle in healthcare, particularly in the context of LSS methodologies, has been exemplified in a study conducted at an Italian hospital, as discussed in the provided information (Rosa et al., 2023). This systematic approach is utilized to address challenges and improve patient outcomes, specifically focusing on acute myocardial infarction (AMI), a critical medical condition.

This study not only follows the DMAIC cycle but also emphasizes the importance of LSS principles in healthcare process optimization. It highlights the value of identifying and eliminating waste, reducing inefficiencies, and ultimately improving patient outcomes. By adopting a systematic approach and data-driven decision-making, the Italian hospital successfully brought down the 30 day mortality rate for AMI patients to the national average of 8%.

The research conducted by Mansur dos Reis et al. (2022) further supports the application of the DMAIC cycle in healthcare settings. Their systematic literature review focuses on the challenges and facilitators of implementing DMAIC-based improvement projects. This review underlines the significance of addressing resistance to change and limited resources, common challenges faced in the implementation of process improvement methodologies in healthcare contexts.

These articles and the study of the application of the DMAIC cycle, particularly within the framework of LSS, has proven to be effective in optimizing healthcare processes and improving patient outcomes. The study discussed how this approach was utilized to address challenges related to patient mortality rates in an Italian hospital. Additionally, the systematic literature review conducted by Mansur dos Reis et al. (2022) further contributes to the understanding of the challenges and facilitators associated with implementing DMAIC based improvement projects in healthcare.

2.3 Healthcare issues for optimization

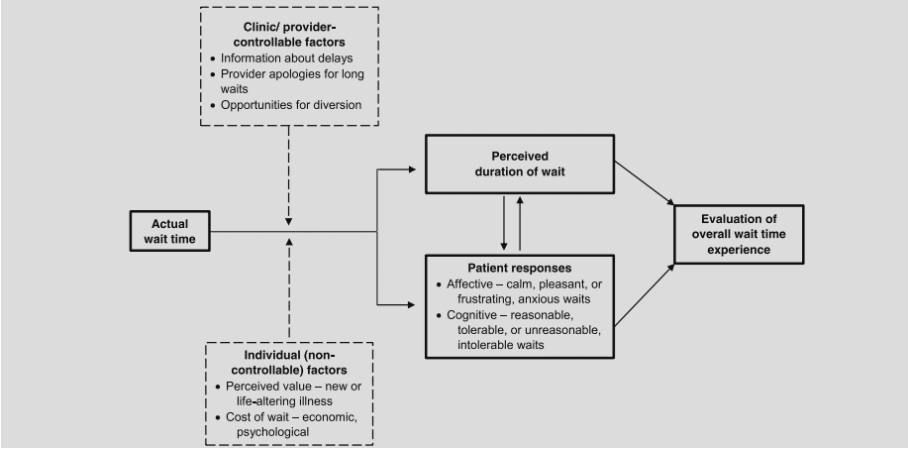
There are numerous issues that can be addressed to optimization in the healthcare sector and specifically to the application of the LSS and the DMAIC cycle.
These issues can be categorized in some areas like reducing medical errors, improving patient flow, reducing costs, improving quality of care and enhancing medical performance. It is mentioned the most common results achieved after a LSS intervention within various case studies in the healthcare area. This results are the decrease in the length of stay, decrease in lead time, reduction of time to perform tasks, improved communication, increase in time of care for health care professionals, reduction of waiting times, reduction of unnecessary procedures among others (de Barros et al., 2021).
The next subsections will explore some of these issues that were addressed to this specific project.

2.3.1 Waiting Times

Waiting times have long been a significant challenge within the healthcare sector. From scheduling appointments to receiving treatment, patients often encounter delays that can have both immediate and long term consequences. This issue is multifaceted, affecting patient experiences, healthcare outcomes, and system efficiency (Daniels et al., 2017; Oostrom et al., 2017; Thompson et al., 1996).

In terms of waiting times some authors consider different definitions for waiting times. **Indirect Wait Time** is the interval between the time a patient requests an appointment and the actual date of the appointment. **Direct Wait Time** is the delay between a patient's appointment time and the time the patient actually sees the provider (Gavriloff et al., n.d.).

Besides these different waiting times there is a term that is transversal and considered for both direct and indirect waiting time, **Perceived Waiting Time**, that is the time that the patients think that they have been waiting (Bleustein et al., 2014). The perceived waiting time is the one with bigger impact in the perception of quality as in shown in the figure 2.2.



Adapted from Chu et al. (2019)

Figure 2.2: Patients response to waiting times

The problems that come from long waiting times are stated below (Daniels et al., 2017; Oostrom et al., 2017; Thompson et al., 1996):

- **Patient Experience and Satisfaction:** Extended waiting times can lead to frustration, anxiety, and dissatisfaction among patients. Waiting in uncomfortable environments, uncertain about their turn for care, patients may feel that their time is not valued. Negative waiting experiences can overshadow the quality of care received and influence patients' perceptions of the overall healthcare system. Patient satisfaction can vary significantly across regions and healthcare facilities, reflecting differences in healthcare delivery, resource availability, and management practices. The patient experience is correlated to the perceived waiting time, since the longer

the waiting time, the probability of a non satisfied patient is higher. Bleustein et al. (2014) studied the relationship between the waiting times and the average satisfaction score of patients and discovered that after 20 minutes of waiting there is a bigger decrease in the satisfaction score and that the tolerance for waiting is bigger for waits in the waiting room instead of waits in the exam room.

- **Impact on Health Outcomes:** In some cases, waiting times can have direct health implications. Conditions that require prompt intervention, such as acute illnesses or time sensitive treatments, can worsen if patients are made to wait extensively. Delays in accessing care may result in disease progression, reduced treatment effectiveness or complications that could have been prevented with timely intervention. Effective information delivery, clear communication about procedures and delays, and the courteousness and friendliness of staff contribute to a positive patient experience. Patients' perception of the quality of interactions and communication during their wait can influence their overall satisfaction.
- **System Efficiency and Resource Allocation:** Prolonged waiting times can strain healthcare resources and capacity. Overburdened facilities and overbooked schedules can lead to bottlenecks and inefficiencies. This not only affects patient experiences but also challenges healthcare providers to manage their time effectively, potentially leading to burnout and reduced job satisfaction.

  Managing patient perceptions of waiting times and expectations is crucial. Communicating estimated waiting times and providing information about delays can help manage patient expectations and minimize dissatisfaction.
- **Accessibility and Equity:** Long waiting times can disproportionately affect certain populations, exacerbating health disparities. Vulnerable groups with limited resources may have difficulty navigating the healthcare system, leading to delays in accessing care. Addressing waiting times is crucial for ensuring that healthcare services are accessible and equitable for all patients, regardless of their socioeconomic status or geographic location.

  Waiting times can vary based on patient demographics, appointment characteristics, and the type of healthcare service sought (preventative, curative or emergency care). Addressing variations in waiting times requires a multi-faceted approach that considers factors beyond simply reducing the actual waiting time.
- **Perception of Quality:** Waiting times are often considered as an indicator of healthcare service quality. Patients may associate shorter wait times with efficient and well-managed healthcare institutions. On the other hand, prolonged waiting periods might be perceived as indicators of an overwhelmed or inadequately resourced healthcare system, negatively impacting its reputation. Patient satisfaction is not solely dependent on actual waiting times; perceived waiting time, information delivery, and expressive quality of interactions with healthcare staff also play crucial roles.

  Patient satisfaction can be influenced by factors such as the environment of the

facility, communication about estimated waiting times and the overall courtesy and friendliness of staff.

- **Financial Implications:** From a financial perspective, waiting times can result in lost productivity for patients and their families. For instance, taking time off work or arranging childcare for appointments can lead to financial strain. On a broader scale, inefficient use of healthcare resources due to waiting times can contribute to rising healthcare costs.
  Patient satisfaction is understood as an important quality indicator for healthcare facilities. High patient satisfaction is associated with better treatment compliance, lower readmission rates, and improved care outcomes.

Balancing efforts to reduce waiting times with maintaining the quality of care is essential. Simply focusing on minimizing waiting times without considering the quality of care can lead to sub-optimal outcomes. Efforts to address waiting times in healthcare involve a combination of strategies (Daniels et al., 2017; Thompson et al., 1996):

Process Improvement: Healthcare institutions can adopt process improvement methodologies such as Lean Six Sigma to streamline workflows, reduce bottlenecks, and enhance efficiency.

Appointment Scheduling: Implementing efficient appointment scheduling systems can help allocate resources more effectively and minimize patient wait times.

Resource Allocation: Adequate staffing, optimized use of facilities, and effective allocation of resources can contribute to reducing waiting times.

Technology Integration: Leveraging technology, such as online appointment scheduling, telemedicine, and digital health records, can improve access and reduce waiting times.

Communication: Transparent and effective communication with patients about expected wait times can manage expectations and mitigate frustrations.

Prioritization: Establishing triage systems to prioritize patients based on medical urgency can ensure timely care for those who need it most.

Patient-Centered Approach: Focusing on patient-centered care and involving patients in decision-making can improve satisfaction and reduce perceived waiting times. Conducting waiting time surveys and providing recommendations based on the survey results can be an effective strategy to reduce waiting times in healthcare facilities.

Monitoring and Data Analysis: Regularly monitoring waiting times, analyzing trends, and acting on the insights gained can lead to continuous improvement. Continuously monitoring and assessing waiting times, patient perceptions and satisfaction levels is essential for ongoing quality improvement in healthcare facilities. Strategies to address waiting times need to be adaptable and flexible taking into account changing patient demographics, facility resources, and healthcare policies.

The waiting times problematic in healthcare is a complex issue with far-reaching consequences. Addressing this challenge requires a comprehensive approach that considers patient experiences, healthcare outcomes, resource allocation, and equitable access to care. By implementing strategies to reduce waiting times, healthcare systems can enhance patient satisfaction, improve outcomes, and optimize resource utilization.

2.3.2 Scheduling Schemes

There is a diversity of challenges and solutions within healthcare scheduling, ranging from maximizing profit and patient satisfaction in outpatient clinics to optimizing resource allocation in emergency departments and outpatient clinics. In healthcare systems, optimizing appointment scheduling is crucial to ensure efficient resource utilization, minimize patient waiting times, and enhance overall patient experience.
Scheduling by patient groups is an innovative approach that tailors appointment allocation based on specific patient characteristics, medical needs and preferences. The approaches involve mathematical modeling, simulation, multi-objective optimization, and lean principles to enhance operational efficiency and patient care.
Some approaches to modify the more common scheduling schemes to respond to the hospital or clinic needs are here presented.

Dynamic Appointment Scheduling in Outpatient Clinics
These techniques are made to address the challenges of uncertainty in appointment systems in outpatient clinics. Considering patient preferences and imbalanced workloads among physicians. This is an alternative to the usual scheduling scheme with an agenda opened and the patients concurring to those same vacancies.
Dynamic appointment scheduling also maximizes profit through a stochastic overbooking model that accounts for patient no-show probabilities and physician preferences (Yan et al., 2022).
Developing a dynamic scheduling method for emergency departments implies minimizing the mean waiting time of patients by considering the impact of new arrivals on already scheduled patients. It is done by balancing the urgency of patients, resource availability, and scheduling interruptions (Ajmi et al., n.d.).

Simulation Optimization for Patient Ultrasound Examinations
Using simulation optimization to solve patient appointment scheduling and examination room assignment problems for ultrasound examinations through balancing workload of radiological technologists, maintaining equipment utilization rates, and reducing patient waiting times. It is also possible to identify the optimal appointment time intervals and examination room assignments through simulation (Chen et al., 2022).

Improving Clinic Efficiency through Scheduling Groups
Redesigning patient scheduling groups to optimize clinic flow and scheduling flexibility. This technique is used for minimizing the total cost of clinic flow and enhancing patient accessibility. Utilizing multi-objective optimization to balance various objectives and stakeholder preferences.
This strategy recognizes that different patient groups have distinct requirements, allowing for more personalized and effective scheduling solutions. Therefore, the possible fields where the scheduling by patient groups is used is in specialty clinics, emergency departments, diagnostic centers, home healthcare and chronic diseases management centers (Li Huang, 2016).

There are some key Aspects of Scheduling by Patient Groups (Li Huang, 2016):

1. Patient Classification:
   Healthcare facilities often serve diverse patient populations with varying medical conditions, urgency levels, and treatment complexities. Scheduling by patient groups involves categorizing patients into different groups based on criteria such as medical condition, required services, urgency, and care provider preferences.

2. Tailored Scheduling Strategies:
   Once patients are classified into groups, healthcare providers can design scheduling strategies that cater to the unique needs of each group. This may involve assigning specific time slots, allocating resources, and considering physician availability based on the requirements of the patient groups.

3. Optimized Resource Allocation:
   By grouping patients with similar needs together, healthcare facilities can optimize the allocation of resources, such as medical staff, equipment, and examination rooms. This minimizes resource under utilization and overloading, leading to improved operational efficiency.

4. Reduced Waiting Times:
   Scheduling by patient groups aims to reduce waiting times for patients by aligning

appointments with the specific services they require. This approach mitigates bottlenecks and ensures that patients receive timely care, leading to enhanced patient satisfaction.

5. Enhanced Patient-Centred Care:
   Scheduling by patient groups emphasizes patient-centred care delivery. Patients receive appointments that align with their medical needs, preferences and availability contributing to a more personalized and positive healthcare experience.

6. Resource-Balanced Allocation:
   The approach ensures a balanced distribution of patients across different time slots, care providers, and services. This prevents overburdening specific healthcare providers or time periods and helps maintain a consistent quality of care.

7. Improved Healthcare Outcomes:
   By tailoring scheduling to patient groups, healthcare facilities can optimize workflows, allocate resources efficiently, and deliver care in a manner that is aligned with evidence-based practices. This can lead to improved healthcare outcomes and patient well-being.

Scheduling by patient groups offers a proactive approach to healthcare appointment systems, aligning resources with patient needs and preferences. By optimizing scheduling strategies for different patient groups, healthcare facilities can achieve improved operational efficiency, patient satisfaction, and better healthcare outcomes.
Overall, there are a lot of solutions for a better management of resources and better patient allocation in the scheduling scheme.

2.3.3 No-Shows

The phenomenon of no-shows, where patients fail to keep or cancel scheduled medical appointments, poses significant challenges to healthcare systems worldwide. This problem is particularly pertinent in various healthcare settings, ranging from primary care to specialized clinics and hospitals. The ramifications of no-shows are extensive, impacting patient outcomes, resource utilization, healthcare costs and overall quality of care (Berg et al., 2013).
This issue has garnered attention due to its detrimental impact on healthcare resource utilization, patient outcomes and overall system efficiency. A comprehensive exploration of the no-show phenomenon reveals multiple dimensions, including its causes, consequences, and potential mitigation strategies. Several articles shed light on different aspects of this problem, offering insights into the reasons behind no-shows, their implications for healthcare systems and potential solutions.

The phenomenon of no-shows is particularly prevalent in under served populations, where factors such as low socioeconomic status, transportation barriers, and competing demands contribute to missed appointments. Chapman et al. (2022) investigated into the experiences of low-income patients who frequently miss primary care appointments. Their qualitative study identifies appointment disinterest, competing demands and insufficient systems as some of the many barriers to attendance. The study underscores the importance of personalized approaches and clinic modifications to address patient disinterest and fears associated with medical encounters.
The implications of no-shows extend beyond individual patients to healthcare providers and society as a whole. Kaplan-Lewis and Percac-Lima (n.d.) highlight how missed appointments disrupt healthcare operations, lead to ineffective resource utilization and hinder quality primary care. Their study focused on understanding patients who do not attend primary care appointments and the reasons behind their no-show behavior. The authors emphasize the need for interventions targeting the root causes of no-shows to enhance access and reduce health disparities in under served populations.
Marbouh et al. (2020) focused in the financial and operational impact of no-shows on outpatient procedure centers. They employ a discrete event simulation model to analyze the effects of no-shows on procedure utilization and expected net gain. The study emphasizes the potential cost and resource implications of no-shows and explores interventions like overbooking to mitigate these effects.

Multiple studies have investigated the problematic nature of no-shows and have identified a range of factors contributing to this behavior:

Patient Characteristics
No-show behavior is associated with various patient characteristics. Young adults, individuals with a history of missed appointments, lower socioeconomic status, under insured or uninsured patients, and minority populations are more likely to miss appointments. Additionally, patients facing transportation issues, living in distant areas, and having competing responsibilities (work, school, family) are at a higher risk of no-shows (Al Sabahi, 2023).

Appointment Characteristics
Certain aspects of appointment scheduling influence no-show rates. Early morning appointments, appointments scheduled far in advance, and appointments during specific times (e.g., Ramadan) are more prone to no-shows. Moreover, appointment reminders, which are commonly used to mitigate no-shows, might need to be tailored to individual patient characteristics to be effective (Oostrom et al., 2017).

Healthcare Setting and Specialty
No-show rates vary across different healthcare settings and specialties. Primary care

clinics, which form the core of healthcare systems, experience high no-show rates. Specialized clinics such as dermatology, ophthalmology and mental health clinics are also affected. The reasons for no-shows can differ based on the nature of the specialty.

Operational and System Factors
Healthcare systems' operational dynamics play a significant role in no-show rates. Factors such as appointment availability, waiting times, and the structure of the healthcare organization can influence patient attendance. Additionally, inadequate bed capacity and resources can lead to cancellations, which contribute to the no-show problem.

Communication and Engagement
Effective patient-provider communication and engagement are crucial in reducing no-show rates. Ensuring that patients understand the importance of appointments, providing information about the consequences of missed appointments, and addressing patient concerns can encourage attendance.

Interventions and Solutions
Healthcare organizations are implementing various interventions to combat no-shows. These interventions include appointment reminder systems, personalized patient education, dynamic scheduling policies, and proactive outreach to high-risk patients. Targeted strategies can lead to reduced no-show rates and improved access to care.
Addressing the issue of no-shows requires a multifaceted approach that takes into account patient demographics, healthcare practices and communication strategies. By understanding the underlying factors and implementing tailored interventions, healthcare organizations can work towards reducing no-show rates, improving resource utilization, and enhancing patient outcomes. However, it's important to acknowledge that the effectiveness of interventions might vary across settings and populations, necessitating ongoing research and adaptation.
Recognizing the need for practical solutions, researchers have proposed various strategies to reduce no-show rates. Teo et al. (2023) explore the effectiveness of nudges in reducing missed appointments. Their randomized trial in the Veterans Health Administration context demonstrates that incorporating behavioral nudges in appointment reminder letters can positively impact attendance. However, not all nudges yield the desired results, highlighting the complexity of behavior change interventions.
On a similar note, Valero-Bover et al. (2022) present a model for predicting non-attendance in healthcare appointments. They emphasize the importance of identifying high-risk patients and tailoring interventions, such as selective phone call reminders, to reduce no-show rates. By harnessing predictive modeling, healthcare organizations can optimize appointment schedules and enhance patient engagement.
To address the challenge of no-shows, healthcare systems must adopt patient-centred strategies that align with the unique circumstances and needs of different populations.

Berg et al. (2013) stress the importance of understanding patient demographics, appointment scheduling and communication preferences. This knowledge can help reduce no-shows and improve resource utilization, ultimately enhancing the patient experience.

No-shows is a multifaceted problem in healthcare and poses significant challenges to both patients and healthcare systems. Through a comprehensive examination of the factors contributing to no-show behavior, the consequences of missed appointments and potential interventions, researchers and healthcare providers can work together to design patient-centred solutions that enhance access, optimize resource utilization and improve the overall quality of care.

2.3.4 Time of Turnaround

The issue of turnaround times is a critical concern in various fields, from healthcare to manufacturing and beyond. This concept refers to the time it takes to complete a specific process or task and it directly impacts operational efficiency, customer satisfaction and overall productivity.
Lamm et al. (2015) studied the operational efficiency in the context of surgical procedures. By evaluating nonoperative times between consecutive surgeries performed by the same surgeon, the study sought to identify opportunities for improvement. The study introduced the concept of the "OR of the Future," a setup that allowed for parallel processing of OR tasks. The findings indicated that nonoperative times improved with this approach, suggesting that optimizing task sequencing and resource allocation can lead to more streamlined processes and reduced delays between surgeries. This underscores the importance of efficient resource management and workflow design in enhancing turnaround times within medical facilities.
In the field of outpatient care, the need for improved turnaround times is evident and critical to enhance chemotherapy preparation turnaround times (Lamm et al., 2015). The study acknowledged the impact of extended wait times on patient satisfaction and the overall quality of care. By analyzing the workflow within the clinic, the researchers identified bottlenecks in the chemotherapy preparation process. These bottlenecks included steps such as primary and secondary verification of chemotherapy orders, which highlighted the complexity of the process and the need for careful review to ensure patient safety. The study's objectives were to optimize the workflow, reduce patient wait time and enhance operational efficiency.
The problematic of turnaround times spans various sectors and contexts, from medical care to other industries. The provided information emphasizes the potential benefits of considering this variability in treatment protocols. Additionally, the research study demonstrates the positive impact of parallel processing on nonoperative times in surgical procedures and underscores the importance of efficient workflow design. In the realm of outpatient care, the study on chemotherapy preparation turnaround times shows the

complexities involved in optimizing processes to reduce patient wait times and improve overall clinic efficiency. Addressing the challenge of turnaround times requires careful analysis of processes, resource allocation, and workflow optimization to achieve higher levels of operational efficiency and better outcomes.

2.3.5 Delay of the first exam of the day

The first delay of the day in hospitals is a significant problem that can impact patient care and overall efficiency. Eventhough there are a few ambiguous definitions of waiting time and delays in healthcare make it difficult to compare and measure the problems related to these issues (Van Zyl-Cillié et al., 2023).
Delays in starting the first cases of the day in an OR are a common problem in hospitals (Hicks et al., 2020). These delays can have a cascading effect on the rest of the day's schedule and can lead to increased waiting times for patients.
Delays in starting the first cases of the day can result in longer wait times for patients, increased anxiety and potential complications (Hicks et al., 2020). It can also lead to inefficiencies in resource utilization and decreased overall productivity. Identifying the causes and burden of first case operating room delays is crucial for developing strategies to address this issue effectively (Hicks et al., 2020). Factors such as inadequate staffing, equipment availability, and communication breakdowns can contribute to these delays.

The first delay of the day in hospitals is an important KPI for several reasons that are discriminated below:

- Patient Care: Delays in starting the first cases of the day can impact patient care and lead to longer wait times, increased anxiety and potential complications. By measuring and monitoring this KPI, hospitals can identify areas for improvement and implement strategies to mitigate delays.
- Efficiency: The first delay of the day can have a cascading effect on the rest of the day's schedule and lead to inefficiencies in resource utilization and decreased overall productivity. By addressing delays in the first case, hospitals can improve the efficiency of their operations and optimize the use of their resources.
- Customer Satisfaction: Delays in the first case can decrease customer satisfaction as patients may have to wait if preceding cases run late. By measuring and improving the first case on-time/early metric, hospitals can increase customer satisfaction and improve their reputation.
- Resource Management: The first case on-time/early metric is one of the most important OR performance metrics. By monitoring this KPI, hospitals can identify areas for improvement in resource management, such as scheduling a small window between consecutive cases to allow for delays or moving cases among OR's that are free when one procedure runs late.

Therefore, the first delay of the day it is an important KPI that impacts patient care, efficiency, customer satisfaction, and resource management. By measuring and monitoring this metric, hospitals can identify areas for improvement and implement strategies to optimize their operations (Pourmohammadi et al., 2018).

2.3.6 Length of Stay in the Exam Room

The problem of long length of stays in hospitals is a significant issue in the healthcare sector. Prolonged hospital stays can have negative impacts on both patients and hospitals. The length of stay variability, the time between patient admission and discharge, poses challenges affecting patient satisfaction, overcrowding, staff burnout, mortality rates and healthcare costs, these are all metrics that can be influenced by a bad managing of LOS in a hospital.
Here are some of the reasons why LOS has growing as a problem both for the patients and the hospital.

1. Impact on Patients:
Increased costs: Longer lengths of stay can lead to higher medical expenses for patients.
Increased risk of complications: Unnecessary days in the hospital can result in healthcare associated infections, falls and other complications (Baek et al., 2018).
Delayed recovery: Extended hospital stays may delay patients' recovery and return to their normal lives.

2. Impact on Hospitals (Fetene et al., 2022; Tipton et al., 2021):
Increased costs: Longer lengths of stay can lead to higher costs for hospitals due to increased resource utilization.
Inefficiency: Prolonged stays may indicate inefficiencies in hospital processes and resource management.
Reduced bed turnover: Longer stays can reduce the beds available for new admissions, leading to decreased capacity and potential delays in care for other patients.

When referring to the efforts that have been made to improve the timings in LOS in the hospitals there are several areas to act on:
Data analysis and management: Using electronic health records and data mining techniques to identify factors associated with length of stay and manage resources more efficiently.Analyzing patient data to identify patterns and develop strategies for reducing hospital stays.
Hospital based interventions: Implementing strategies to reduce unnecessary delays in hospital discharge, such as improving admission processes and discharge dispositions. Categorizing and evaluating various strategies to reduce length of stay.
System level interventions: Evaluating system level interventions to reduce length of

stay for high risk populations. Implementing evidence based strategies to improve hospital management and reduce length of stay (Tipton et al., 2021).

Efforts to mitigate LOS variability have led to methodologies like LSS. However, these approaches have shown limited success in healthcare settings. In response, a tailored method called H-6S, based on 6 Sigma principles, has been introduced to address LOS challenges. H-6S aims to identify "opportunities for improvements" and reduce process variance, promoting a consistent and streamlined patient experience.
The implementation of H-6S within the Emergency Room (ER) of the Josephtal Medical Center in Eilat, Israel, by Kobo-Greenhut et al. (2021), demonstrated significant reductions in LOS variance within a short time frame. This improvement was sustained over the course of a year, suggesting the potential effectiveness of the H-6s approach in managing LOS variability.
A key takeaway is the importance of educating healthcare teams entering the ER to ensure alignment with system routines and expectations. This minimizes discrepancies arising from variations in previous education and training. Additionally, continuous education programs are essential to address patient condition variations and staff competency differences.

In the end, LOS in hospitals, particularly in the ER, is a pressing concern affecting patient care, staff well-being, and healthcare costs. The H-6S methodology offers a novel way to reduce LOS variability and improve healthcare efficiency. While the study's results are promising, further research and implementation across different healthcare settings are needed to ascertain its broader effectiveness and potential for adoption.

Chapter 3

Lean Six Sigma Methodology and DMAIC Cycle

The last chapter synthesised how the LSS has been used in the last decade in the healthcare sector. This chapter aims to continue the frame about the LSS methodology given in the first chapter, furthering in its purposes and ways to implement.
The LSS will be explained as long with its philosophy and the DMAIC cycle will be divided in the most common tools that are implemented in each phase.
In the end, it will be possible to understand the frameworks and tools that were used to finish this project.

3.1 Lean Six Sigma Methodology

3.1.1 Lean Management

The lean management philosophy, sometimes abbreviated as "Lean", is a systematic method for enhancing productivity and removing waste from processes, with the ultimate aim of providing consumers with value while maximizing resources.
Lean management has its roots in the Toyota Production System (TPS), that Toyota created in the middle of the 20th century. TPS was a philosophy that aimed to eliminate every form of waste towards more efficient and effective procedures. This way, Lean has now established itself as a pillar in a number of sectors outside of manufacturing, including healthcare, services and software development.

Lean management's fundamental principles include (Wilson, 2010):

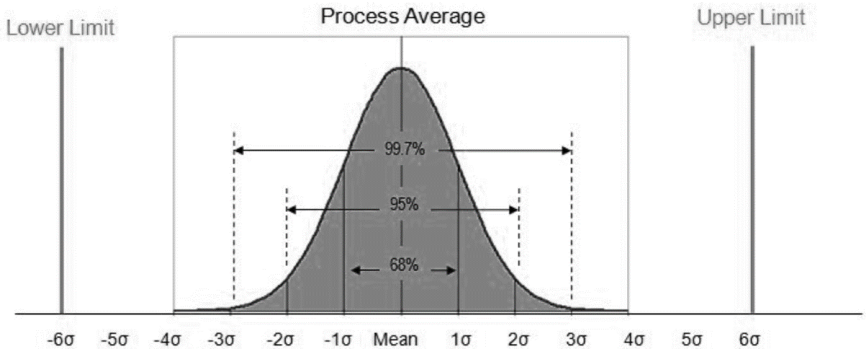
- **Defining Value:** Recognize what the consumer considers valuable and concentrate on providing it while removing anything that does not add to it.

- **Value Stream Mapping:** Examine the entire process from the beginning to the end to determine which phases offer value and which are unnecessary. This aids in identifying potential bottlenecks and the movement of activities.
- **Creating Flow:** Ensure smooth transitions between process phases, do away with interruptions and reduce waiting times to ensure continuous work flow.
- **Pull System:** Create mechanisms where work is starts on client demand, preventing excess inventory and overproduction.
- **Seeking Perfection:** Promote a culture of learning, experimenting and problem-solving. Constantly work to improve. All degrees of involvement are required.

Lean fundamentally stresses the detection and elimination of waste, or "MUDA" which can be classified in the category of transportation, inventory, overprocessing, overproducing, motion, waiting and defects. The healthcare sector usually mentions an additional waste that is the waste of talent.
Along with diminishing the "MUDA" there is also the need to reduce "MURA" that is the imbalance of production and the "MURI" that is the overload of the organization, the staff or the equipments (Dennis, 2015).
Organizations can improve the quality of their products or services, save costs and streamline processes by focusing on and avoiding these inefficient behaviors. By implementing lean principles, organizations cannot only enhance their competitive edge but also foster a culture of collaboration, innovation and adaptability.
Overall, Lean Management aims to forward the organization into a continuous improvement philosophy that will involve everyone in the process by implementing a culture of continuous diminishing of the non-value added activities and non necessary costs and focusing on the client to produce value.

3.1.2 Six Sigma

The six sigma idea is connected with many definitions in the literature, and its logic can be implemented in a wide range of industries (Marzagão & Carvalho, 2016; Sabry, 2014). This notion can be summarized in the literature as a program, a strategy, a system, or even a philosophy that strives to enhance and innovate processes, increasing productivity by minimizing variability (Gleeson et al., 2019; Pugna et al., 2016).
Six sigma is a statistical measure of the performance of quality procedures. The major objective is to achieve 3.4 DPMO (Sabry, 2014). This means that a 6σ process was achieved and that there are 6 standard deviations between the process average and the specification limits as shown in the figure below, which will automatically reduce the number of defects (Daniyan et al., 2022; Pereira et al., 2019; Pugna et al., 2016).
As a result, depending on the nature of the process, there are two main approaches used: DMAIC for already implemented processes and Define, Measure, Analyse, Design, Verify (DMADV) for a new product or process development.



Adapted from Eckes (2001)

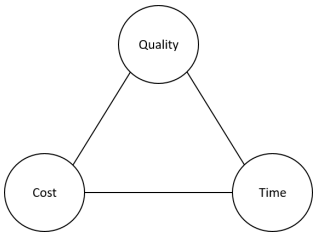
Figure 3.1: Segmented bell-shaped curve of the six sigma distribution

The key principles of Six Sigma methodology, supported by peer-reviewed references, are as follows (Brennan et al., 2017; Lal Bhaskar, 2020):

- **Customer focus:** Six Sigma methodology places a strong emphasis on understanding and meeting customer needs. It aims to deliver high-quality products and services that meet or exceed customer expectations.
- **Data-driven decision making:** Six Sigma methodology relies on data and statistical analysis to drive decision making. It uses data to measure process performance, identify root causes of defects and track progress towards improvement goals.
- **Process improvement:** Six Sigma methodology focuses on improving processes to eliminate defects and reduce variability. It aims to create stable and predictable processes that consistently meet customer requirements.
- **Teamwork:** Six Sigma methodology encourages cross-functional teamwork and collaboration since driving process improvements require the collective effort and expertise of a diverse team. The top management support is also a key factor to the project success.
- **Continuous improvement:** Six Sigma methodology is a continuous improvement process that aims to achieve ongoing improvements in quality, efficiency and customer satisfaction. It involves setting improvement goals, measuring progress and making adjustments to achieve those goals.

3.1.3 Lean Six Sigma

It is stated that the two philosophies combined can achieve a better result since the two focuses on different matters (De Feo et al., 2003). The value of a process or product is in producing in the minimum time, with the maximum quality and with the minimum cost possible as represented in the figure 3.2. The LSS increases value, since Lean focuses in increasing efficiency by minimizing waste, errors and delays and Six Sigma is quality oriented through the reduction of processes variability. This way LSS offers the customer more Value through more efficient and consistent processes and therefore better products.



Adapted from Hardie and Saha (2012)

Figure 3.2: Value Triangle

One of the benefits of Lean Six Sigma is that it can be applied to nearly any industry, including healthcare, manufacturing and military organizations. In healthcare, Lean Six Sigma has been used to improve professional practice and healthcare outcomes in primary care. In manufacturing, it has been used to ensure high quality and remove wasteful steps in a process. In military organizations, it has been used to optimize existing human and financial resources (Brennan et al., 2017; Lal Bhaskar, 2020).
There are various methodological approaches that can be used to support process improvement in different industries. These include simulation, queuing, critical pathways, regression, continuous quality improvement and Lean Six Sigma (Ortíz-Barrios & Alfaro-Saíz, 2020).
A structured review of Lean Six Sigma in various industrial sectors has shown that it has been widely applied in manufacturing, healthcare and service industries. The review also highlights the benefits and challenges of implementing Lean Six Sigma in different industries (Singh & Rathi, 2019).

3.1.4 Organizational Structure

The organizational structure of LSS can be characterized as the same as the one used in the Six Sigma. A well defined and organized structure is important to manage and support all improvement activities. Therefore, the methodology structure is denominated "Belt" (Pyzdek & Keller, 2010).
This structure includes Six Sigma professionals that are dedicated to continuous improvement and for other key users in the company that might help in the projects development, and these users can go from top management to the daily operative staff. The organization usually includes (Achterkamp & Vos, 2008):

- **Sponsors:** top management team members, with a high executive role. The sponsor leads the Six Sigma initiative, leading all the articulated projects and reporting to the board the initiative full potential keeping the project support from the top management.
- **Champions:** they are executives that take the responsibility for one or more Six Sigma projects. The department directors are usually nominated Champions and

they manage the processes affected to the project. It is from its responsibility to approve and balance the resources utilization by the project. Its role is crucial so that the team understands all the strategic goals of the Six Sigma initiative.

- **Process Owners:** responsible for all that is contained in one process. The Process Owner must support its team and has the responsibility to implement and maintain the process improvements implemented, therefore, it must be a change manager and promoter.
- **Green Belts:** it is a Six Sigma practitioner that usually doesn't work full-time. It is trained in Six Sigma and in the DMAIC cycle and in basic statistical tools.
- **Black Belts:** they work full-time in Six Sigma projects and are carefully trained in statistical and improvement methods and are used to work in an efficient way with teams to deliver a successful project.
- **Master Black Belt:** they are Black Belts with a lot of experience and that work full-time in the Six Sigma campaign that they have to direct. Its also their responsibility to train all the Black and Green Belts in statistical analysis.
- **Project Team:** they implement the DMAIC cycle in the process in analysis. Its their responsibility to collect and analyse the data and determine the main sources of variability, then suggest improvements, implement them and maintain them with the control tools. They have a leader that is the Champion, and the team constitution may include any individuals with experience or responsibility in the designated process.

3.2 DMAIC Cycle

The DMAIC cycle is considered to be the tool that is the most used in LSS projects with a healthcare related application (de Barros et al., 2021). The DMAIC cycle is derived from Deming's improvement cycle called Plan, Do, Check, Act (PDCA) and involves the application of five phases: Define, Measure, Analyse, Improve and Control (Alfaro et al., 2020; Ertürk et al., 2016; Ferreira et al., 2019). Even though there is not a direct correspondence between the PDCA and the DMAIC cycles, it is mentioned that the three first phases Define, Measure and Analyse might be compared to the Plan phase, the Improve phase to the Do phase and the Control phase is similar to the Check and Act phase of the PDCA cycle (Vilasini et al., 2014).
All these phases will be further explored ahead as well as the tools that will be used in each one of them.

3.2.1 Define

The Define phase aims to find the answers to the problem source(s). The focus of this phase is to identify the improvement opportunities and conclude about its feasibility

(Montgomery, 2009).
The key steps for this phase are (Pyzdek & Keller, 2010):

- Develop the project charter
- Identify the clients needs and the Key Users involved in the project
- Analyse project feasibility
- Identify the principal processes involved

At the end of this phase it is important that the problem is well defined and that all the roles in the project team are well defined. All the barriers and difficulties must be known in order to better act on them (Holtz & Campbell, 2003).

Project Charter
The first element to be elaborated is the Project Charter. This is a document that contains all the project related important information.
In this, all the metrics and project scope must be well defined as well as all the milestones, benefits and risks for the client. Another important information is the team members and their roles (Montgomery, 2009).
The Project Charter has this key elements:

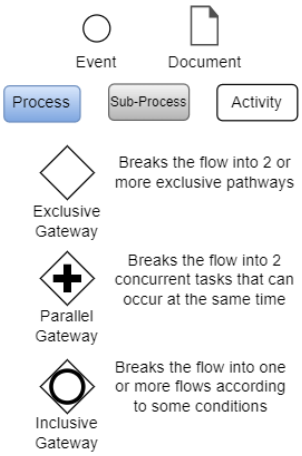
- Project Identification: identifies the project name and all the team members with the roles specified.
- Project Justification: a small description of the reasons why the project is needed.
- Main Goals: identify what are the achievements expected in the end of the project. All the goals must be based in the goals definition technique Specific, Measurable, Achievable, Relevant and Time Constrained (SMART).
- Project Scope: which are the limits of the project and which projects might be under its objectives and what is not in its scope.
- Expected Benefits and Risks: what can be expected in the end of the project and what might difficult its implementation.
- Project Approach: the strategy for the project implementation and all the milestones that might be accomplished.
- Documents to Deliver: what documents must be delivered for the project control.

Voice of Customer
The Voice of Customer (VOC) is a vital stage in the Six Sigma approach that assists firms in understanding their customers' requirements and expectations. It is a systematic technique to gathering the customer's needs, wants, requirements, or expectations regarding the products or services offered to them (Yang et al., 2022).
The VOC methodology can be used to capture both present and latent customer demands through stated verbatim remarks. It aids in the translation of verbatim remarks into customer needs and product or service output characteristics (Sujova et al., 2016).
In the healthcare sector, a commonly used tool is the Net Promoter Score (NPS) metric.

This metric measures customer satisfaction and loyalty by asking one key question: "How likely are you to recommend our company/product/service to a friend or colleague?". The NPS is calculated based on the responses to this question and provides a score ranging from −100 to +100. It categorizes respondents into three groups: Promoters, Passives, and Detractors in which Promoters are highly likely to recommend, Passives are neutral, and Detractors are unlikely to recommend the unit (Costa et al., 2020).

Business Process Model and Notation

There are a few languages for graphical process modelling that aim to help the organizations in documenting their processes and work developed. These can go from simple flowcharts to complex process simulations and executions (Recker, 2010).
The Business Process Model Notation (BPMN) its widely used every time a process needs to be identified, since it affects the principal key users and documents of each process. The processes diagram represents graphically all the activities that are included in a process and that must be executed and in which conditions. All the exceptions must be included. The notation used is represented in the figure below 3.3.



Adapted from the Hospital common notation for BPMN

Figure 3.3: Elements used in the BPMN drawings

Stakeholders Analysis

A Stakeholder is an individual or a group of individuals that has a personal interest and the ability to influence the actions and activities of a given organization, project or management strategy. The stakeholders analysis has the goal to understand the stakeholders and what might be their relevance in the project development (Brugha, 2000).
A process failure is caused by a lack of analysis of the project's intervenes rather than

inefficient management procedures. As a result, stakeholder analysis is an essential component of a successful project (Achterkamp & Vos, 2008).
To better analyse these stakeholders, the matrix shown below can be considered. In this there are two main dimensions: the stakeholders potential to null the project or to enhance it. This matrix helps identifying which approaches to take with each of the project intervenes (Pakdil, 2020).

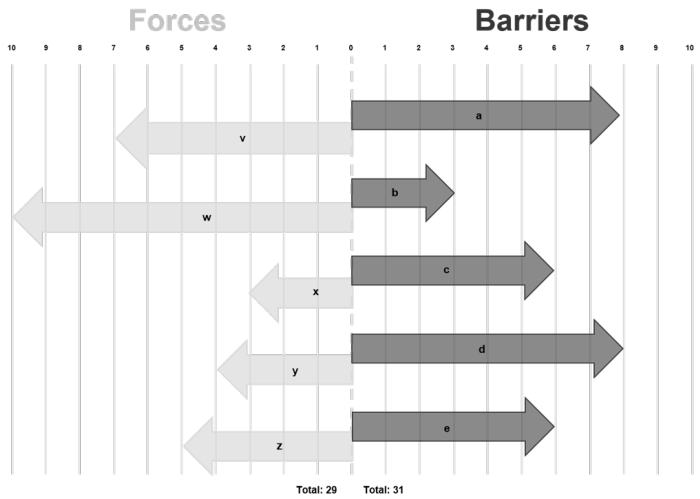
Table 3.1: Example of Stakeholders Analysis Matrix

		Stakeholders Potential to null the Project	
		High	Low
Stakeholders Potential to enhance the Project	High	Stakeholder: In Between Strategy: Co-Operate	Stakeholder: Favourable Strategy: Involve
	Low	Stakeholder: Unfavourable Strategy: Contest	Stakeholder: Irrelevant Strategy: Monitoring

Adapted from: Pakdil (2020)

Force Field Analysis

Kurt Lewin introduced the Force Field Analysis concept in the 50's. This concept is based in the physical sciences idea of relative forces quantified by vectors. Comparing this to a company reality, there are forces against and for a given project, even though they are not easy to quantify as physical forces they can still be quantified along with the company inclination towards change (Thomas, 1985). On the left side, the forces moving towards the change and in the right side the forces against the change. This representation can be seen in the figure 3.4 that shows an example of a force field analysis where there's not a significant difference between the forces and barriers of the project.



Adapted from: Kumar (1999)

Figure 3.4: Example of a Force Field Analysis

After this analysis, the forces must be integrated in the project implementation strategies and must be used in the project favour. The barriers must be eliminated or mitigated (Voehl et al., 2013).

3.2.2 Measure

In the Measure phase, the main goal is to define how the process will be measured and what is the following process performance (Mishra & Kumar Sharma, 2014). For this, the next requirements must be fulfilled (Pyzdek & Keller, 2010):

- Manage the data gathering.
- Define the process.
- Determine which characteristics must be measured.
- Develop the measuring system.
- Establish the baseline performance for the given process.

Data Collection
The data set collection is one of the most important parts of the measure phase since they define all the metrics being inferred after.
There are a lot of different types of samples that can be gathered, and these are (Elfil & Negida, n.d.):

1. Probability Sampling: This type of sampling involves random selection of participants from the population. Probability sampling techniques include simple random sampling, systematic random sampling and stratified random sampling.
2. Non-probability Sampling: This type of sampling does not involve random selection of participants from the population. Non-probability sampling techniques include quota sampling, self-selection sampling, convenience sampling, snowball sampling and purposive sampling.
3. Judgement Sampling: This type of sampling involves the researcher using their expertise to select a sample that is most useful to the purposes of the research.
4. Cluster Sampling: This type of sampling involves dividing the population into clusters or groups and then randomly selecting clusters to participate in the study.
5. Systematic Sampling: This type of sampling occurs when researchers reference a list and choose a certain subgroup as study participants.

To determine a sample size there are a few different manners to do it, depending on the factors that are known. The key important factors to know when calculating a sample size are:

- Size of the population, N
- Confidence level which will determine the Z-Score, Z

- Standard Deviation, p
- Margin of Error, e

After determining these parameters, there are also distinct ways of determining the sample size whether the size of the population is known or not. For an unknown population size, the equation that determines the necessary sample size is (Pourhoseingholi et al., n.d.):

$$Sample\ Size = \frac{Z^2 \times p(1-p)}{e^2} \tag{3.1}$$

For a known population size, the sample size is based on the the number, N, a formula provided by Yamane is presented below (Uakarn et al., n.d.):

$$Sample\ Size = \frac{N}{(1 + N \times e^2)} \tag{3.2}$$

Defining Sigma Levels

In this phase the sigma level is defined. This definition implies a decision about the defects that are considered. Therefore a few concepts must be understood before doing it (Pyzdek & Keller, 2010):

Product/ Service Unit: what is being processed that its delivered to the client.

Defect: failure to deliver what is understood by the client as a quality product or service.

Defective: a product or service that presents one or more defects; a product or service that presents a value of their quality characteristic out of the limit of specification.

Defect Opportunity: each requirement that is necessary for the client satisfaction. Each one of these requirements are assumed as opportunities for failure.

After all the defects are defined according to the concepts presented before, there are a few metrics that can be calculated when defining the sigma level (Pyzdek & Keller, 2010):

$$Defects\ per\ Unit = \frac{Number\ of\ Defects}{Total\ Number\ of\ Units\ evaluated} \tag{3.3}$$

$$Defects\ per\ Opportunity\ (DPO) = \frac{Number\ of\ Defects}{Total\ Number\ of\ Units \times Number\ of\ Opportunities} \tag{3.4}$$

$$DPMO = DPO \times 1000000 \tag{3.5}$$

For the sigma level calculation, there is a conversion table presented in the Annex I, where it is possible to convert the DPMO level directly for the sigma level.

3.2.3 Analyse

In the Analyse phase, it is expected that the data gathered and analysed in the previous phase gives the team the process' sources of variability and how are they influencing the process quality. The analyse phase must accomplish these guidelines (Pyzdek & Keller, 2010):

- Analyse data variability.
- Analyse the sources of variability that are contributing for a bad performance.
- Analyse the value flow to identify what can be eliminated to achieve the ideal performance.
- Determine the causes of a bad performance and hierarquise them.

One-Way ANOVA

The variability analysis, here represented in the form of the One-Way ANOVA, its a technique that allows to compare different parameters between different populations. The key characteristic of this technique is that distributes the variability between all the variables that contribute to this variability, allowing to understand which of these variables are statistically significant (Requeijo & Pereira, 2012).

In order to perform the variability analysis, a common hypothesis test is performed using the Fisher's Exact Test. This test is applied to the mean of three or more groups, mutually independent and satisfying the assumptions of normality and homoscedasticity. If the goal is to determine whether or not these differences exist in the means of three or more groups, the One-Way ANOVA is the technique chosen.

The hypothesis test to use for three different groups would be:

$$H_0 : \mu_1 = \mu_2 = \mu_3$$

$$H_1 : \mu_1 \neq \mu_2 or \mu_1 \neq \mu_3 or \mu_2 \neq \mu_3$$

For the variability analysis recurring to the One-Way ANOVA technique, is presented in the table 3.2 where:

k - number of groups, i=1,2, ..., k

n - number of replications, j=1,2, ..., n

N - total number of observations, k x n

$$Y_{..} = \sum_{i=1}^{k} \sum_{j=1}^{n} y_{ij} \tag{3.6}$$

$$\bar{Y}_{..} = \frac{Y_{..}}{N} \tag{3.7}$$

$$SS_T = \sum_{i=1}^{k}\sum_{j=1}^{n}(y_{ij} - \bar{Y}..)^2 = SS_B + SS_W \tag{3.8}$$

$$SS_B = n\sum_{i=1}^{k}(\bar{Y}i. - \bar{Y}..)^2 \tag{3.9}$$

$$SS_W = \sum_{i=1}^{k}\sum_{j=1}^{n}(y_{ij} - \bar{Y}i.)^2 \tag{3.10}$$

Table 3.2: ANOVA: One factor with various groups

Source	Sum of Squares (dF)	Degrees of Freedom (SS)	Mean Square (MS)	F_0
Between Groups	SS_B	k-1	$\frac{SS_B}{(k-1)} = MS_B$	$\frac{MS_B}{MS_W}$
Within Groups	SS_W	N-K	$\frac{SS_W}{N-k} = MS_W$	
Total	SS_T	N-1		

When $F_0 > F_{\alpha;(k-1)(N-k)}$, the null hypothesis is rejected and it can be concluded that there are significant differences between the groups, an analysis that can also be done using the p-value.

LSD Test

The Least Significant Difference (LSD) test is a statistical method used to compare the means of two or more groups. This test can be performed using any statistical software. This test is used after H_0 is rejected (Requeijo & Pereira, 2012).

After the application of the test it will be possible to understand which of the groups have a significant difference between their means or not and then organize these groups into clusters, for example.

Causes Analysis

There are various forms of causes analysis. The commonly used tool for the causes analysis is the Ishikawa Diagram. It is important when there is not a clear idea of what are the main causes to the problem in analysis (Kiran, 2017).

The Ishikawa Diagram is one of the seven basic quality tools and it was developed by Kaoru Ishikawa in the 60's.

It is used after a brainstorming about all the possible causes of a given problem and then organise them in categories. These categories are commonly divided in Machine, Method, Material, People and Environment, but they can be modified according with the problem in analysis. The causes organised in categories makes it easier to provide the best suited solutions (Rodgers & Oppenheim, 2019).

Cause-Effect Matrix

The Cause-Effect Matrix is a form of prioritization matrix. It is a decision making tool that list the elements by order of relevance, allowing to define quantitatively the cause effect relationship between all the defined criteria and the identified causes (Marriott et al., 2013).

There are different types of cause-effect matrix, some are simple where all the criteria has the same weight and the weighted cause-effect matrix where every criteria has their own weight according to their relevance to the problem itself (Kiran, 2017).

This tool is commonly used in the following situations:

- Prioritizing complex problems that are unclear where there are multiple criteria to decide on the causes relevance;
- When there are not enough data to hierarchise causes;
- When there is a group of people, it helps to obtain an agreement about which are the priorities and the key factors with a simple voting.

3.2.4 Improve

In the Improve phase, the project team must develop and implement improvement initiatives to the main sources of variability found in the previous phases (Shankar, 2009). The improve phase is suppose to achieve the following steps (Pyzdek & Keller, 2010):

- Identify the possible solutions.
- Prioritize the different improvement opportunities.
- Implement the solutions to the chosen improvement action as long with the careful definition of ideal parameters.
- Evaluate if the new implementations are really achieving the goals wanted.

Concept Diagram

A concept diagram is a visual tool used to represent the relationships between different concepts and ideas. It is a diagram that depicts suggested relationships between concepts and is used to organize and structure knowledge (Baliga et al., 2021).

Concept diagrams are hierarchical, with one main idea or focus question and several subtopics, key concepts and related ideas. They are similar to other node-linking mapping methods such as topic maps, but concept diagrams differ due to their philosophical basis, which holds that concepts and ideas are interconnected and interdependent.

Concept diagrams are used in various fields, including instructional design and engineering. They are used for brainstorming new ideas and innovation as they make it easy to organize, structure and display the knowledge they have gained on a particular subject by helping you understand the relationships between various ideas, see how concepts are connected, discover related concepts and organize your findings logically and visually.

In the six sigma methodology they can be used for organizing causes or even solutions.

3.2.5 Control

In the last DMAIC phase, all the implementations conclusions must be specified with all the suggested control measures. All the procedures that guarantee the maintenance of all gains must be carefully specified (Shankar, 2009).
This phase steps are covered below (Pyzdek & Keller, 2010):

- Define the metrics that will be controlled in the future.
- Statistically validate the new process achievement of the defined goals.
- Develop and implement a control plan to guarantee the compliance with the new process.

Chapter 4

Hospital Characterization and Project Selection

In this chapter, the healthcare corporate group will be presented, along with the hospital itself and the project selection process.

4.1 Healthcare Corporate Group

This corporate group focused in the healthcare sector was established in Portugal in the year of 2000. It holds 14 hospitals, 13 smaller clinics and 1 senior residence throughout the Portuguese territory. Since it is one of the references in the private healthcare sector in this country, it aims to achieve excellence in the health care given to the population by bringing the most recent technology and innovation that medicine has to offer.
Through their facilities it is possible to proceed since the diagnostic to the end of the treatment, because through all hospitals and clinics all medical and surgical valences are covered.
There is also a strong commitment to quality in their facilities. They have been accredited with the Joint Commission International (JCI), that gives a non-biased patient safety and hospital quality grant to each patient that enters a group hospital or clinic. Their quality efforts, focuses on safety, effectiveness, accessibility, equity, patient centred care. Another relevant focus in on the scientific community and their will to integrate their innovation and excellence with teaching and scientific investigation.
The focus on quality allied with the connection to the scientific investigation, made it possible to proceed with this case study in which there was a lot of interest in the institution part.

4.2 The Hospital

This case study was performed in a particular hospital of the corporate group mentioned before. This hospital is located in the metropolitan area of Lisbon and it is one of the biggest private hospitals in the area. It has 57 different medical specialties and subspecialties, 23 dedicated areas and 11 services. The most relevant services are the Emergency Room (differentiated in Adults, Pediatrics and Obstetrics-Gynaecology), Maternity ward, Surgery (OR), Intensive Care Unit, several outpatient clinics and diagnostic departments.
For this particular case, the highlight will be in Gynaecology and Obstetrics medical specialty and the dedicated area of Gynaecological Oncology. This department in the hospital - Obstetrics and Gynaecology - has two different services that are Outpatient medical appointment and Urgent Care for Obstetrics and Gynaecology:

- In the **Outpatient medical appointment area**, only small appointments with small or none intervention are performed. Therefore, all rooms have the same typology.
- In the **Urgent Care area**, there are Urgent Care appointments with the On Call doctors 24 hours/day, and also all the exams that need specific equipment or are invasive, like ultrasounds or colposcopies among others. Even though it is called Urgent Care area it is also where all special exams take place. All the requirements will be explored in the next section.

4.3 Obstetrics and Gynaecology Department

Obstetrics and Gynaecology is a particular department of the hospital that is dedicated to the prevention, diagnostic and treatment of the female reproductive system (gynaecology) and the follow-up of the women and the fetus during the pregnancy, childbirth and *post-partum*. The gynaecological follow-up it's essential for a good health promotion, a healthy sexual activity as long as a gynaecological and sexually transmissible diseases prevention.
In this particular hospital, the department operates in 29 different areas of gynaecology and obstetrics like cervical, vaginal and vulvar cancer screening. For this, there are 6 kinds of appointments available that can direct the woman to the better doctor for their pathology.
There are 26 different exams and treatments that can be performed, in which the colposcopy and other exams related to the HPV are included. All of this exams are performed in two specific rooms with the specific equipment for the exam performance. This exam rooms will be the ones in study.
To better understand the performance of the department when related to other departments of the hospital, a few performance metrics of the year of 2022 will be presented in the next table.

Table 4.1: Comparison of the Key Performance Indicators of the Department with the Hospital Average.

KPI	Obstetrics and Gynaecology (%)	Hospital Average (%)
Percentage of No-shows	7.9	8.2
First Appointments with Delay >10min.	51.6	37.9
Number of Appointments /Hour	3.2	1.8
First Appointments	24.5	42.9

It is possible to understand from Table 4.1 that there are much more delays of first appointments when compared to the hospital average, which is an even bigger number when it is only relatable to the colposcopies performance as it will be shown in the fourth chapter. The percentage of no-shows it's similar to other departments with no need for a special intervention. The number of appointments per hour it's higher because of the appointment style that can be much faster and the first appointment are lower because it is a specialty with much more follow-up and in which women prefer to stay with their doctor.

4.4 Cervix and Lower Genital Tract Unit

For all the factors mentioned in the previous section, the hospital has established a particular unit that aims to screen and treat the HPV infection and possibly diminish cervical cancer incidence among Portuguese women. This is the Cervix and Lower Genital Tract Unit in which colposcopies are performed as long as other treatments.
The unit is inserted in the Obstetrics-Gynaecology emergency room and has 2 exam rooms with two different typologies:

- **Room 1:** this room is divided in two different rooms, one for doctor appointment before and after the exam and the other to perform the exam or treatment.
- **Room 2:** in this room the places for the exams and the doctor appointment are the same.

The two different rooms have different impacts when performing the exam. The **Room 1**, provides more privacy for the client, but it also leads to more time of exam since it includes the dislocation of the patient and the doctor which means more time of exam. The **Room** 2, can have an effect in the patient reaction to the exam since they can see all the room preparation by the nurse while in the appointment with the doctor and all this leads to less privacy since the client also change clothes in the same room.
The unit has 9 colposcopist doctors, 2 nurses, 2 back-office Customer Service Technician (CST) and 24 front-office CST that are shared with the Obstetrics-Gynaecology emergency room.

In 2022, were performed 3784 exams and treatments in the unit in which 3030 were colposcopies. The exams and treatments, or procedures, included in the evaluation are the ones listed below:

1. CO_2 Laser Surgery - Vaporisation;
2. Vagina Laser Surgery;
3. Vulva Laser Surgery;
4. Colposcopy;
5. Loop Diathermy Conisation;
6. CO_2 Laser Conisation;
7. Criocoagulation;
8. Electrocoagulation;
9. Diagnostic Hysteroscopy;
10. Vaginal Regeneration Treatment;
11. Vulvoscopy.

The distribution of how many exams each doctor performs by month is shown in the figure 4.1. The graph shows no seasonality, but a significant difference in what share of exams each doctor represents.

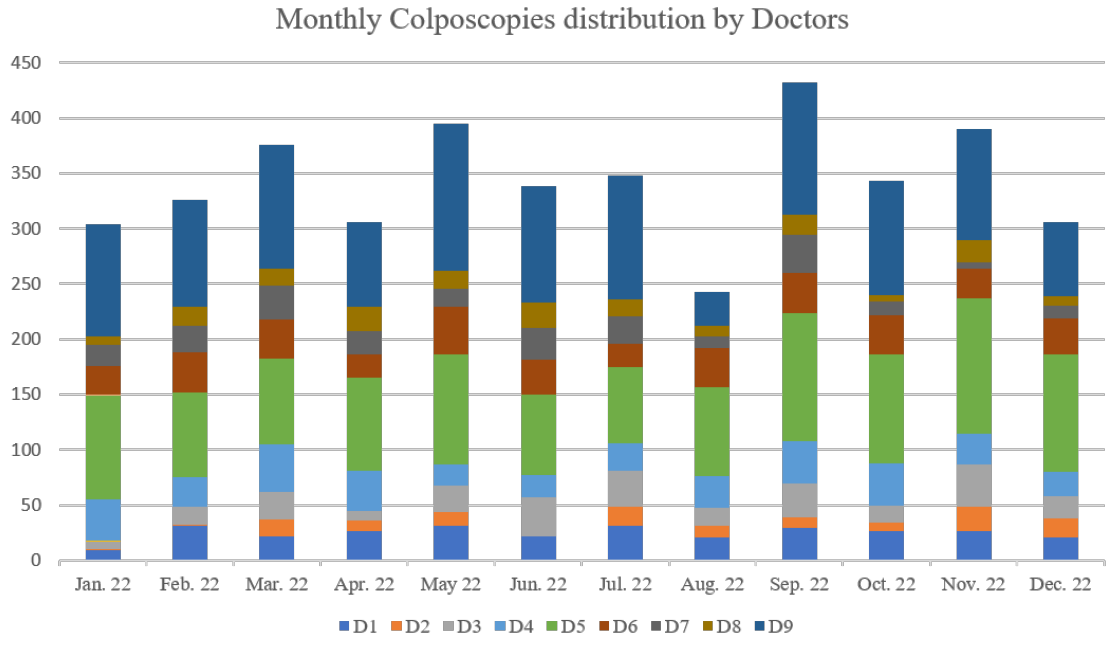


Figure 4.1: Graphic Representation of the monthly exams distribution by doctor

All the exams stated before have a few requirements to be fulfilled so that the exam can be performed. These requirements include:

- Not being menstruated;
- Not having sexual intercourse in the 24 hours before the exam or treatment;
- Not using any vaginal creams or gels in the 24h before the exam or treatment.

4.4.1 HPV and Colposcopy

In this subsection, Human Papilloma Virus will be explained since mostly all the exams and treatments performed in the designated rooms are related to this virus infection. The HPV it's one of the main causes of cervical cancer among other diseases, since it can evolve both to cervical neoplasia or cervical cancer. There are a lot of different types of genotypes in which HPV can appear, and these can be distinguished in high-risk and low-risk types that can lead to cervical neoplasia and cancer or genital warts respectively (Świderska-Kiec et al., 2020).
According to the National Program for oncologic diseases in Portugal, from 114.718 women between the age of 20 to 60 years, that performed a cervical cancer screening in 2020, 6% presented a HPV primary positive result (Dinis et al., 2021). These numbers are predicted to be lower than the real ones, since they are affected by the COVID-19 pandemic.
These HPV positive results, can be refered to a colposcopy to identify possible Low-Grade Squamous Intraephithelial Lesions (LSIL), High-Grade Squamous Intraephithelial Lesions (HSIL) or Atypical Squamous Cells of Undetermined Significance (ASCUS).
The colposcopy it's an essential exam to evaluate women with a positive result in the cervical cancer screening or with a cervix that looks clinically suspicious when observed. When there's any kind of lesions, women can be referred to a treatment, or to a continuous monitoring (Pedro et al., 2023). The Portuguese consensus guidelines for the management of abnormal cervical cancer screening tests (Pedro et al., 2023) has determined which are the conducts to perform according to each possible outcome of a colposcopy or a HPV screening. In these guidelines it is mentioned that when the HPV test is positive, 3 out of 7 outcomes are to perform a colposcopy, from these colposcopies, when a lesion is confirmed, most of them have to be re-observed in 12 and 24 months.
It is estimated that the second most found form of cancer in women between the age of 15 and 44 in Europe is the cervical and in 2017, the Portuguese mortality rate of cervical cancer was 1.25 per 100 000 women (Wojtyla et al., 2020).
Taking this factors into consideration, and the World Health Organization efforts to diminish the cervical cancer incidence by vaccinating 90% of 15 year old girls, screening 70% of women between 30 and 45 years and treat 90% of the ones diagnosed with any kind of lesions (Pedro et al., 2023), this will surely lead to an increase in colposcopies in the Portuguese population.

4.5 Project Selection

Colposcopies are commonly performed after an HPV diagnosis and it is stated that these exams are generally associated with high anxiety levels (Burness et al., 2020). Therefore, there is a necessity to increase time of contact with the healthcare providers in order to promote a greater client comfort. This greater comfort can be achieved with the elimination of the non-value added activities and the optimization of the process as a whole, which will give the client an improved experience.
It is expected that the demand for colposcopies will increase, as long as all treatments that might be necessary after an HPV confirmed diagnosis and for this reason, it is also necessary to improve exam room occupation rate and to optimize all processes attached to the exam as well as a need to analyze the special exams and external appointments, since it is a non explored area in terms of optimization.
Lean Six Sigma Methodology was asked to be implemented, in order to improve scheduling rate, diminish client waiting time, diminish the variability between doctors process approach's and eliminate the non-value added activities. All of these aspects are expected to have an impact both in client experience and hospital use of rooms and resources.
Through the implementation of this project it is possible to better understand the impact of optimization in this non explored area of the hospital - outpatient exams and appointments.

CHAPTER 5

CASE STUDY: LEAN SIX SIGMA IN A GYNAECOLOGY EXAM ROOM

"Progress cannot be generated when we are satisfied with existing solutions."

Taiichi Ohno

In this chapter, the implementation of the DMAIC cycle is explained through every part of the process as it was showed in the section 3.2. Every phase of the DMAIC cycle will be presented with each step and tool that was used to go through the entire phase.

5.1 Define

The first phase of the DMAIC cycle is the phase "Define" and the steps used for this phase are stated in the Figure 5.1. In this phase, the main goal is to define with precision the project scope of action. For this reason, a Project Charter was elaborated in order to specify the project's team, justification, main goals, expected benefits and risks and milestones.

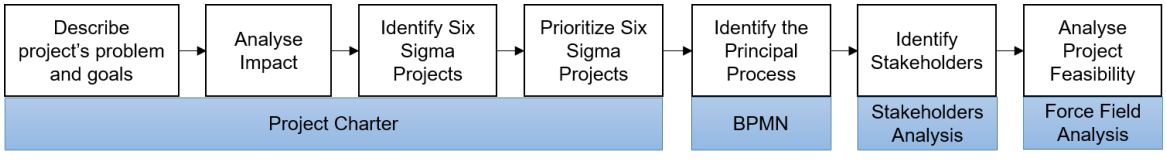


Figure 5.1: Define Phase - Steps and Tools

5.1.1 Project Charter

This first step in the Define Phase aims to clearly identify all that is part of the project and everything that will be included in future considerations.
The Figure 5.2 shows the last version of it, even though it is a dynamic document that keeps changing during the project's evolution in order to orient the direction in which the team is going.

1. Project Identification		
Name	Improvement of Client Experience in the special exams of the Gynaecology and Obstetrics Department	
Champion	Dr.ª Cristina Mesquita	Head of Design and Operational Control
Sponsor	Dr. ª Teresa Durães	Head of Gynaecology and Obstetrics Department Management Center - HL Lisboa
Project Manager	Inês Rebelo Pinto	
Team Members	Dr. ª Virgínia Monteiro	Head of Cervix and Lower Genital Tract Unit
	Patrícia Gonçalves	Gynaecology and Obstetrics Department Administrative Coordinator
2. Project Justification		
• High Variability in processes performed by doctors • Need to improve the quality of the service provided • Need to increase the exam room productivity		
3. Main Goal		
• Reduction of the waiting times and elimination of the sub-waiting moment • Improve setting of exam slots • Eliminate all the non-value added activities for each key users		
4. Project Scope		
• "Projeto Berlim – Exames Especiais"		
5. Expected Benefits		
• More time of care with clients for healthcare providers • Reduction of overprocessed information • Eliminate unnecessary moments of contact between clients and staff • Increase in productivity and exams possible supply • Improvement of the service quality and client experience		
6. Risks and Barriers		
• Staff Resistance to the suggested changes • Lack of software support to some implementations • Infrastructure barriers • Lack of doctors to increase the exams total capacity • Legal and Certification Special Requirements		
7. Project Milestones		
Milestone		**Date**
Process Mapping and Diagnosis		24/03/2023
Data Analysis		14/04/2023
Measure of the problem scope		21/04/2023
New Data gathering		30/06/2023
Doctors Clusters Definition		07/07/2023
Definition of the Improvement Measurements to Implement		21/07/2023
Definition of the Control Program		30/07/2023

Figure 5.2: Project Charter

This particular Project Charter was elaborated after the decision on which project to work on, since there were two main projects identified in the same area:

1. Improvement of the client experience in the special exams of the Gynaecology and Obstetrics Department - the one chosen.

2. Improvement of the registering system - this project was excluded since the systems department didn't had enough capacity to respond to a project that also had a major application in the hospital and not only in this department.

5.1.2 Voice of Customer

To better understand which are the clients needs and expectations with this particular unit, the VOC phase is performed.
For this part, it was not possible to directly interrogate this unit clients due to the complexity and delicacy of the unit object of evaluation. Therefore, to understand what must be the VOC in this case, a unit that has a similar behaviour was analysed. This analysis was performed using the NPS metric, that as explained above measures the clients overall loyalty and satisfaction.
The unit analysed was the Imagiology Center that also performs special exams and even though it doesn't have the same typology since there is no appointment, the kind of exams can be compared to identify the motives that would justify a client to be a detractor.
For the Imagiology Center, the motives for detractor clients were:

- Waiting Time at the hospital - **25%**
- Non Specified others - **17.19%**
- Time between scheduling moment and exam performance - **17.19%**
- Attention provided during time of care - **10.94%**

For the promoters motives, reasons to recommend the unit, were identified the motives below:

- Attention provided during time of care - **18.01%**
- Facilities - **14.05%**
- Waiting Time at the hospital - **12.9%**
- Method of Scheduling - **11.74%**
- Time between scheduling moment and exam performance - **11.1%**

These motives, both the positive and negatives ones, can validate the key factors to improve that were highlighted in the Project Charter before. Even if this evaluation doesn't correspond to the unit in question it can be considered equivalent.

5.1.3 Business Process Model and Notation

This phase was meant to define all the processes that take place in this procedure. For this, the BPMN tool was used instead of the Suppliers, Inputs, Process, Outputs, Customers (SIPOC), since the suppliers, inputs and outputs are not in the scope of the investigation. In the figure below 5.3 it is defined the Macro Process As Is.

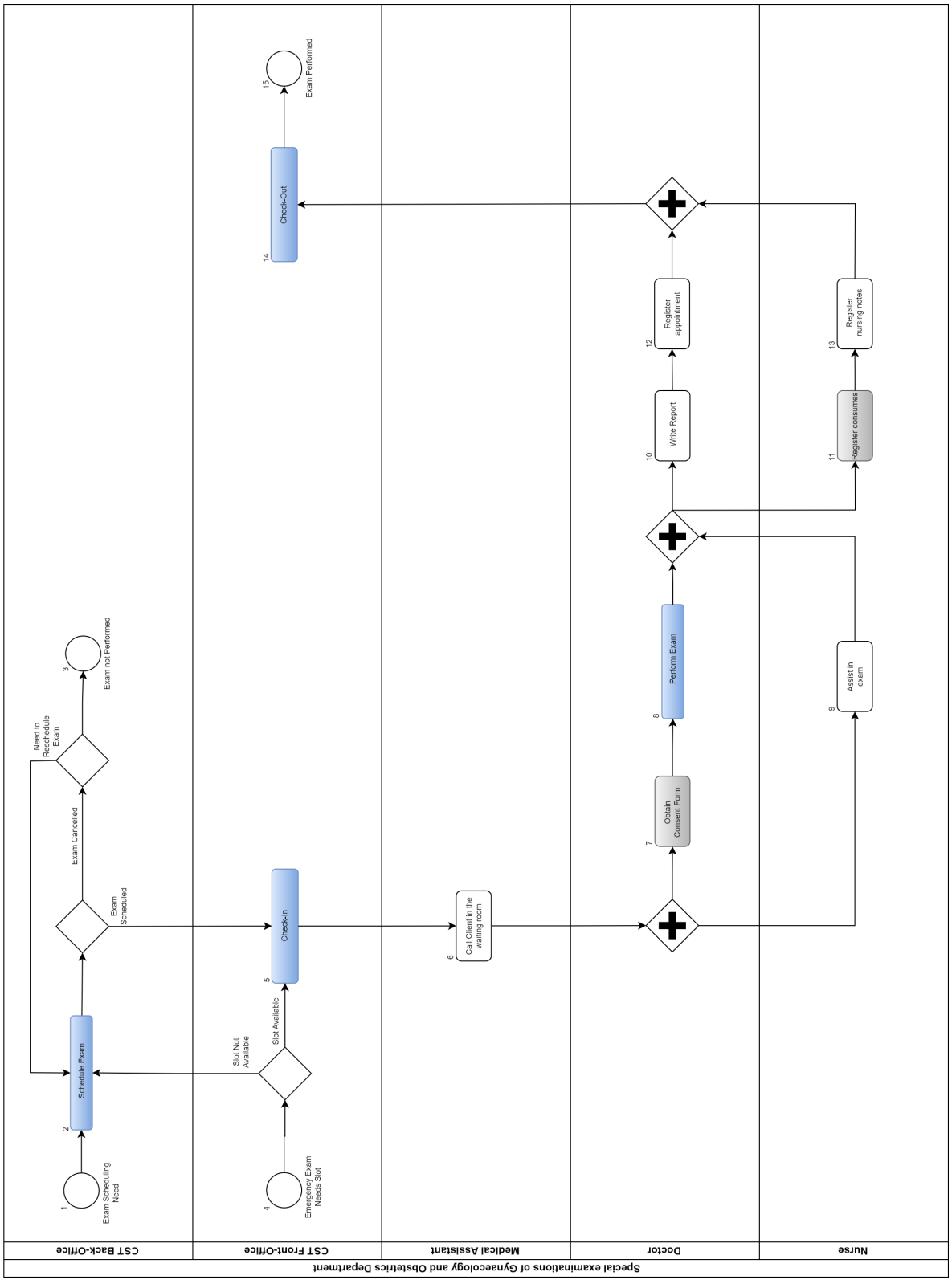


Figure 5.3: BPMN As Is: Macro Process

Inside this process there are four more processes that are highlighted in blue, that are:

- Schedule Exam - To schedule an exam after a doctor request;
- Check-In - Process of entering the hospital;
- Perform Exam - Every step involved in the exam performance;
- Check-Out - Process of paying for the procedures and exiting the hospital.

These particular processes, are defined in more detail in the analyse phase, so that the non-value added activities can be identified.
The process identified contemplates all the moments since the client tries to schedule an exam, goes to the hospital and goes through all the exam process. It also considers the main stakeholders, that have a direct contact with the client, that are: Doctors, Nurses, Medical Assistants and Front and Back Office Administratives.
To design the "Special Exams in the Gynaecology and Obstetrics Department" Macro Process, a field observation concerning all the main stakeholders was performed. This observation allowed a better understanding of the process along with a better relationship with the principal stakeholders that would help during the evolution of the Lean Six Sigma Project.

5.1.4 Stakeholders Analysis

For a better understanding of how the project will be implemented and how much resistance or incentives the stakeholders will give, the stakeholders analysis was performed and is shown in the Figure 5.4. This takes into consideration all the stakeholders, from the ones with direct contact with the client to the ones in the top management of the hospital. The main factors to consider, are they influence in the project success and their interest as well.
The main stakeholders identified are the main ones with direct contact and these ones were mentioned before in the 5.1.3 section and the ones with little contact that can be the Hospital Administrator, the Head of Gynaecology and Obstetrics Department Management Center, the Gynaecology and Obstetrics Administrative Coordinator, the Head of the Cervix and Lower Tract Unit, and the Systems Department. Another stakeholder with no contact and low influence are the cleaning assistants.
Even though some stakeholders are not present in the daily basis, all of them some interest or influence in it, having the power to barrier or enhance the project good progression. Therefore, this analysis led to a better management of the situation with the ones that could have more impact.
Considering that all the top management intervenes would not be in a daily basis intervention, the stakeholders that need a more careful attention were the Head of Gynaecology and Obstetrics Department, the Head of Gynaecology and Obstetrics Administrative Area, the Head of the Cervix and Lower Tract Unit and all the Doctors and Nurses that were the ones of which the presence could be more relevant during the course of the day.

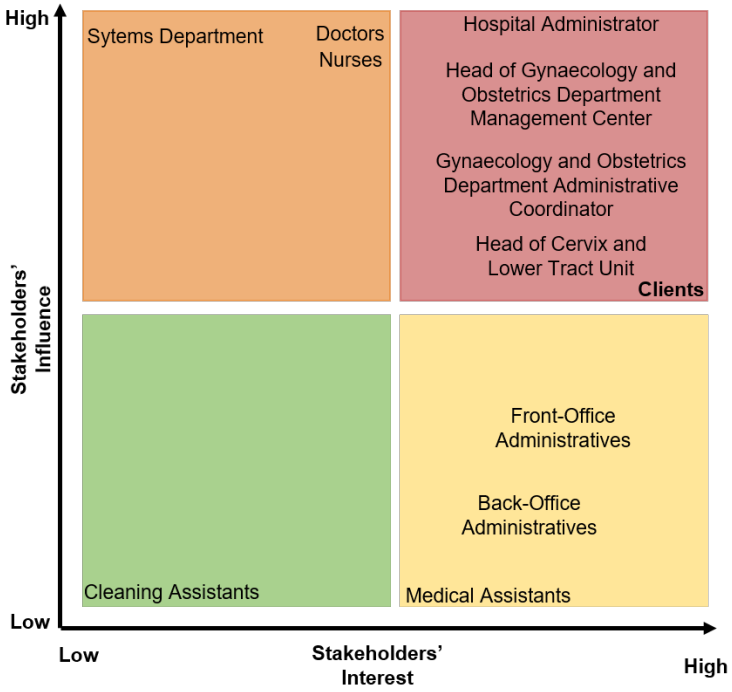


Figure 5.4: Stakeholders Analysis

5.1.5 Force Field Analysis

In the end of this phase, the last important step was to identify the forces and the barriers that could lead to an overall resistance to change in the project implementation.
For this reason, the force field analysis present below 5.5 was elaborated in order to understand if the project could be carried out. Some forces for the project implementation and some barriers against were identified and quantified in a scale from 1 to 10.
An overview of the forces and barriers analysis will show that there are more forces than barriers and that the project should be taken forward.
The strong need for a supply increase and the department management support are the main factors that will help in the project success, along side with the future implementation of an attendance management system and the hospital recent close look to the special exams and outpatient appointments area.
In the barriers side, there is an extreme change resistance for the doctors and nurses point of view which is always a barrier in these kind of projects and also the overload of the systems department that is the key department in every technological change in the hospital and it is also the bottleneck department in every hospital project.

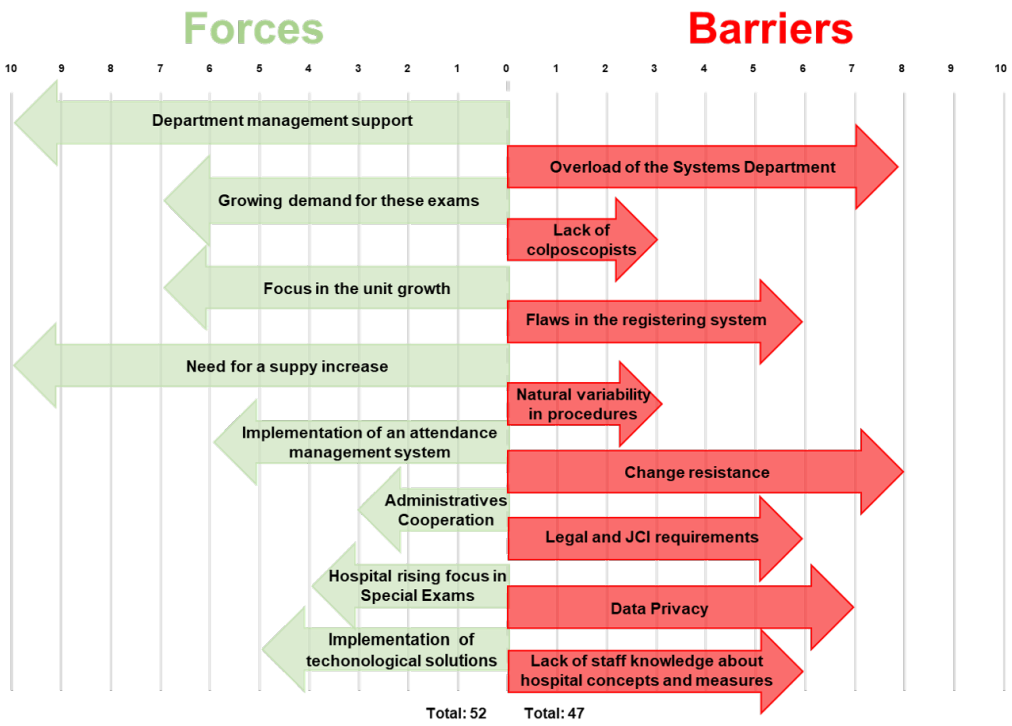


Figure 5.5: Force Field Analysis

5.2 Measure

This phase aims to identify the problem focus and it is the phase were all the data is verified and the sigma level of the project is inferred.
The figure 5.6 below shows the different steps and tools that were covered to achieve measure's goals.
In the next sections an overall of the data sets analysed and its validation will be shown. After, all the relevant elements that were measured will be shown in the form of KPI, sources of variability and in the end the sigma levels will be measured so that a new goal can be defined.

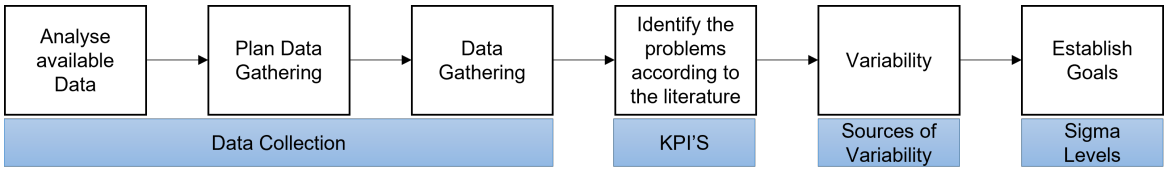


Figure 5.6: Measure Phase - Steps and Tools

5.2.1 Data Collection

Based on the literature, the metrics to analyse were already defined. Therefore, the elements in need for the Measure phase of the DMAIC cycle are:

- Date and time of scheduling;
- Times related to exam performance;
- Patient identification;[1]
- Doctor and nurse associated;[1]
- Status of scheduling:
  - Visited (V)- Exam Performed
  - Cited (C)- Exam Performed but "Exit" not registered;
  - No-Show or Failure to Attend (F)- Client failed to attend;
  - Not Performed (NP)- Client attended but the exam was not performed;
- Type of scheduling;
  - Scheduled (S);
  - Not Scheduled (NS);
- Procedure scheduled;
- Insurance provider.

The Data Collection analysed in this project was divided in two data sets. The first one was a result of two hospital softwares, the administrative one and the clinical one. The second data set was a result of a stratified random sample taken in the hospital by direct observation, then the sample was organized by type of exam or treatment performed.

5.2.1.1 First Data Set

This data set had two softwares has sources of information and a structure similar to the one in the Appendix A.
While doing the validation of this information, the softwares outputs were confronted to check for differences since they had different actors placing information in it. the table 5.1 shows that the numbers are significantly different.
The administrative data is registered by the CST when the client arrives and by the medical assistant when the client enters the exam room. The clinical data is registered by doctors and nurses during the procedure. When a client enters the exam room and an issue is open in the clinical software but the client doesn't have enough requirements to complete the exam it is not possible to null it in the administrative software. This shows that the data presented is not reliable enough to make assumptions about these exams. Therefore, the numbers considered are the ones contemplated in the clinical data.

[1] This information was encoded for ethical reasons

Table 5.1: Outputs of administrative and clinical hospital's softwares

Procedures	Administrative Data	Clinical Data
P1	150	139
P2	24	24
P3	87	81
P4	3304	3030
P5	70	67
P6	87	87
P7	4	4
P8	30	28
P9	99	92
P10	4	4
P11	246	228
Total	4105	3784

In the analysis of times, it was also considered that times were not reliable due to the different actors intervention and due to different time stamps being recorded in two different softwares as shown in the table 5.2.
This information had an additional problem of time stamps not recorded and some inconsistencies between the information of the two exams. All the times registered by nurses are sometimes registered at the end of the day since the time for all their duties is short, therefore this can be biased. The "Entry" registered by the Medical Assistant (MA) it is not accurate since the MA divides its attention between the ER, the Cardiotocographies Room and these exam rooms and it is possible to miss the exact time at which a person enters the exam. The "Exit" moment is biased as well since it is recorded when a person pays and the payment can be done through the Hospital mobile app until the next appointment in the hospital, if the payment is not done until this appointment the client will not be able to attend the appointment until all value is paid. For all the considerations above, the output of the first data set allowed just for the calculation of some KPI identified in the literature like the scheduling rate of the exam room, the no-show rate, the LOS of the client in the exam, the waiting time in the waiting room, the exam room turnaround and the delay of the first exam of the day. Timing information was considered to be obsolete, except for the "Scheduled Hour", "Arrival", "Entry" and "Exam Room Entry".

After this data evaluation there were metrics missing evaluation. Therefore, it was necessary to gather more information related to the exam timings and moments in order to analyse the idle and occupation times of exam rooms, doctors and nurses. This data set will be defined and analysed in the next subsection 5.2.1.2.

Table 5.2: Time stamps Registering scheme

Time Stamp	Software	Actor	Moment
Time Scheduled	Administrative	CST - BO	When Scheduling
Arrival	Administrative	CST - FO	Entrance in the Front-Office
Entry	Administrative	MA	Entrance in Pre-Appointment
Exam Room Entry	Clinical	Nurse	Entry in the Exam Room
Anaesthesia Beginning	Clinical	Nurse	When giving the anaesthesia
Intervention Beginning	Clinical	Nurse	Exam Beginning
End of Intervention	Clinical	Nurse	End of Exam
End of Anaesthesia	Clinical	Nurse	End of Recovery
Exam Room Exit	Clinical	Nurse	Exit of the Exam Room
Exit	Administrative	CST - FO	When payment is done

* Front-Office(FO); Back-Office(BO)

5.2.1.2 Data Gathering

As mentioned above, this data gathering was necessary to complete some gaps in timing related information. All the data gathered is presented in the Appendix A.
The main goal was to differentiate between some key moments that could not be distinguished with the first data set. The moments are the waiting and sub-waiting, the pre-exam appointment, the exam itself and the post-exam appointment. The difference between the utilization of Room 1 and Room 2 was also inferred through the registration of the room at which the exam was taking place, since Room 2 doesn't differentiate the different moments of exam was also an important measure through the registration of the Room. Another important time stamp recorded was the "Exit" moment that now is defined and can help understand the total time of exam.
This differentiation was made according to the moments shown in the figure 5.7.

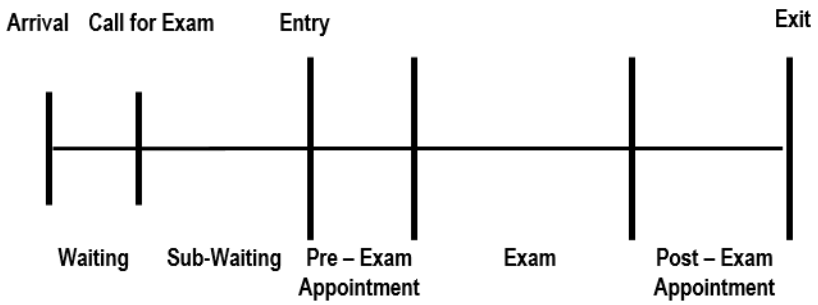


Figure 5.7: Exam Timings

Before starting the data gathering, the sample size was calculated. Since the population size was unknown, to calculate the sample size it was considered the equation 3.2.
Considering a confidence level of 95% the Z-score (Z) is of 1.96 a standard deviation (p)

of 50% and a margin of error (e) of 7%, the sample size should be of 196 observations. This data set was collected through direct observation of discrete elements. The number of observations obtained was of 204 exams and treatments that after removing the observations without exams or treatments became a sample of 194 observations.
The information gathered in this data set was:

- Date of Scheduling;
- Doctor;
- Exam Room;
- Procedure;
- Times:
  - Time Scheduled;
  - Time of Arrival;
  - Time of Call for the Exam;
  - Time of Entry in the Pre-Exam Appointment;
  - Time of Exit of the Pre-Exam Appointment;
  - Time of Entry in the Exam Room;
  - Time of Exit of the Exam Room;
  - Time of Entry in the Post-Exam Appointment;

NOTE: The Room 2 doesn't record the pre and post appointment times since it has no differentiation.

5.2.2 Key Performance Indicators

This section summarises all the indicators measured with the help of the two different data sets. This KPI were the ones used in the analyse phase to infer about the variability and the metrics to be improved.

1. **Exam rooms performance:**
   There are four types of exams that will help in the measuring of how are the exam rooms being used:
   - Slots Available - Number of exams that can be performed in one day;
   - Exams Performed - Exams that were scheduled and were actually performed;
   - Exams Expected - Exams that are scheduled and expected in a given day;
   - Exams Not Scheduled - Exams that were not scheduled at first.

   To better understand the exams room performance, the metrics evaluated were:

$$Scheduling\ Rate = \frac{Exams\ Expected}{Slots\ Available} \tag{5.1}$$

$$Performance\ Rate = \frac{Exams\ Performed}{Exams\ Expected} \tag{5.2}$$

$$Occupation\ Rate = \frac{Exams\ Performed}{Slots\ Available} \tag{5.3}$$

$$\frac{Occupation\ Rate\ with}{Exams\ Not\ Scheduled} = \frac{Exams\ Performed + Exams\ Not\ Scheduled}{Slots\ Available} \tag{5.4}$$

The calculations are shown in the tables below 5.3, 5.4 and the further analysis in the Appendix D.

Table 5.3: Scheduling and Performance Rate

Doctor	Scheduling Rate (%)	Performance Rate (%)
D1	78.35	88.33
D2	92.17	90.57
D3	84.69	93.46
D4	80.88	91.21
D5	88.62	91.22
D6	86.11	91.67
D7	31.43	93.18
D8	77.27	91.50
D9	76.01	92.84
Total	77.09	91.79

Table 5.4: Occupation Rate

Doctor	Occupation Rate (%)	Occupation Rate w/ Not Scheduled (%)	Difference (%)
D1	69.21	79.88	10.67
D2	83.48	97.39	13.91
D3	79.15	82.74	3.58
D4	73.77	80.64	6.86
D5	80.84	108.99	28.16
D6	78.94	81.02	2.08
D7	29.29	53.81	24.52
D8	70.71	81.82	11.11
D9	70.57	74.69	4.11
Total	70.76	82.69	11.93

2. **No-show rate:**
   This metric is defined by the quotient of the exams and treatments that have a status of scheduling of "No-Show" with the total exams performed. This metric also differentiates the total exams with the colposcopies that are the main exam.

For this calculation, the numbers considered were the ones of the administrative software since it is in there that the status of scheduling is recorded.
It was identified a no-show rate of 7% in all exams and treatments and of 8% when referring to the colposcopies only.

3. **Length of stay in the exam:**
   The calculation of this metric is used for the sigma level definition. The length of stay is considered to be the difference between the moments of "Exit the Exam Room" and "Entry" and it doesn't behold the "Exit" moment since the registering of "Exit" is not reliable as explained before.
   The average of the length of stay is 00:17:48 and the standard deviation is 00:16:52.
   This metric is going to be further discussed with the help of the second data set.

4. **Time Spent in the waiting room:**
   Time spent in the waiting room is defined as the difference between the two time stamps defined in the table 5.2: "Entry" and "Arrival". If the moment of arrival is before the scheduled hour it is to consider the difference between "Entry" and "Scheduled Hour".
   This waiting time was found to have an average of 00:30:42 and a standard deviation of 00:26:01.
   The waiting times are going to be further discussed with the help of the second data set.

5. **Exam room turnaround:**
   This value was defined to be the difference between the "Exit of the Exam Room" of one client and the "Entry in the Exam Room" of the next client.
   This time showed an average of 00:24:38 and a standard deviation of 00:29:37.
   This evaluation was also perceived as biased since the observation in real time didn't showed this value since there is not a relevant moment of cleaning the exam room.
   This will also be a focus of the second data set analysis.

6. **Delay of the first exam of the day:**
   For this metric it was considered the first delay of the day since it is one of the hospital KPI's for the rest of the departments and the first exam of the day will impact the whole day. Since the rooms change doctors from the morning to the afternoon, the exams considered as the "First of the day" were the first exam of the morning and the first exam of the afternoon.
   The hospital considers that a significant delay is a delay > 10 minutes, therefore this was another measure obtained in this topic.
   The first exam of the day showed an average of 00:34:00 with a standard deviation of 00:33:32.

To evaluate the delays between different doctors, the percentage of the first exams with delay were quantified as long with the percentage of those delays that were > 10 minutes.

Table 5.5: Delays of the First Exam of the day

Doctor	First exam of the day with delay (%)	First exam of the day w/ delay > 10 min. (%)
D1	95.24	75.00
D2	90.32	64.29
D3	100.00	96.97
D4	97.56	80.00
D5	93.17	87.96
D6	97.73	97.67
D7	89.57	88.35
D8	96.55	85.71
D9	96.17	88.92
Total	95.06	88.10

Times identified with the second data set:
The first data set had some results shown in the Appendix E that were not reliable since they were not in line with the results of the observation. For this reason, there was a need for measuring the real times in the exam with some information that was missing.
This measurement was made according to the time stamps defined in the figure 5.7.
The results obtained from this were the ones represented in the tables 5.6 and 5.7.

Table 5.6: Average of waiting times of the second data set

Doctor	Waiting Time	Sub-Waiting Time	Total Waiting Time
D1	00:10:26	00:10:12	00:18:33
D2	00:05:32	00:08:00	00:11:33
D3	00:40:17	00:11:20	00:42:40
D4	00:10:07	00:06:17	00:16:23
D5	00:36:06	00:14:43	00:50:04
D6	00:06:47	00:10:13	00:17:00
D7	00:14:00	00:10:45	00:22:25
D8	00:03:20	00:07:28	00:09:46
D9	00:22:09	00:13:19	00:33:34
Total	00:20:16	00:11:57	00:34:56

The timings record show some variability between the doctors and shows a difference to times evaluation done in the first data set.

Table 5.7: Average of Exam times of the second data set

Doctor	Pre-Exam App.	Exam	Post-Exam App.	Exam Total Time
D1	00:05:19	00:09:34	00:06:26	00:25:54
D2		Room 2		00:18:51
D3	00:03:20	00:16:40	00:06:27	00:31:53
D4	00:00:00	00:07:10	00:03:50	00:14:47
D5	00:02:55	00:11:29	00:05:26	00:20:51
D6	00:02:39	00:08:43	00:07:39	00:25:26
D7		Room 2		00:36:40
D8		Room 2		00:25:37
D9	00:03:16	00:08:21	00:05:46	00:24:51
Total	00:02:52	00:09:34	00:06:14	00:23:31

The times presented as "Room 2" are the ones at which the doctors only performed their exams in the Room 2 and therefore their exam timings cannot distinguish exam moments.

5.2.3 Sources of Variability

After all the measures done in the previous subsection, the possible sources of variability were identified so that in the Analyse phase they can be verified.
There are two kinds of variability, the registering and the times variability. Although the registering was identified as a project itself, there is still some variability identified in this area that is not directly related to the registering system.

Registering Variability:
The registering variability is mostly related to the understanding of the software concepts and with some procedures to ease the daily basis problems that may arise.
A recurrent issue is that when a patient is admitted in the administrative software but doesn't fulfill the requirements to perform the exam, it cannot be marked as "No-show" and this exam will appear as performed.
Another issue is that when a doctor wants to extend its exams schedule and the CST-BO doesn't want to wait for the "Scheduling Team" to open it, the CST-BO will force an opening which will appear as a NS type of exam even though it is scheduled in time. This will lead to a misunderstanding of what is a NS exam and of the real unit performance. It was estimated that 49% of the NS exams were poorly marked. For this estimation, some assumptions were made:

- Exams performed in an not scheduled slot for more than three days in a row, this slot was assumed as a scheduled slot;
- A whole day appeared as NS, it was assumed that all the slots were S instead;
- Since the slot for this kind of exams and treatments was set at a time slot of 30 minutes, every slot outside of the 30 minute range was considered that the exam was really NS.

Time Related Variability:
Related to times, the possible sources of variability are between the time that each doctor takes to perform a given exam or treatment as well as variability between different exams and treatments. Another variability issue that will be evaluated is the variability between the two different rooms.
The waiting times also show a different behaviour according to the different doctors as it is possible to see by the standard deviations shown in the tables 5.7 and 5.6. Therefore the total time that a client spends in the hospital in order to attend one of these exams has also some variability which will lead to a further analysis in the next DMAIC phase.

5.2.4 Definition of Sigma Levels

In this part, two sigma levels will be defined. Since in the section 5.1.1 there were two different projects defined, even though the second project was abandoned its sigma level was also inferred for future reference. To define the sigma level it is necessary to define the defects we are evaluating for each project.
Project 1:
This project had the main goal of improve the overall client experience when going through the exams of this department. Therefore, the defects defined were:

(a) Time spent in the waiting room > 20 minutes;
(b) Length of Stay in the exam > 30 minutes.

Time spent in the waiting room (a) and Length of stay in the exam room (b) are defined before in the 5.2.2 subsection.
The threshold defined for (a) is according to the literature the amount of time that a client accepts to be waiting (Bleustein et al., 2014), that is 20 minutes. For (b) the threshold is defined at 30 minutes since all the exams and treatments have a 30 minutes slot and it is admitted that if the time defined as the LOS over dues the 30 minutes, than the exam total time is already being overrun. The values accounted as defects were calculated based on the First data base. Even with some biased values, the ones considered in these calculations were considered to be valid.

Project 2:
Although the second project was not chosen to be carried out due to lack of resources, its main goal was to improve the registering system, that was necessary not only to ease the daily use of it but also to improve the output of the systems, both in the clinical software and the administrative.
To calculate this sigma level, the defects taken into consideration were:

(c) Fail to register Appointment;
(d) Fail to register "Entry" moment;
(e) Fail to register "Room Entry" moment;

(f) Fail to register "Intervention Beginning" moment;
(g) Fail to register "End of Intervention" moment;
(h) Fail to register "Exam Room Exit" moment;
(i) Fail to register "Exit" moment.

These defects are just detected when there is no registering of the mentioned moments (c, d, e, g, h, i, j). The moments related to the anaesthesia are not considered defects because it is not possible to know in advance when it is necessary to apply anaesthesia since it depends on the procedure, the doctor and the client. The moments of "Arrival" and the "Scheduled Hour" also mentioned in the table 5.2 are automatic and assumed to be always registered by default.

Table 5.8: Sigma Level - Projects 1 and 2

Project	Defects	Count of Defects	Observations	DPMO	Sigma Level
Project 1	(a) (b)	2247 337	3128	413043.5	1.7-1.8
Project 2	(c) (d) (e) (f) (g) (h) (i)	1843 4 408 3784 589 494 35	3784	270197.8	2.1-2.2

5.3 Analyse

The third phase of the DMAIC cycle it is used to identify the main causes of the problem and which ones are priorities. For this phase the steps and tools are shown in the figure 5.8. The sub-processes mentioned in the Define phase will be further explored and the sources of variability analysed in order to understand were the improvements should be directed.

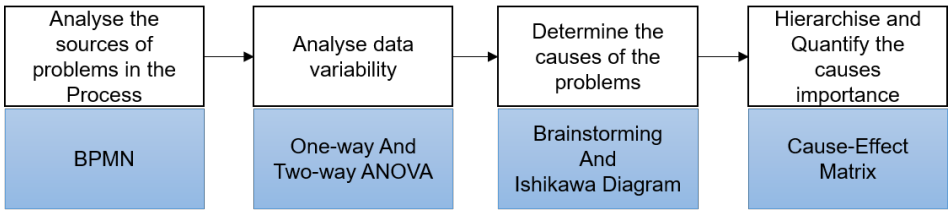


Figure 5.8: Analyse Phase - Steps and Tools

5.3.1 Processes Analysis

In this analysis, all the processes were further described. Along with the stakeholders involved in these processes. The processes analysed in detail are the ones identified in the figure 5.3:

2. Schedule Exam;
5. Check-In;
8. Perform Exam;
14. Check-Out.

After the processes definition (figures 5.9, 5.10, 5.11 and 5.12) the non-value added activities were identified. These activities are:

2.18. Force slot opening - This activity is performed by a CST- BO and sometimes the rules to force a slot opening are not being followed since doctors authorize for some slots that are qualified as NS even though they are scheduled in time;
5.10. Give bracelet and Consent Form to Client - This activity is being carried out by a CST- FO and it has no good value since there is no need to give these papers in this moment and it is because of these papers that the check-in has to be performed personally, otherwise it can be done through the mobile app or through the hospital kiosks' for this matter. This activity is still performed since it is a JCI requirement;
8.2. Pre-Exam Appointment - It is performed by the doctor, since it is a legal requirement that a doctor explains the procedure to the client. It occurs so that the client can sign the consent form with the doctor and to check if the requirements for the exam performance are fulfilled. This moment creates one more moment in the whole exam performance and it is short so it can be considered for elimination;
8.13. Register Appointments - This activity is performed by the doctors in the end of the examination and happens when the doctor considers that besides the exam an appointment occured. Its registering is subject to the considerations of each doctor and it is not defined which are the rules to an appointment charge or not;
8.15. Register Consumes - This activity is performed by the nurse when the exam ends and it consists in registering in the system what medicines and consumables were used in the procedure so that it can be billed. This activity has some problems since it has some packs of consumes done and when the nurse registers it has to deselect some of medicines and consumables not used and sometimes due to the low turnaround the nurse doesn't have enough time;
14.5. Archive Consent Form - It is performed by a CST- FO and it takes more time than adds value. Usually consent forms from all the exams and treatments of the day are accumulated and taken care together and it usually takes up to 5 minutes for consent form with an average of 16 exams per day. This activity should be automated since it is manual and other documents are already being inserted automatically with the help of a tag identifying the client in each client document.

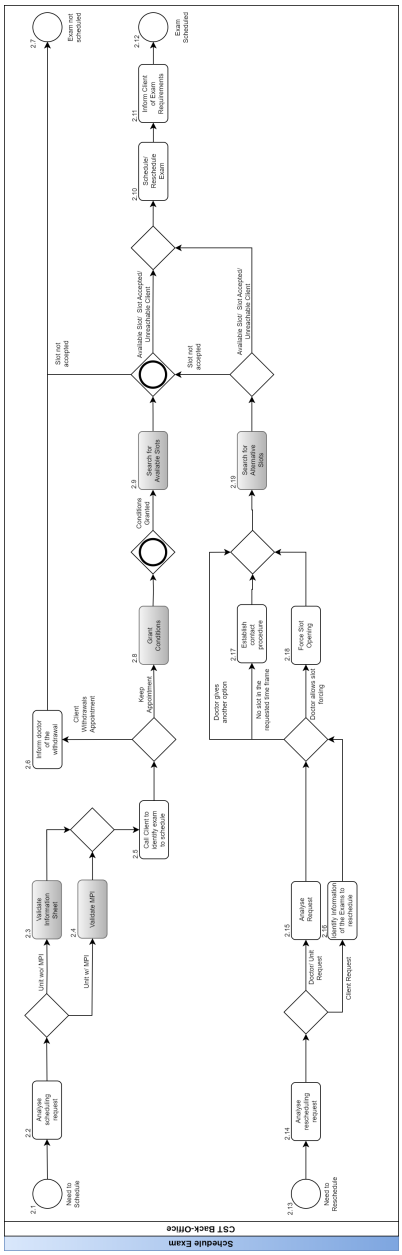


Figure 5.9: BPMN As Is: 2.Schedule Exam

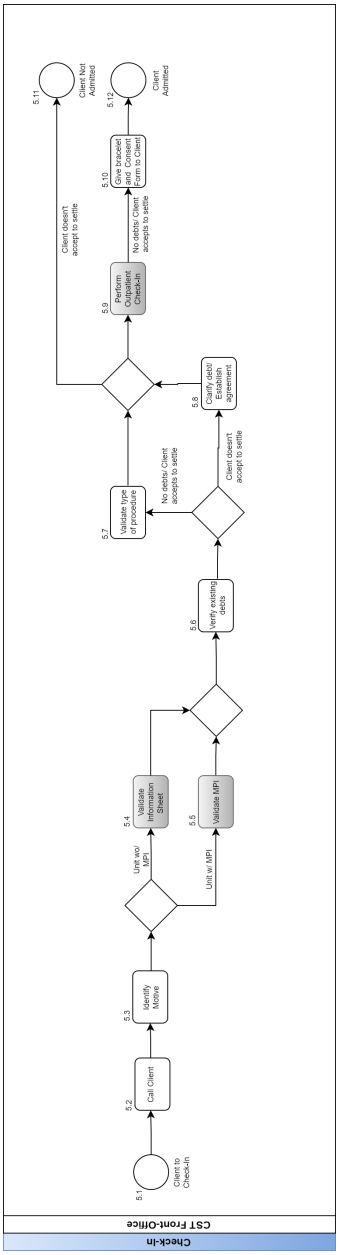


Figure 5.10: BPMN As Is: 5.Check-In

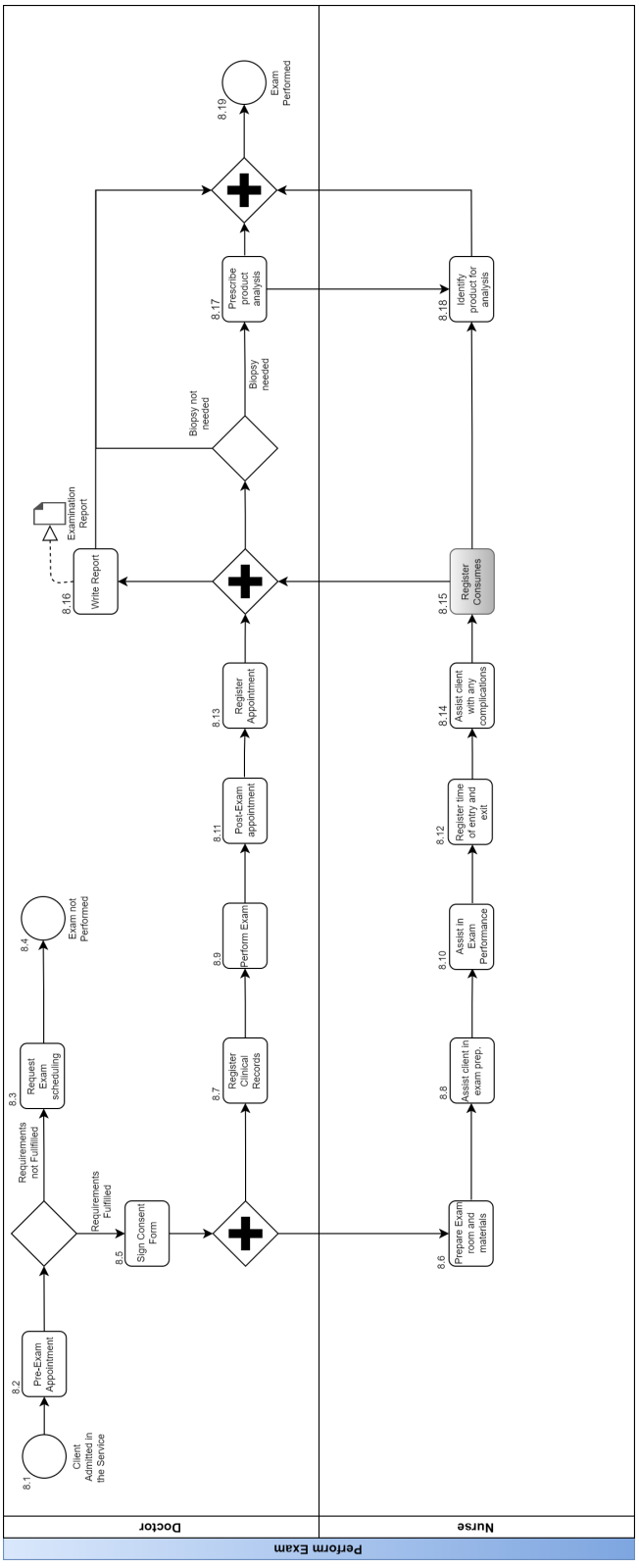


Figure 5.11: BPMN As Is: 8.Perform Exam

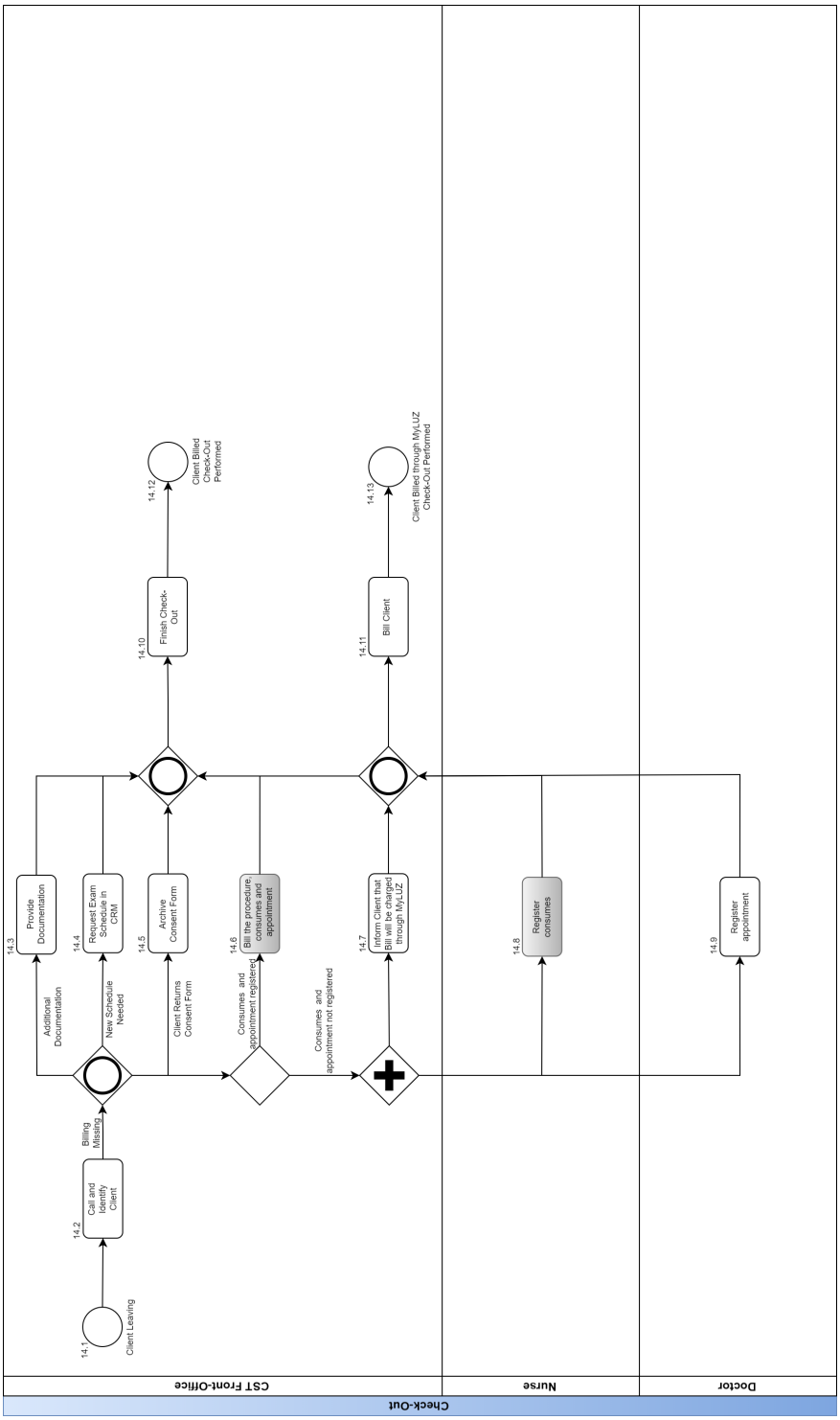


Figure 5.12: BPMN As Is: 14.Check-Out

5.3.2 Variability Analysis

In this section, an analysis on the sources of variability identified in the section 5.2.3 was performed. The analysis was done with the statistical test of One-Way ANOVA. Three main topics of variability were analised: **Doctors Variability**, **Procedures Variability** and **Rooms Variability**.

Doctors Variability

For this evaluation, a total of 146 exams were taken into consideration and the samples for each doctor were not at the same quantity, since different doctors have different working days at the hospital the amount of slots available is not the same. The sample had a total of 146 observations that varied from the doctor D3 with 9 observations to the doctors D1, D2, D5 nd D9 with 20 observations each.

Table 5.9: One-Way ANOVA: Variability in exam times performance between doctors

	Sum of Squares	dF	Mean Square	F	P-Value	Critical F
Between Groups	4716.02	8	589.50	6.07	$1.12e^{-10}$	2.01
Within Groups	13304.92	137	97.12			
Total	18020.94	145				

The table 5.9 shows the variability analysis done with the One-way ANOVA test and the results are of a highly significant p-value since its order of magnitude it's very low and close to zero. The assumptions of the data normality and homoscedasticity are verified in the figures C.1 and C.2 in the Appendix C. The data independence is assumed to be verified since all the data was taken from different doctors and collected in different days. For this reason it was considered that the doctors performance had a significant variability and a deeper analysis was performed with the LSD test. The values of this test are shown in the Appendix C and the results summarized in the figure 5.13.

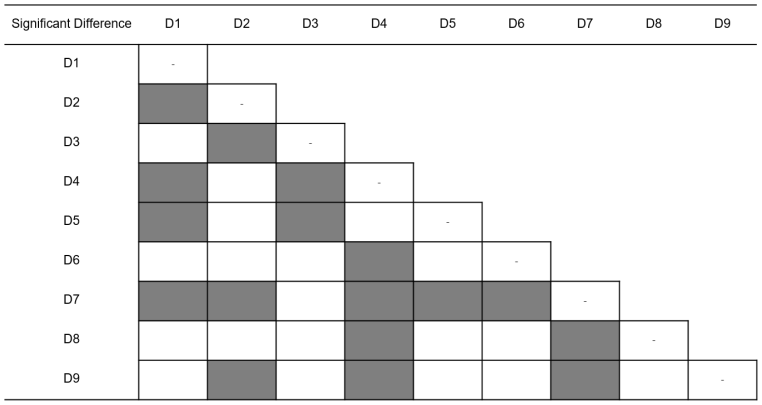


Figure 5.13: LSD Test - Significant Difference between doctors performance

Procedures Variability

Since there were a few different kinds of exams and treatments being performed in the unit and that they all have defined a slot of 30 minutes, it was necessary to check if the different procedures should have different slots attributed.

The sample chosen for this evaluation didn't considered all the 11 procedures described to happen in this unit. The procedures considered were the P4 (9 observations), P5 (4 observations), P9 (4 observations), P11 (9 observations) and (P1, P2, P3) (9 observations) were considered in the same category since they are all laser surgeries.

For this evaluation the results are in the table below 5.10. Even though there is a significant difference that is shown by the P-value of 0.0005, the LSD test only showed this difference in one of the procedures that was the P9.

Table 5.10: One-Way ANOVA: Variability between different procedures

	Sum of Squares	dF	Mean Square	F	P-Value	Critical F
Between Groups	4347.57	4	1086.89	6.87	0.0005	2.69
Within Groups	4743	30	158.1			
Total	9090.57	34				

The assumptions for the application of the One-Way ANOVA were also verified in the Appendix C in a similar way to the doctors variability.

Rooms Variability

This evaluation was performed using the same variability analysis. The 2 Rooms different layouts, with a dislocation for the Room 1, could impact the doctors performance.

The sample had 60 random observations of exams performed for each one of the two exam rooms when performing the exam P4, so that the means of comparison are the same. As it is possible to see in the table 5.11 the statistical test didn't show any significant differences and therefore the LSD Test was not performed. The ANOVA was applied since the assumptions are all verified in the figures C.5 and C.6 in the Appendix C.

The two rooms have a similar effect in the exams and doctors performance.

Table 5.11: One-Way ANOVA: Variability between different Exam Rooms

	Sum of Squares	dF	Mean Square	F	P-Value	Critical F
Between Groups	102.68	1	102.68	1.49	0.22	3.92
Within Groups	8104.32	118	68.68			
Total	8206.99	119				

5.3.3 Causes Analysis

In this section we are focusing on the problem identified as the low unit efficiency. This analysis was divided into six different categories of the key aspects involved and they are Clients, Infrastructure, Health Care Providers, Administrative Staff, IT Systems and Process. The analysis is represented in the figure 5.14.

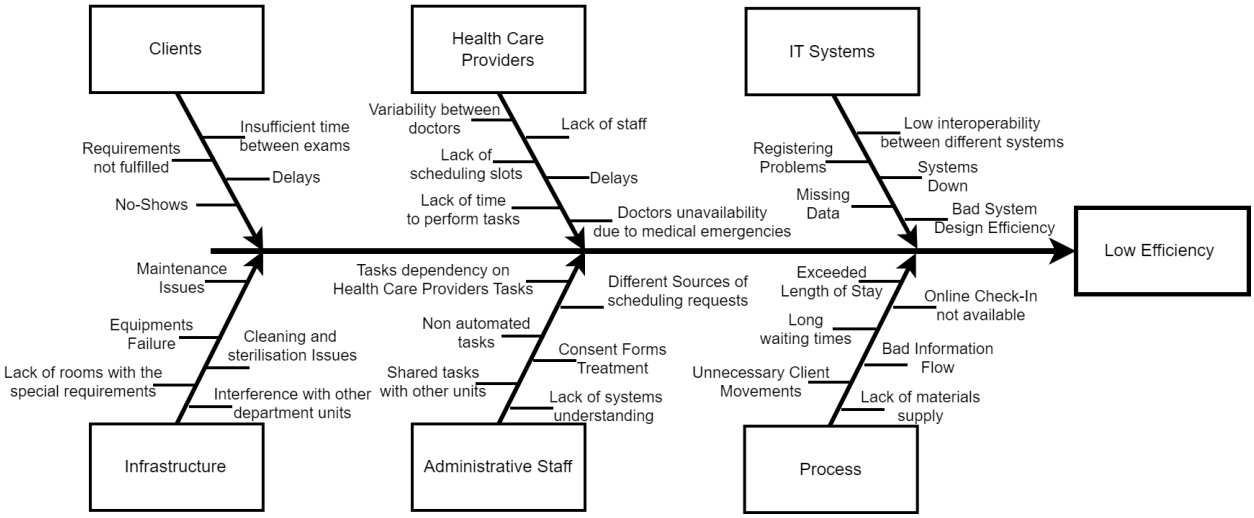


Figure 5.14: Ishikawa Diagram - Analysing Low Efficiency

After the key aspects were identified, the main causes of failures were enumerated in each category.
In the clients category all causes forestall or delay the exam occurrence which affects the normal functioning of the unit. The infrastructure category, manifests causes that are mostly related to lack of conditions to perform the exams. In the health care providers category the causes will, in most cases, delay the exams schedule but almost never prevent its occurrence. The causes present in the administrative staff area are not directly related to the exams performance but to client experience and can cause constraints with the client interaction. The It Systems category can sometimes cause a lack of data recording or a delay in the schedule but should not interfere with the exams performance. The process part records causes related to the normal flow of the client and can affect the overall client experience.

5.3.4 Cause-Effect Matrix

In the end of the Analyse phase, there is a need to define where the improvements should be applied in the Improve phase. For this the tool used was the Cause-Effect Matrix.
The criteria first used were the **Impact** that shows how the failure impacts the normal functioning of the unit, the **Frequency** that shows the amount of times at which it happens and the **Predictability**, that shows how predictable is the failure so that it can be prevented before it happens.The exclusion factor was predictability, considering that if a

cause is predictable it is possible to take action against it. The score considered for this factor was 9 and it was classified as Predictable (9) or Non-Predictable (0). For the other two factors, it was considered a score of 8 for each of them since the impact can be as harsh as the frequency at which the failure occurs. The weights considered for each factor were 9, 6, 3 or 0 for the classification defined in the table 5.12 were used to elaborate the Cause-Effect Matrix presented in the figure 5.15.

Table 5.12: Criteria weights in relation to causes

Weight	Impact	Frequency
9	High Impact	Always
6	Moderate Impact	Sometimes
3	Low Impact	Rarely
0	No Impact	Never

		Impact	Frequency	Predictability	Criteria
		8	8	9	Weight
Area	Root Causes	Relation between Cause and Criteria			Total
Clients	Requirements Not Fulfilled	9	3	9	177
	Insufficient time between Exams	9	3	9	177
	Delays	6	6	0	96
	No-Shows	9	6	0	120
Infrastructure	Maintenance Issues	3	3	9	129
	Equipments Failure	9	3	0	96
	Lack of Rooms with Special Requirements	3	0	9	105
	Cleaning and Sterilisation Issues	3	3	9	129
	Interference with other department issues	3	3	9	129
Health Care Providers	Variability between doctors	6	9	9	201
	Lack of Scheduling Slots	3	9	9	177
	Lack of time to perform tasks	3	3	9	129
	Lack of Staff	3	3	9	129
	Delays	6	9	0	120
	Doctors Unnavailability due to medical emergencies	9	6	0	120
Administrative Staff	Tasks dependency on Health Care Providers Tasks	3	6	9	153
	Non Automated Tasks	6	6	9	177
	Shared tasks with other units	0	0	9	81
	Different Sources of Scheduling requests	3	3	9	129
	Consent Forms Treatment	6	9	9	201
	Lack of systems understanding	6	6	9	177
It Systems	Missing Data	9	6	9	201
	Registering Problems	6	6	9	177
	Low interoperability between different systems	6	6	9	177
	Systems Down	9	6	0	120
	Bad System Design Efficiency	6	9	9	201
Process	Exceeded Length of Stay	9	9	9	225
	Long Waiting Times	9	9	9	225
	Unnecessary Client Movement	3	6	9	153
	Online Check-In not available	0	9	9	153
	Bad Information Flow	3	3	9	129
	Lack of materials Supply	3	3	9	129

Figure 5.15: Cause Effect Matrix: Hierarchisation of causes

It is possible to understand the causes at which there's an urgency to act and that will be the object of study in the next section 5.4. The red boxes (Risk Priority Number (RPN)>200) represent the causes that need an immediate reaction and the orange ones (150< RPN< 200) are the ones that can be postponed for a while.

After all the analysis is done it is now possible to proceed to the improve phase where these terms will be analysed.

5.4 Improve

The fourth phase of the DMAIC cycle has the goal of propose, evaluate and implement solutions for the root causes identified in the last phase. And the figure 5.16 shows the process to achieve a solutions proposal.

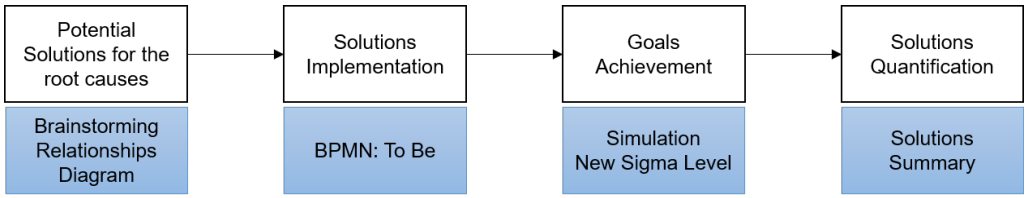


Figure 5.16: Improve Phase - Steps and Tools

5.4.1 Brainstorming and Relationships Diagram

In this first part of the Improve Phase, a few improvement measures are suggested. Some of these proposals arise as a response for various of the causes identified before and are listed below.

Rearranging slots by doctors clusters
This measure is a direct response to the variability found between doctors and exams and treatments. Analysing the different doctors' performance there are three suggestions for different slots times by defining three different doctors' clusters according to their performance. Even if LSS methodology aims to diminish the variability, in this case we are taking advantage of the existing variability and assuming it as a valuable characteristic of the unit in analysis.

Table 5.13: Different Scenarios Proposal

	Cluster 1 - 40 min.	Cluster 2 - 30 min.	Cluster 3 - 20 min.	DPMO
Scenario 1	D3, D7	D1, D6, D8, D9	D2, D4, D5	332800.5
Scenario 2	D7	D1, D2, D6, D8, D9	D2, D4, D5	336317.1
Scenario 3	-	D1, D2, D6, D7, D8, D9	D2, D4, D5	339134.4

These scenarios are listed above in the table 5.13. The scenario that will be adopted will be discussed in the subsection 5.4.2.

Along with the slots rearranging between doctors it is suggested that at the first slot of the day two exams are scheduled in a one slot to mitigate the delay of the first appointment of the day. For example, in a slot of 30 minutes that starts at 9 a.m., there would be an appointment at 9 a.m. and another at 9:15 a.m. to guarantee that there is always one client there to attend the exam.

Digital Signature through the hospital mobile app

This solution urge as a response to the consent forms problem. Consent forms are one of the most time consuming tasks that CST-FO perform. These documents need to be connected both to the doctors and the clients profiles and they are signed manually for all the intervenes and then the CST-FO will introduce the document in the correct place in the "Documents Management" area.

Implementing a digital signature mechanism will save an average of 80 minutes per day of dealing with consent forms. It is estimated that this implementation saves more time since this kind of documents are also necessary for shared departments like the ER or the delivery room.

Staff Training Program

It was understood that some problems happen because there is a lack of staff's understanding of some softwares concepts and how some mechanisms in the institution work. Problems like "Forcing Slots" happen because sometimes hospital staff tries to turnaround the problem and that can create other problems.

Another growing issue is about the continuous rotation of staff like MA and CST's both back and front-office, and therefore there's a continuous need of staff training.

For all of these factors it is recommended that a strong and permanent training program its implemented so that all concepts in the software use can be clarified as well as the whole department. This program can prevent some minor issues that can occur and promote a better flow of information and an easier pathway of the client.

Restructuring the clinical and administrative system

This proposal corresponds to the Project 2 mentioned in the Define section 5.1.

It is proposed that when its possible and when its decided that the project should be taken through, both clinical and administrative software are restructured in projects where the main key users are involved and that the systems' redesign is done according to their feedback.

It is important that all the boxes not filled are stated as mandatory and that some boxes that don't exist as the rooms' differentiation are implemented for a better unit management.

Another important and relevant feature is the interoperability between these two softwares and even with the hospital mobile app, so that all information is centralised and all intervenes know that their information is correct. Aside from interoperability, it is

critical that at various points in the process, it is feasible to nullify exams that were not done and genuinely classify the exams as not planned or as a forced slot, so that every exam is properly classified.

Gateway Mechanisms for registering

This mechanisms are suggested as a response to those moments when a health care provider doesn't have time to perform a given task that it is necessary for administrative tasks after, as registering appointments, medicines and consumes.

It is suggested that the nurses or doctors have a template paper that they can fill manually and that can be given to the CST-FO that can registered it if there is a written proof that it came from a health care provider.

These mechanisms already took place and eventhough they should not be permanent, they are a good measure to act on the short-run. With the adjust of the schedules it is expected that the time to perform tasks also augments and that this lack of time for registering can be diminished.

Attendance Management System

This new system will eliminate the moment of sub-waiting presented in the figure 5.7. Elimination of this moment is important as it is stated in the literature that a sub-waiting moment increases the clients expectation and then creates more stress if this moment is too long (Ogaji & Mezie-Okoye, 2017).

This way, doctors will call their clients directly and remove a task from the MA. Additionally, clients will only be called when the doctor is available, removing this expectation not accomplished.

It is expected that this will only be implemented in a year, therefore the impacts can't be measured for now. This tool allied with the digital signature and the possibility of an online Check-In will strongly augment the technologies dependence but it will also improve their rapid response and their information storage, as it will be a better method for storing the correct timings.

Check-In Online

This suggestion was to eliminate the Check-In moment since it is non-value added and that augments the flow in the front-office, and that this should be diminished to improve the ER administrative response.

The measure would be for the client to perform the moment of Check-In in the hospital mobile app. This would mean that the tasks of "Give bracelet and Consent Form to Client" would have to change for another role. Therefore, this task would pass to the MA for the identification bracelet and to the doctor with the Consent Form.

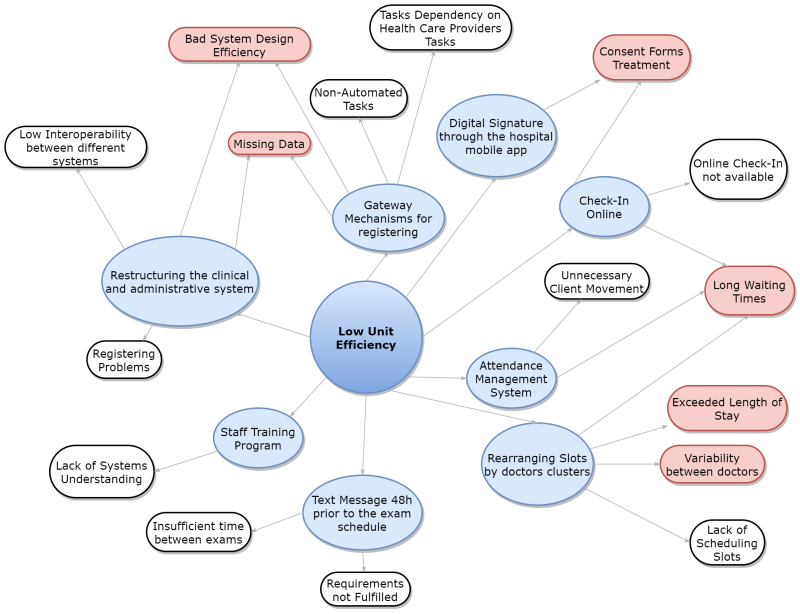
This change was not accepted since the attendance management system would be implemented. Nevertheless, the moment of the "Pre-Exam Appointment" was possible to eliminate, considering that some doctors don't do it and that the Pre-Exam Appointment

has an average of 00:02:52 minutes and that this is not valuable time, it is considered that it can be eliminated and that the doctors can signed it alone.

Text Message 48h prior to the exam schedule
This measure is common in hospitals and it is already being done in other hospital units. It consists in sending clients a message 48 hours before the exam scheduled hour. The message should contain the following information:

- Hour of Scheduling and that the time of attendance should be 15 minutes before the time scheduled and not before - This information is important to prevent no-shows and delays and also to control the flux of clients in the waiting room since it is a place of great traffic;
- Location of the exam in the hospital and explanation of how to access;
- Reminding all the exam requirements (mentioned in the Chapter 4) - preventing clients from coming if they can't fulfill these;
- Reminding for the additional documents (Ex: Insurance documents, previous exams...) that might be asked - this will increase the client experience avoiding rescheduling by lack of materials;
- In the end, it is important to ask for a contact in case of inability to attend the exam - this way the slot can be filled and the doctor informed.

This message will act in the no-shows and delays and mainly on the client area. It will also improve the client and information flows in general.



Blue Items - Solutions proposed; **Red Items** - Critical Causes; **White Items** - Non Critical causes

Figure 5.17: Relationship Diagram - Connecting Solutions to their Root Causes

Even though these measures don't respond to all the causes identified, some of them can solve more than one issue. In the end, all the critical causes were a priority when thinking of possible solutions. To analyse the measures to implement the Relationship Diagram 5.17 between all solutions and their root causes were represented according to the connections they have between them.
To resume the solutions to be implemented, the BPMN's To Be for each process were drawn and are presented in the Appendix B. There was a substantial decrease in each process key users and in the non-value added activities. In the next subsection the actual improvements will be reflected in numbers.

5.4.2 Simulation and New Sigma Level

After all the improvements are implemented it is expected that a new sigma level is achieved and that some optimization can be seen.
Since the sigma level takes into account the length of stay in the exam room and the waiting time in the waiting room a simulation was performed in order to prospect about the new sigma level that can be achieved.
When measuring the length of stay, there are three scenarios to decide on, and to a better analysis of the case, the number of defects for each defect was looked into as is shown in the table 5.14.

Table 5.14: Count of Defects Per Doctor

Defect	D1	D2	D3	D4	D5	D6	D7	D8	D9
Waiting Time > 20 min.	145	28	204	167	648	225	151	56	623
LOS in the Exam > 30 min.	8	3	38	7	48	33	56	7	137

The critical doctors in terms of length of stay in the exam are D3, D5, D6, D7 and D9. When combining this information with the time spent in the exam obtained on the second data set, the ones that were critical to move were D3 and D7. Even if D9 also has a significant amount of defects, the other numbers contradict the case that it is necessary to augment D9 time slot.
Knowing these facts, it is suggested that the scenario adopted is the Scenario 1 present in the table 5.13. All the scenarios have a similar DPMO and allow for the achievement of a sigma level between 1.9 and 2. If there is doctors' resistance, the Scenario 3 is also a good option that only considers two different scheduling groups.
The waiting time has a bigger impact in the sigma level since the number of defects is higher. For this matter the doctors in a critical zone are D1, D3, D5, D6, D7, D9.
It was not possible to perform a simulation since it is not possible to predict at what time are the clients arriving with the new scheduling slots. Nevertheless, if it is considered that the sub-waiting time can be removed from the total waiting time and the average of the sub-waiting (00:11:57) is removed from the total waiting time, the number of defects

of the time (a) decreases from 1663 to 1438.
The two measures combined, will lead to a sigma level of 2.1-2.2. This number is underestimated since it is expected that the new slots arrangement will also have an impact on the doctors' waiting times that it is not possible to calculate.

5.4.3 Solutions Summary

In this subsection, the course of all solutions implemented and to be implemented is stated with the gains from each one of them.
In the LSS methodology there are other important achievements besides achieving a better sigma level. These can be the reduction of the non-value added activities and a better process flow.
The goal to the client flow in the unit is the one represented in the figure 5.18. When compared to the one showed in the Measure Phase, the total time of the patient in the unit is reduced.
When analysing the different roles, the time spent by the doctor is reduced as long

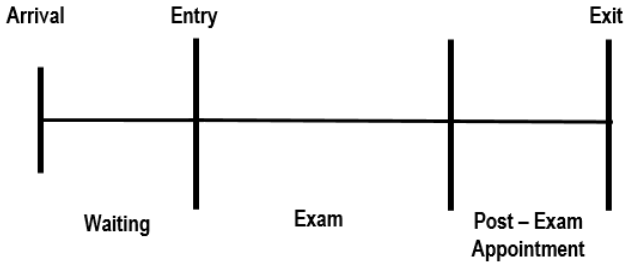


Figure 5.18: Exam Timings - After Improvements

as the total waiting time for the client, by excluding the sub-waiting moment. These accomplishments are shown in the figure 5.19. Being the client cycle time the sum of the client part with the doctor one plus the check-out that (Check-Out timings are not possible to show due to lack of timing information).

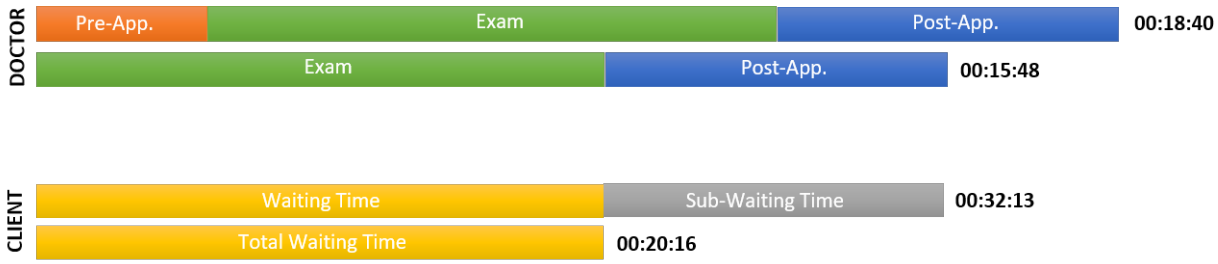


Figure 5.19: Time Saved after Improvements

When referring to other key users, CST-FO save 80 minutes/day in processing Consent

Forms since it digital and automated.
It is also expected that the front-office is less crowded due to the more availability of the multiple CST-FO.
The scheduling rate is expected to be augmented but it's not possible to calculate what is the extent of it.
About the non-value added activities mitigating two activities and eliminating other two, it was possible to eliminate 33% of these activities since the "Force Slot Opening" and the "Give bracelet and Consent Form to Client" cannot be eliminate.
After the improvement phase and the analysis of what was possible to implement it is time to set a control program to maintain what was established and to monitor the goals already achieved. This will be done in the next section 5.5.

5.5 Control

The last phase of this methodology aims to guarantee that the goal is kept in the long run and future works might also be suggested. Therefore, the steps defined for this phase are shown in the figure 5.20 where there's a need to evaluate the long run goals and how are they going to be met.

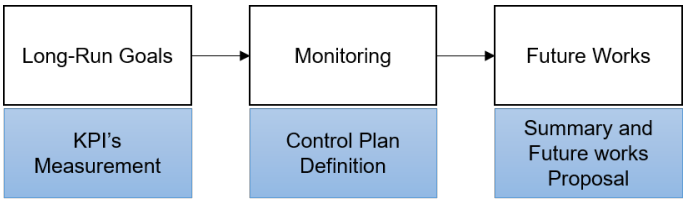


Figure 5.20: Control Phase - Steps and Tools

5.5.1 KPI Measurement

In the control section it is important to state which KPI will be measured so that a plan of action can be defined. According to the KPI defined in the first phase of the DMAIC cycle the metrics to be monitored can be related to the sigma level or just to efficiency metrics.

1. Sigma Level Metrics:

Length of Stay in the Exam Room
This first metric and the next one are both critical. They are the ones who define the sigma level, therefore are the ones important to be monitoring.
The LOS in the exam room should be kept not under 30 minutes as set before, but under the time slot of the group attributed to each doctor. For example, if a doctor is in the Cluster 1, defined in the table 5.13, their length of stay should be under those 40 minutes

defined.

Time Spent in the Waiting Room
Being the second metric evaluated in this LSS project, as the last one is the priority to monitor.
The threshold for the time spent in the waiting room should be under the 10 minutes since it is the hospital standard.
Even though the optimal level would be of less than 10 minutes, the critical point is defined as above 20 minutes of waiting.
With the elimination of the sub-waiting it is expected that the total waiting time increases but it is important that the total time is still under the 20 minutes.

2. Efficiency Metrics:

Exam Rooms Performance
This metric and those that follow are helpful to guarantee a minimum level of exams performed that will allow the good service functioning.
For this reason, the scheduling rate should be maintained at a level of 85%. globally. This is not defined by doctor because of their different profiles, but it is assumed that the whole unit should perform at this level.
The level of the Occupation Rate should be above the level of 85%, globally and it is defined at the same way as the scheduling rate.
The Occupation Rate with not scheduled should be close to the scheduling rate to guarantee that some emergencies can be accounted and that fulfill the spots of the no-shows.
The goal is to guarantee that the exam rooms are at full functioning.
The Performance Rate is also reflected in the no-show rate presented below.

No-Show Rate
Even though there is not a certain level of no-show defined in the literature the No-show rate should be under 10%. To be more specific the no-show rate of the service should be in line with the hospital average.

Exam Room Turnaround
In this case the exam room turnaround can be compared to a minor surgery room turnaround considering a certain level of disinfection and sanitising.
This level is difficult to measure in this exam typology because of room changing but it should be under 5 minutes.

Delay of the first Exam of the day
It is defined globally at the hospital that the delay of first exams of the day or even first appointments, should be under 10 min. Therefore, what is measured at this point is the

percentage of first appointments of the day that is more than 10 minutes.
There is no specific goal for this metric but once again, this metric should be in line with the hospital average.

Registering System
This metric is just accounted to be sure that all the other metrics can be measured and that there is no information missing. Therefore, it is important to keep track of what is being recorded or not.
The failure modes defined for the Project 2 should be measured even if the project is not implemented. For this control all the fields should be made mandatory.

After all the KPI to control are defined the control plan will be set.

5.5.2 Control Plan Definition

For the success of an improvement project in the long run it is determinant to follow the processes and to monitor the KPI defined before. It is also important that this control plan has a named responsible to guarantee that it is accomplished.
The key activities of the control plan are:

1. Verify processes compliance
   There is a need to verify the change in behaviour that is necessary for the new processes implementation. There is also a resistance to change in new implementations and the staff is already used to a way of working that might need some changing in order to achieve these improvements.

2. Statistical Analysis
   In this phase, it is important to keep measuring the KPI defined in the last section. This measurement should be done with regular intervals of six months.

3. Critical Interventions
   When in the second phase it is identified that some of the metrics are not at the levels that they should, the interventions should be set to replace the metrics at the defined levels.

4. Staff regular training
   To respond to the continuous changing of staff and to the lack of systems knowledge, there should be a training program to maintain the level of knowledge specially in the CST category. The training programs should include a presentation about the processes and the softwares in practice.

All the control plan should be closed looked into and be followed carefully to maintain the sigma level simulated in the improve phase and try to improve it even more.

5.5.3 Future Works Proposal

It is important that the unit continues growing and that this growth doesn't affect its performance.
Some problems with potential for improvement were already identified through the document and they are now summarised:

- The Project 2 should be implemented to help the monitoring of the unit and to facilitate the daily tasks of all key users;
- All the online check-in implementations that were now discarded should be analysed in the future to understand if there is a margin for implementation after the Attendance Management System and the digital signature are implemented;
- There should be a further analysis on the patient identification inside the unit that is needed for the JCI requirements. "Give bracelet and Consent Form to Client" was identified as a critical activity and was not possible to eliminate yet;
- To finalise, it should be evaluated if this form of optimization can be extended for other special exams units even if the typology is significantly different.

In the end, if all these future works proposals are analysed, there should be a significant improvement in all the unit and possibly in other units if the project can be overstretched.

Chapter 6

Results and Conclusions

Finished the literature review and the LSS project with the DMAIC cycle implementation, some conclusions were taken of the present case study.

This project implementation supports the relevance of the LSS application in the healthcare sector. With the help of the data collection analysis and the processes definition, it was possible to identify the main sources of problems in the unit and which would be the places to act on. By means of the DMAIC cycle it was possible to achieve given improvements in a structured and logical way by following all steps.

Even without a continuous improvement philosophy in the organisation there was a strong support of the team to all the implementations needed, which led to an overall achievement of the main and specific goals. Knowing that some results are not visible at the current moment, it is still important to keep them in the long run.

This project had a significant impact for the unit at the phase of development that it was, and even if the sigma level achieved was low, the project increased the staff awareness to the level of efficiency that the unit can aim to, as well as growing improvement culture in the hospitals' teams.

The definition of control metrics was important to the management team to make decisions while the growing of the unit occurs. it was not possible to estimate monetary impacts but it is expected that the overall client experience is improved and that the revenue can also improve with that.

It became evident that the systems team has a big impact in all the hospital developments and that the team overload can impact not only this project development but also other hospital or group needs. For this reason, there is a strong will among the hospital staff to develop short term solutions that sometimes originate more problems, because they are not permanent solutions and they are not of everyone's knowledge.

The sigma level achieved, which is around 2, even if better than the primary sigma level,

it is not ideal and the hospital should aim for a continuous improvement policy where increasing the sigma level should be a priority. However, a sigma level of 2 is in line with other hospitals processes where the sigma level is estimated to be between 2 and 3.
Regarding the investigation questions mentioned in the proposed methodology, it was possible to understand that the main factors affecting the outpatient exam department effectiveness and productivity in this specific unit can be different than the ones found in the literature to be the ones affecting other hospital contexts like in the ER or in the OR. For all the KPI mentioned in the section 5.5 of the DMAIC cycle, the more relevant ones in this context are the LOS in the exam room and the time spent in the waiting room, as well as the delay of the first exam of the day, that will influence all the timings after this. Due to the delicacy of the pathologies treated in the unit, factors that can increase the clients' nerves and anxiety related to the topic are important influences on the clients' quality perception of the unit. The no-show and time of turnaround have shown to be not relevant to the case, even though they should continue to be monitored, in case they go out of what is expected.
The metric of the exam room performance rate can be related to the second question purposed. This metric has been in line with what is expected, but it should be improved after the restructuring of the scheduling system. This restructuring showed that the variability between the doctors performance is relevant, and should be used to enhance the scheduling rate by improving the amount of exams scheduled per day.
To conclude, even with a not ideal sigma level, the project was well succeeded, and all the goals were achieved. Knowing all the barriers and difficulties, the project had positive results and identified other sources of problems that can be improved in the future with other LSS project implementations.

Bibliography

Abid, M., Butt, O. M., Ann, Q., Rashid, B., & Sri Devi, N. (2020). Role of Critical Success factors (CSF) in the implementation of Six Sigma in hospitals: A preliminary study in Pakistan. *Asia Pacific Journal of Health Management*, *15*(1), 5–13. https://doi.org/10.24083/apjhm.v15i1.333 (cit. on pp. 3, 9)

Achterkamp, M. C., & Vos, J. F. (2008). Investigating the use of the stakeholder notion in project management literature, a meta-analysis. *International Journal of Project Management*, *26*(7), 749–757. https://doi.org/10.1016/j.ijproman.2007.10.001 (cit. on pp. 30, 34)

Ahmad Ansari, M. S. (2022). Lean Six Sigma in healthcare: some sobering thoughts on implementation. *Proceedings on Engineering Sciences*, *4*(4), 457–468. https://doi.org/10.24874/PES04.04.007 (cit. on p. 2)

Ajmi, F., Othman, S. B., Zgaya, H., Hammadi, S., & Renard, J.-M. (n.d.). An Innovative Approach to Jointly Scheduling and Assigning a Consultation Time to Patients Arriving in the Emergency Department (cit. on p. 17).

Al Sabahi, S. (2023). Characterizing No-shows in the Omani Primary Healthcare Setting. *Oman Medical Journal*, *38*(1), e457–e457. https://doi.org/10.5001/omj.2023.33 (cit. on p. 20)

Alfaro, C. R., Madrigal, G. B., & Hernández, M. C. (2020). Improving forensic processes performance: A Lean Six Sigma approach. *Forensic Science International: Synergy*, *2*, 90–94. https://doi.org/10.1016/j.fsisyn.2020.02.001 (cit. on p. 31)

Baek, H., Cho, M., Kim, S., Hwang, H., Song, M., & Yoo, S. (2018). Analysis of length of hospital stay using electronic health records: A statistical and data mining approach (T. Abe, Ed.). *PLOS ONE*, *13*(4), e0195901. https://doi.org/10.1371/journal.pone.0195901 (cit. on pp. 12, 24)

Baliga, S., Walvekar, P., & Mahantshetti, G. (2021). Concept map as a teaching and learning tool for medical students. *Journal of Education and Health Promotion*, *10*(1), 35. https://doi.org/10.4103/jehp.jehp_146_20 (cit. on p. 39)

Berg, B. P., Murr, M., Chermak, D., Woodall, J., Pignone, M., Sandler, R. S., & Denton, B. T. (2013). Estimating the Cost of No-Shows and Evaluating the Effects of Mitigation Strategies. *Medical Decision Making*, *33*(8), 976–985. https://doi.org/10.1177/0272989X13478194 (cit. on pp. 19, 22)

Bharsakade, R. S., Acharya, P., Ganapathy, L., & Tiwari, M. K. (2021). A lean approach to healthcare management using multi criteria decision making. *Opsearch*, *58*(3), 610–635. https://doi.org/10.1007/s12597-020-00490-5 (cit. on p. 2)

Bleustein, C., Rothschild, D. B., Valen, A., Valaitis, E., Schweitzer, L., & Jones, R. (2014). Wait Times, Patient Satisfaction Scores, and the Perception of Care. *The american journal of managed care*, *20*(5) (cit. on pp. 14, 15, 62).

Brennan, S., McKenzie, J. E., Whitty, P., Buchan, H., Green, S., Bosch, M., Fiander, M., Strobel, N. A., Donoghue, E., Page, M. J., Yost, J., & Gonçalves-Bradley, D. C. (2017). Continuous quality improvement: Effects on professional practice and healthcare outcomes in primary care (Cochrane Effective Practice and Organisation of Care Group, Ed.). *Cochrane Database of Systematic Reviews*. https://doi.org/10.1002/14651858.CD003319.pub3 (cit. on pp. 29, 30)

Brugha, R. (2000). Stakeholder analysis: A review. *Health Policy and Planning*, *15*(3), 239–246. https://doi.org/10.1093/heapol/15.3.239 (cit. on p. 33)

Buestan, M., & Perez, C. (2022). Identification of Predictive Nursing Workload Factors: A Six Sigma Approach. *Sustainability*, *14*(20), 13169. https://doi.org/10.3390/su142013169 (cit. on p. 12)

Burness, J. V., Schroeder, J. M., & Warren, J. B. (2020). Cervical Colposcopy:Indications and Risk Assessment. *102*(1) (cit. on p. 46).

Chapman, K. A., Machado, S. S., Van Der Merwe, K., Bryson, A., & Smith, D. (2022). Exploring Primary Care Non-Attendance: A Study of Low-Income Patients. *Journal of Primary Care & Community Health*, *13*, 215013192210823. https://doi.org/10.1177/21501319221082352 (cit. on p. 20)

Chen, P.-S., Chen, G. Y.-H., Liu, L.-W., Zheng, C.-P., & Huang, W.-T. (2022). Using Simulation Optimization to Solve Patient Appointment Scheduling and Examination Room Assignment Problems for Patients Undergoing Ultrasound Examination. *Healthcare*, *10*(1), 164. https://doi.org/10.3390/healthcare10010164 (cit. on p. 18)

Chu, H., Westbrook, R. A., Njue-Marendes, S., Giordano, T. P., & Dang, B. N. (2019). The psychology of the wait time experience – what clinics can do to manage the waiting experience for patients: A longitudinal, qualitative study. *BMC Health Services Research*, *19*(1), 459. https://doi.org/10.1186/s12913-019-4301-0 (cit. on p. 14)

Costa, R., Resende, T., Dias, A., Pereira, L., & Santos, J. (2020). Public Sector Shared Services and the Lean Methodology: Implications on Military Organizations. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(3), 78. https://doi.org/10.3390/joitmc6030078 (cit. on p. 33)

Crowe, S., Cresswell, K., Robertson, A., Huby, G., Avery, A., & Sheikh, A. (2011). The case study approach. *BMC Medical Research Methodology*, *11*(1), 100. https://doi.org/10.1186/1471-2288-11-100 (cit. on p. 4)

Daniels, J., Zweigenthal, V., & Reagon, G. (2017). Assessing the impact of a waiting time survey on reducing waiting times in urban primary care clinics in Cape Town, South Africa. *Journal of Public Health in Africa*, *8*(1). https://doi.org/10.4081/jphia.2017.639 (cit. on pp. 14, 16)

Daniyan, I., Adeodu, A., Mpofu, K., Maladzhi, R., & Kana-Kana Katumba, M. G. (2022). Application of lean Six Sigma methodology using DMAIC approach for the improvement of bogie assembly process in the railcar industry. *Heliyon*, *8*(3), e09043. https://doi.org/10.1016/j.heliyon.2022.e09043 (cit. on p. 28)

De Feo, J., William, B., & Institute, J. (2003). *Juran institute's six sigma breakthrough and beyond : Quality performance breakthrough methods: Quality performance breakthrough methods*. McGraw Hill Professional. (Cit. on p. 29).

de Barros, L. B., Bassi, L. d. C., Caldas, L. P., Sarantopoulos, A., Zeferino, E. B. B., Minatogawa, V., & Gasparino, R. C. (2021). Lean Healthcare Tools for Processes Evaluation: An Integrative Review. *International Journal of Environmental Research and Public Health*, *18*(14), 7389. https://doi.org/10.3390/ijerph18147389 (cit. on pp. 8, 10, 13, 31)

Dennis, P. (2015). *Lean production simplified: A plain-language guide to the world's most powerful production system* (3rd ed). CRC Press. (Cit. on p. 28).

Dinis, J., Portugal, C., Sousa, N., Fernandes, I., & Netto, E. (2021). Avaliação e monitorização dos rastreios oncologicos organizados de base populacional 2019/2020 – portugal [Last accessed 11 May 2021]. https://www.ffms.pt/sites/default/files/2022-07/i028766.pdf. (Cit. on pp. 3, 45)

Eckes, G. (2001). *The six sigma revolution: How general electric and others turned process into profits*. Wiley. (Cit. on p. 29).

Elfil, M., & Negida, A. (n.d.). Sampling methods in Clinical Research; an Educational Review (cit. on p. 35).

Ertürk, M., Tuerdi(Maimaitiaili. Tuerdi), M., & Wujiabudula, A. (2016). The Effects of Six Sigma Approach on Business Performance: A Study of White Goods (Home Appliances) Sector in Turkey. *Procedia - Social and Behavioral Sciences*, *229*, 444–452. https://doi.org/10.1016/j.sbspro.2016.07.154 (cit. on p. 31)

Ferreira, C., Sá, J., Ferreira, L., Lopes, M., Pereira, T., Ferreira, L., & Silva, F. (2019). iLeanDMAIC – A methodology for implementing the lean tools. *Procedia Manufacturing*, *41*, 1095–1102. https://doi.org/10.1016/j.promfg.2019.10.038 (cit. on pp. 11, 31)

Fetene, D., Tekalegn, Y., Abdela, J., Aynalem, A., Bekele, G., & Molla, E. (2022). *Prolonged Length of hospital stay and associated factors among patients admitted at a surgical ward in selected public hospitals Arsi zone, Oromia, Ethiopia, 2022* (preprint). Health Systems and Quality Improvement. https://doi.org/10.1101/2022.10.18.22281234. (Cit. on p. 24)

Gavriloff, C., Ostrowski-Delahanty, S., & Oldfield, K. (n.d.). The Impact of Lean Six Sigma Methodology on Patient Scheduling (cit. on p. 14).

Gleeson, F., Coughlan, P., Goodman, L., Newell, A., & Hargaden, V. (2019). Improving manufacturing productivity by combining cognitive engineering and lean-six sigma methods. *Procedia CIRP*, *81*, 641–646. https://doi.org/10.1016/j.procir.2019.03.169 (cit. on p. 28)

Hardie, M., & Saha, S. (2012). Builders' Perceptions of Lowest Cost Procurement and Its Impact on Quality. *Construction Economics and Building*, *9*(1), 1–8. https://doi.org/10.5130/AJCEB.v9i1.3009 (cit. on p. 30)

Hicks, K. B., Glaser, K., Scott, C., Sparks, D., & McHenry, C. R. (2020). Enumerating the causes and burden of first case operating room delays. *The American Journal of Surgery*, *219*(3), 486–489. https://doi.org/10.1016/j.amjsurg.2019.09.016 (cit. on p. 23)

Holtz, R., & Campbell, P. (2003). Six Sigma: Its implementation in Ford's facility management and maintenance functions. *Journal of Facilities Management*, *2*(4), 320–329. https://doi.org/10.1108/14725960410808285 (cit. on p. 32)

Höög, E., Lysholm, J., Garvare, R., Weinehall, L., & Nyström, M. E. (2016). Quality improvement in large healthcare organizations: Searching for system-wide and coherent monitoring and follow-up strategies. *Journal of Health Organization and Management*, *30*(1), 133–153. https://doi.org/10.1108/JHOM-10-2013-0209 (cit. on p. 8)

Improta, G., Balato, G., Romano, M., Ponsiglione, A. M., Raiola, E., Russo, M. A., Cuccaro, P., Santillo, L. C., & Cesarelli, M. (2017). Improving performances of the knee replacement surgery process by applying DMAIC principles. *Journal of Evaluation in Clinical Practice*, *23*(6), 1401–1407. https://doi.org/10.1111/jep.12810 (cit. on p. 12)

Improta, G., Cesarelli, M., Montuori, P., Santillo, L. C., & Triassi, M. (2018). Reducing the risk of healthcare-associated infections through Lean Six Sigma: The case of the medicine areas at the Federico II University Hospital in Naples (Italy). *Journal of Evaluation in Clinical Practice*, *24*(2), 338–346. https://doi.org/10.1111/jep.12844 (cit. on pp. 1, 2)

Improta, G., Guizzi, G., Ricciardi, C., Giordano, V., Ponsiglione, A. M., Converso, G., & Triassi, M. (2020). Agile Six Sigma in Healthcare: Case Study at Santobono Pediatric Hospital. *International Journal of Environmental Research and Public Health*, *17*(3), 1052. https://doi.org/10.3390/ijerph17031052 (cit. on p. 1)

Kaplan-Lewis, E., & Percac-Lima, S. (n.d.). No-Show to Primary Care Appointments: Why Patients Do Not Come. *Community Health*. https://doi.org/10.1177/2150131913498513 (cit. on p. 20)

Kiran, D. (2017). The Seven Modern Tools of TQM. In *Total Quality Management* (pp. 291–311). Elsevier. https://doi.org/10.1016/B978-0-12-811035-5.00021-0. (Cit. on pp. 38, 39)

Knudsen, S. V., Laursen, H. V. B., Johnsen, S. P., Bartels, P. D., Ehlers, L. H., & Mainz, J. (2019). Can quality improvement improve the quality of care? A systematic

review of reported effects and methodological rigor in plan-do-study-act projects. *BMC Health Services Research*, *19*(1), 683. https://doi.org/10.1186/s12913-019-4482-6 (cit. on p. 7)

Kobo-Greenhut, A., Holzman, K., Raviv, O., Arad, J., & Ben Shlomo, I. (2021). Applying health-six-sigma principles helps reducing the variability of length of stay in the emergency department. *International Journal for Quality in Health Care*, *33*(2), mzab086. https://doi.org/10.1093/intqhc/mzab086 (cit. on p. 25)

Kumar, S. (1999). Force field analysis: Applications in PRA. (36) (cit. on p. 34).

Lal Bhaskar, H. (2020). Lean Six Sigma in Manufacturing: A Comprehensive Review. In F. Pedro García Márquez, I. Segovia Ramirez, T. Bányai, & P. Tamás (Eds.), *Lean Manufacturing and Six Sigma - Behind the Mask*. IntechOpen. https://doi.org/10.5772/intechopen.89859. (Cit. on pp. 29, 30)

Lamm, M. H., Eckel, S., Daniels, R., & Amerine, L. B. (2015). Using lean principles to improve outpatient adult infusion clinic chemotherapy preparation turnaround times. *American Journal of Health-System Pharmacy*, *72*(13), 1138–1146. https://doi.org/10.2146/ajhp140453 (cit. on p. 22)

Li Huang, Y. (2016). The Development of Patient Scheduling Groups for an Effective Appointment System. *Applied Clinical Informatics*, *07*(01), 43–58. https://doi.org/10.4338/ACI-2015-08-RA-0097 (cit. on p. 18)

Lin, P.-Y., Chen, K.-Y., Cheng, C.-Y., Su, W.-H., & Lu, L. Y. Y. (2022). The Academic Development Trajectories of the Lean Production Based on Main Path Analysis Method. *Processes*, *10*(8), 1495. https://doi.org/10.3390/pr10081495 (cit. on p. 9)

Lourenço, J. M. (2021). *The NOVAthesis LaTeX Template User's Manual*. NOVA University Lisbon. https://github.com/joaomlourenco/novathesis/raw/master/template.pdf. (Cit. on p. iii)

Mansur dos Reis, M. E. D., de Abreu, M. F., Neto, O. d. O. B., Viera, L. E. V., Torres, L. F., & Calado, R. D. (2022). DMAIC in improving patient care processes: Replication and Lessons learned in context of healthcare. *IFAC-PapersOnLine*, *55*(10), 549–554. https://doi.org/10.1016/j.ifacol.2022.09.451 (cit. on p. 13)

Marbouh, D., Khaleel, I., Al Shanqiti, K., Al Tamimi, M., Simsekler, M. C. E., Ellahham, S., Alibazoglu, D., & Alibazoglu, H. (2020). Evaluating the Impact of Patient No-Shows on Service Quality. *Risk Management and Healthcare Policy*, *Volume 13*, 509–517. https://doi.org/10.2147/RMHP.S232114 (cit. on p. 20)

Marriott, B., Arturo Garza-Reyes, J., Soriano-Meier, H., & Antony, J. (2013). An integrated methodology to prioritise improvement initiatives in low volume-high integrity product manufacturing organisations. *Journal of Manufacturing Technology Management*, *24*(2), 197–217. https://doi.org/10.1108/17410381311292304 (cit. on p. 39)

Marzagão, D. S. L., & Carvalho, M. M. (2016). Critical success factors for Six Sigma projects. *International Journal of Project Management*, *34*(8), 1505–1518. https://doi.org/10.1016/j.ijproman.2016.08.005 (cit. on pp. 9, 28)

McDermott, O., Antony, J., Bhat, S., Jayaraman, R., Rosa, A., Marolla, G., & Parida, R. (2022). Lean Six Sigma in Healthcare: A Systematic Literature Review on Challenges, Organisational Readiness and Critical Success Factors. *Processes*, *10*(10), 1945. https://doi.org/10.3390/pr10101945 (cit. on p. 9)

Mishra, P., & Kumar Sharma, R. (2014). A hybrid framework based on SIPOC and Six Sigma DMAIC for improving process dimensions in supply chain network. *International Journal of Quality & Reliability Management*, *31*(5), 522–546. https://doi.org/10.1108/IJQRM-06-2012-0089 (cit. on p. 35)

Mistarihi, M. Z., AL-Tahat, M. D., & AL-Nimer, S. H. (2023). Improving Process Efficiency at Pediatric Hospital Emergency Department Using an Integrated Six-Sigma Simulation Methodology. *Processes*, *11*(2), 399. https://doi.org/10.3390/pr11020399 (cit. on pp. 8, 12)

Montgomery, D. (2009). *Introduction to statistical quality control, sixth edition* (6th ed). John Wiley Sons, Inc. (Cit. on p. 32).

Ogaji, D., & Mezie-Okoye, M. (2017). Waiting time and patient satisfaction: Survey of patients seeking care at the general outpatient clinic of the University of Port Harcourt Teaching Hospital. *Port Harcourt Medical Journal*, *11*(3), 148. https://doi.org/10.4103/phmj.phmj_41_17 (cit. on p. 74)

O'Mahony, L., McCarthy, K., O'Donoghue, J., Teeling, S. P., Ward, M., & McNamara, M. (2021). Using Lean Six Sigma to Redesign the Supply Chain to the Operating Room Department of a Private Hospital to Reduce Associated Costs and Release Nursing Time to Care. *International Journal of Environmental Research and Public Health*, *18*(21), 11011. https://doi.org/10.3390/ijerph182111011 (cit. on p. 2)

Oostrom, T., Einav, L., & Finkelstein, A. (2017). Outpatient Office Wait Times And Quality Of Care For Medicaid Patients. *Health Affairs*, *36*(5), 826–832. https://doi.org/10.1377/hlthaff.2016.1478 (cit. on pp. 14, 20)

Ortíz-Barrios, M. A., & Alfaro-Saíz, J.-J. (2020). Methodological Approaches to Support Process Improvement in Emergency Departments: A Systematic Review. *International Journal of Environmental Research and Public Health*, *17*(8), 2664. https://doi.org/10.3390/ijerph17082664 (cit. on p. 30)

Pakdil, F. (2020). *Six Sigma for Students: A Problem-Solving Methodology*. Springer International Publishing. https://doi.org/10.1007/978-3-030-40709-4. (Cit. on p. 34)

Pedro, A., Pacheco, A., Sousa, R., Mendinhos, G., Miranda, M., Urzal, C., Monteiro, V., Fraga, T., Pereira da Silva, D., Paula, T., Oliveira, I., Cabral, J., & Fonseca Moutinho, J. (2023). Orientações de Consenso para a Abordagem dos Resultados Alterados nos Testes de Rastreio do Cancro do Colo do útero pela SPCPTGI. *Acta Médica Portuguesa*. https://doi.org/10.20344/amp.18776 (cit. on pp. 3, 45)

Pereira, M., Bento, M. I., Ferreira, L., Sá, J., Silva, F., & Baptista, A. (2019). Using Six Sigma to analyse Customer Satisfaction at the product design and development stage.

Procedia Manufacturing, *38*, 1608–1614. https://doi.org/10.1016/j.promfg.2020.01.124 (cit. on p. 28)

Pourhoseingholi, M. A., Vahedi, M., & Rahimzadeh, M. (n.d.). Sample size calculation in medical studies (cit. on p. 36).

Pourmohammadi, K., Hatam, N., Shojaei, P., & Bastani, P. (2018). A comprehensive map of the evidence on the performance evaluation indicators of public hospitals: A scoping study and best fit framework synthesis. *Cost Effectiveness and Resource Allocation*, *16*(1), 64. https://doi.org/10.1186/s12962-018-0166-z (cit. on p. 24)

Pugna, A., Negrea, R., & Miclea, S. (2016). Using Six Sigma Methodology to Improve the Assembly Process in an Automotive Company. *Procedia - Social and Behavioral Sciences*, *221*, 308–316. https://doi.org/10.1016/j.sbspro.2016.05.120 (cit. on p. 28)

Pyzdek, T., & Keller, P. A. (2010). *The Six Sigma handbook: A complete guide for green belts, black belts, and managers at all levels* (3rd ed) [OCLC: 463295960]. McGraw-Hill Companies. (Cit. on pp. 30, 32, 35–37, 39, 40).

Recker, J. (2010). Opportunities and constraints: The current struggle with BPMN. *Business Process Management Journal*, *16*(1), 181–201. https://doi.org/10.1108/14637151011018001 (cit. on p. 33)

Requeijo, J., & Pereira, Z. (2012). *Qualidade: Planeamento e controlo estatístico de processos* (2ª). Fundação da Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa. (Cit. on pp. 37, 38).

Rodgers, M., & Oppenheim, R. (2019). Ishikawa diagrams and Bayesian belief networks for continuous improvement applications. *The TQM Journal*, *31*(3), 294–318. https://doi.org/10.1108/TQM-11-2018-0184 (cit. on p. 38)

Rosa, A., Trunfio, T. A., Marolla, G., Costantino, A., Nardella, D., & McDermott, O. (2023). Lean Six Sigma to reduce the acute myocardial infarction mortality rate: A single center study. *The TQM Journal*, *35*(9), 25–41. https://doi.org/10.1108/TQM-03-2022-0082 (cit. on pp. 11, 13)

Runeson, P., & Höst, M. (2009). Guidelines for conducting and reporting case study research in software engineering. *Empirical Software Engineering*, *14*(2), 131–164. https://doi.org/10.1007/s10664-008-9102-8 (cit. on p. 4)

Sabry, A. (2014). Factors critical to the success of Six-Sigma quality program and their influence on performance indicators in some of Lebanese hospitals. *Arab Economic and Business Journal*, *9*(2), 93–114. https://doi.org/10.1016/j.aebj.2014.07.001 (cit. on p. 28)

Schretlen, S., Hoefsmit, P., Kats, S., van Merode, G., Maessen, J., & Zandbergen, R. (2021). Reducing surgical cancellations: A successful application of Lean Six Sigma in healthcare. *BMJ Open Quality*, *10*(3), e001342. https://doi.org/10.1136/bmjoq-2021-001342 (cit. on p. 2)

Shankar, R. (2009). *Process improvement using Six Sigma: A DMAIC guide*. ASQ Quality Press. (Cit. on pp. 39, 40).

Shi, Z.-Y., Huang, P.-H., Chen, Y.-C., Huang, H.-M., Chen, Y.-F., Chen, I.-C., Sheen, Y.-J., Shen, C.-H., Hon, J.-S., & Huang, C.-Y. (2022). Sustaining Improvements of Surgical Site Infections by Six Sigma DMAIC Approach. *Healthcare*, *10*(11), 2291. https://doi.org/10.3390/healthcare10112291 (cit. on pp. 3, 12)

Singh, M., & Rathi, R. (2019). A structured review of Lean Six Sigma in various industrial sectors. *International Journal of Lean Six Sigma*, *10*(2), 622–664. https://doi.org/10.1108/IJLSS-03-2018-0018 (cit. on p. 30)

Sohal, A., De Vass, T., Vasquez, T., Bamber, G. J., Bartram, T., & Stanton, P. (2022). Success factors for lean six sigma projects in healthcare. *Journal of Management Control*, *33*(2), 215–240. https://doi.org/10.1007/s00187-022-00336-9 (cit. on p. 9)

Sujova, A., Simanova, L., & Marcinekova, K. (2016). Sustainable Process Performance by Application of Six Sigma Concepts: The Research Study of Two Industrial Cases. *Sustainability*, *8*(3), 260. https://doi.org/10.3390/su8030260 (cit. on p. 32)

Świderska-Kiec, J., Czajkowski, K., Zaręba-Szczudlik, J., Kacperczyk-Bartnik, J., Bartnik, P., & Romejko-Wolniewicz, E. (2020). Comparison of HPV Testing and Colposcopy in Detecting Cervical Dysplasia in Patients With Cytological Abnormalities. *In Vivo*, *34*(3), 1307–1315. https://doi.org/10.21873/invivo.11906 (cit. on p. 45)

Teeling, S. P., Dewing, J., & Baldie, D. (2021). A Realist Inquiry to Identify the Contribution of Lean Six Sigma to Person-Centred Care and Cultures. *International Journal of Environmental Research and Public Health*, *18*(19), 10427. https://doi.org/10.3390/ijerph181910427 (cit. on p. 9)

Teo, A. R., Niederhausen, M., Handley, R., Metcalf, E. E., Call, A. A., Jacob, R. L., Zikmund-Fisher, B. J., Dobscha, S. K., & Kaboli, P. J. (2023). Using Nudges to Reduce Missed Appointments in Primary Care and Mental Health: A Pragmatic Trial. *Journal of General Internal Medicine*, *38*(S3), 894–904. https://doi.org/10.1007/s11606-023-08131-5 (cit. on p. 21)

Thomas, J. (1985). Force field analysis: A new way to evaluate your strategy. *Long Range Planning*, *18*(6), 54–59. https://doi.org/10.1016/0024-6301(85)90064-0 (cit. on p. 34)

Thompson, D. A., Yarnold, P. R., Williams, D. R., & Adams, S. L. (1996). Effects of Actual Waiting Time, Perceived Waiting Time, Information Delivery, and Expressive Quality on Patient Satisfaction in the Emergency Department. *Annals of Emergency Medicine*, *28*, 657–665. https://doi.org/10.1016/S0196-0644(96)70090-2 (cit. on pp. 14, 16)

Tipton, K., Leas, B. F., Mull, N. K., Siddique, S. M., Greysen, S. R., Lane-Fall, M. B., & Tsou, A. Y. (2021). *Interventions To Decrease Hospital Length of Stay* (tech. rep.). Agency for Healthcare Research and Quality (AHRQ). https://doi.org/10.23970/AHRQEPCTB40. (Cit. on pp. 12, 24, 25)

Tlapa, D., Tortorella, G., Fogliatto, F., Kumar, M., Mac Cawley, A., Vassolo, R., Enberg, L., & Baez-Lopez, Y. (2022). Effects of Lean Interventions Supported by Digital Technologies on Healthcare Services: A Systematic Review. *International Journal*

of Environmental Research and Public Health, *19*(15), 9018. https://doi.org/10.3390/ijerph19159018 (cit. on pp. 2, 10, 12)

Tufail, M. M. B., Shamim, A., Ali, A., Ibrahim, M., Mehdi, D., & Nawaz, W. (2022). DMAIC methodology for achieving public satisfaction with health departments in various districts of Punjab and optimizing CT scan patient load in urban city hospitals. *AIMS Public Health*, *9*(2), 440–457. https://doi.org/10.3934/publichealth.2022030 (cit. on p. 12)

Uakarn, C., Chaokromthong, K., & Sintao, N. (n.d.). Sample Size Estimation using Yamane and Cochran and Krejcie and Morgan and Green Formulas and Cohen Statistical Power Analysis by G*Power and Comparisons (cit. on p. 36).

Valero-Bover, D., González, P., Carot-Sans, G., Cano, I., Saura, P., Otermin, P., Garcia, C., Gálvez, M., Lupiáñez-Villanueva, F., & Piera-Jiménez, J. (2022). Reducing non-attendance in outpatient appointments: Predictive model development, validation, and clinical assessment. *BMC Health Services Research*. https://doi.org/https://doi.org/10.1186/s12913-022-07865-y (cit. on p. 21)

Van Zyl-Cillié, M., Demirtas, D., & Hans, E. (2023). Wait!What does that mean?: Eliminating ambiguity of delays in healthcare from an OR/MS perspective. *Health Systems*, *12*(1), 3–21. https://doi.org/10.1080/20476965.2021.2018362 (cit. on p. 23)

Vilasini, N., Neitzert, T., & Rotimi, J. (2014). Developing and evaluating a framework for process improvement in an alliance project: A New Zealand case study. *Construction Management and Economics*, *32*(6), 625–640. https://doi.org/10.1080/01446193.2013.874565 (cit. on p. 31)

Voehl, F., Harrington, H. J., Mignosa, C., & Charron, R. (2013). *The Lean Six Sigma Black Belt Handbook: Tools and Methods for Process Acceleration* (0th ed.). Productivity Press. https://doi.org/10.1201/b15163. (Cit. on p. 35)

Wackers, E., Stadhouders, N., Heil, A., Westert, G., Van Dulmen, S., & Jeurissen, P. (2021). Hospitals Bending the Cost Curve With Increased Quality: A Scoping Review Into Integrated Hospital Strategies. *International Journal of Health Policy and Management*, 1. https://doi.org/10.34172/ijhpm.2021.168 (cit. on p. 8)

Williams, S. J., & Best, S. (2022). What Does a Systems Approach to Quality Improvement Look Like in Practice? *International Journal of Environmental Research and Public Health*, *19*(2), 747. https://doi.org/10.3390/ijerph19020747 (cit. on p. 8)

Wilson, L. (2010). *How to implement lean manufacturing* [OCLC: 436878091]. McGraw-Hill. (Cit. on p. 27).

Wojtyla, C., Janik-Koncewicz, K., & La Vecchia, C. (2020). Cervical cancer mortality in young adult European women. *European Journal of Cancer*, *126*, 56–64. https://doi.org/10.1016/j.ejca.2019.11.018 (cit. on pp. 3, 45)

Yan, C., Huang, G. G., Kuo, Y.-H., & Tang, J. (2022). Dynamic appointment scheduling for outpatient clinics with multiple physicians and patient choice. *Journal of Management Science and Engineering*, *7*, 19–35. https://doi.org/10.1016/j.jmse.2021.02.002 (cit. on p. 17)

Yang, C.-C., Jou, Y.-T., Lin, M.-C., Silitonga, R. M., & Sukwadi, R. (2022). The Development of the New Process of Design for Six Sigma (DFSS) and Its Application. *Sustainability*, *14*. https://doi.org/10.3390/su14159294 (cit. on p. 32)

Zhu, L.-F., Qian, W.-Y., Zhou, G., Yang, M., Lin, J.-J., Jin, J.-L., Dong, S.-J., Zhu, L.-H., & Chen, H.-X. (2020). Applying Lean Six Sigma to Reduce the Incidence of Unplanned Surgery Cancellation at a Large Comprehensive Tertiary Hospital in China. *INQUIRY: The Journal of Health Care Organization, Provision, and Financing*, *57*, 004695802095399. https://doi.org/10.1177/0046958020953997 (cit. on p. 3)

APPENDIX

DATA SET

Table A.1: Data Set 1 - Administrative Software

Date	Time Scheduled	Doctor	Status of Scheduling	Type of Scheduling	Procedure	Time of Arrival	Time of Entry	Time of Exit
03.01	09:00	D9	V	S	P8	09:08	09:19	09:57
03.01	10:30	D9	V	S	P11	10:36	10:36	11:54
03.01	11:00	D9	V	S	P4	12:04	12:04	14:10
03.01	11:30	D9	V	S	P4	11:29	11:48	12:04
03.01	12:00	D9	C	S	P4	SAMS Quadros	12:06	12:39
03.01	14:15	D5	V	NS	P5	13:15	14:17	15:01
03.01	14:30	D5	V	S	P4	14:09	15:01	15:22
03.01	16:00	D5	V	S	P4	15:58	16:06	16:25
03.01	16:30	D5	V	S	P8	16:39	16:44	18:03
03.01	17:30	D5	V	S	P4	17:41	17:45	18:03
03.01	18:30	D5	V	S	P4	17:46	18:03	19:49
03.01	19:00	D5	V	NS	P8	18:58	19:04	19:32
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮								
30.12	09:00	D5	V	NS	P4	08:59	09:29	09:35
30.12	09:15	D5	V	NS	P4	09:51	10:27	11:00
30.12	09:30	D5	V	NS	P4	09:12	09:35	10:00
30.12	10:030	D5	V	NS	P1	10:19	11:03	11:33
30.12	11:00	D5	V	NS	P4	10:31	11:33	11:51
30.12	11:15	D5	V	NS	P6	10:59	11:51	12:18
30.12	11:30	D5	V	NS	P4	11:29	12:18	12:29
30.12	13:00	D5	V	S	P4	13:05	13:27	13:47
30.12	14:00	D5	V	S	P4	14:08	14:41	14:42
30.12	14:15	D5	V	NS	P4	13:37	13:47	14:41
30.12	14:30	D5	V	S	P4	14:29	14:50	15:05
30.12	15:00	D5	V	S	P4	14:36	15:05	15:30
30.12	15:15	D5	V	NS	P4	15:05	15:30	15:52

All the information is related to the year of 2022.

Table A.2: Data Set 1 - Clinical Software

Date	Doctor	Nurse	Exam Room Entry	Anaesthesia Beginning	Intervention Beginning	End of Anaesthesia	End of Intervention	Exam Room Exit
03.01	D9	N1	09:20	09:21		09:40	09:42	09:45
03.01	D9	N1	10:40			11:10		11:10
03.01	D9	N1	12:00			12:20		12:20
03.01	D9	N1	11:50			12:00		12:00
03.01	D9	N1	12:49			13:00		13:00
03.01	D5	N1	14:20	14:21		14:54	14:55	14:56
03.01	D5	N1	14:58			15:10		15:15
03.01	D5	N2	16:08			16:15		16:16
03.01	D5	N2	16:52			16:55		16:55
03.01	D5	N2	17:48			17:55		17:55
03.01	D5	N2	18:07			18:12		18:12
03.01	D5	N2	19:09			19:33		19:33
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
30.12	D5	N2	09:20			09:28		09:28
30.12	D5	N2	10:33			10:52		10:52
30.12	D5	N2	09:44			09:54		09:54
30.12	D5	N2	11:00	11:01		11:25	11:26	11:27
30.12	D5	N2						
30.12	D5	N2	11:50	11:51		12:14	12:15	12:16
30.12	D5	N2	12:18			12:28		12:28
30.12	D5	N2	13:33			13:42		13:42
30.12	D5	N2	14:30			14:39		14:39
30.12	D5	N2	13:48			14:00		14:00
30.12	D5	N2	14:48			14:59		14:59
30.12	D5	N2	15:12			15:20		15:20
30.12	D5	N2						

All the information is related to the year of 2022.

Table A.3: Data Set 2 Gathering - Example of the stratified random sample obtained by direct observation of the author

Exam Room	Doc.	Date	Procedure	Time Scheduled	Check In	Arrival at the Sub-Waiting	Entry Pre-Exam Appoint.	Exit Pre-Exam Appoint.	Exam Entry	Exam Exit	Entry Post-Exam Appoint.	Exit Post-Exam Appoint.
2	D1	23.05	P4	14:00	13:10	14:14			14:24	14:49		
2	D1	23.05	P4	14:30	14:08	14:25			14:50	15:07		
2	D1	23.05	P4	15:00	14:21	15:07			15:11	15:32		
2	D1	23.05	P4	15:30	15:30	15:33			15:38	15:54		
1	D6	23.05	P4	14:00	13:54	14:30	14:33	14:35	14:38	14:44	14:46	14:58
1	D6	23.05	P4	15:00	15:19	15:26	15:26	15:31	15:35	15:46	15:47	15:53
1	D6	23.05	P4	15:30	15:33	15:35	15:56	15:57	16:01	16:07	16:10	16:14
1	D6	23.05	P4	16:30	15:58	16:07	16:17	16:21	16:27	16:41	16:44	17:04
1	D6	23.05	P4	17:00	17:03	17:06	17:08	17:09	17:13	17:20	17:22	17:30
2	D2	24.05	P4	12:00	12:14	12:24			12:38	12:55		
2	D2	24.05	P4	12:30	12:19	12:38			12:58	13:00		
2	D2	24.05	P4	13:00	12:23	12:59			13:15	13:43		
1	D3	24.05	P4	11:10	12:00	12:38	12:46	12:49	12:49	12:58	13:01	13:08
1	D4	24.05	P4	15:40	14:50	15:55			16:02	16:05	16:07	16:08
1	D4	24.05	P11	16:20	16:25	16:31			16:35	16:47	16:49	16:051
1	D4	24.05	P4	16:40	16:33	16:44			16:54	17:01	17:04	17:08
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1	D3	21.07	P5	10:00	09:48	10:04			10:35	10:58	11:02	11:11
1	D3	21.07	P4	11:00	10:55	11:04	11:18	11:26	11:34	11:51	11:54	12:01
1	D3	21.07	P4	11:30	09:48	11:44	12:02	12:09	12:11	12:27	12:31	12:37
1	D3	21.07	P4	12:30	12:24	12:29	12:41	12:43	12:44	13:01	13:03	13:07
2	D2	21.07	P3	10:00	09:31	10:10			10:24	10:33		
2	D2	21.07	P4	10:30	10:14	10:29			10:41	10:58		
2	D2	21.07	P4	11:00	10:45	10:50			10:59	11:13		
2	D2	21.07	P4	11:30	10:43	11:10			11:38	12:00		
2	D2	21.07	P4	12:00	10:57	11:44			12:00	12:16		
2	D2	21.07	P4	12:15	11:52	12:06			12:19	12:34		
2	D2	21.07	P4	12:30	12:23	12:27			12:38	12:54		

All the information is related to the year of 2023.

Appendix B

Processes Diagrams: To Be

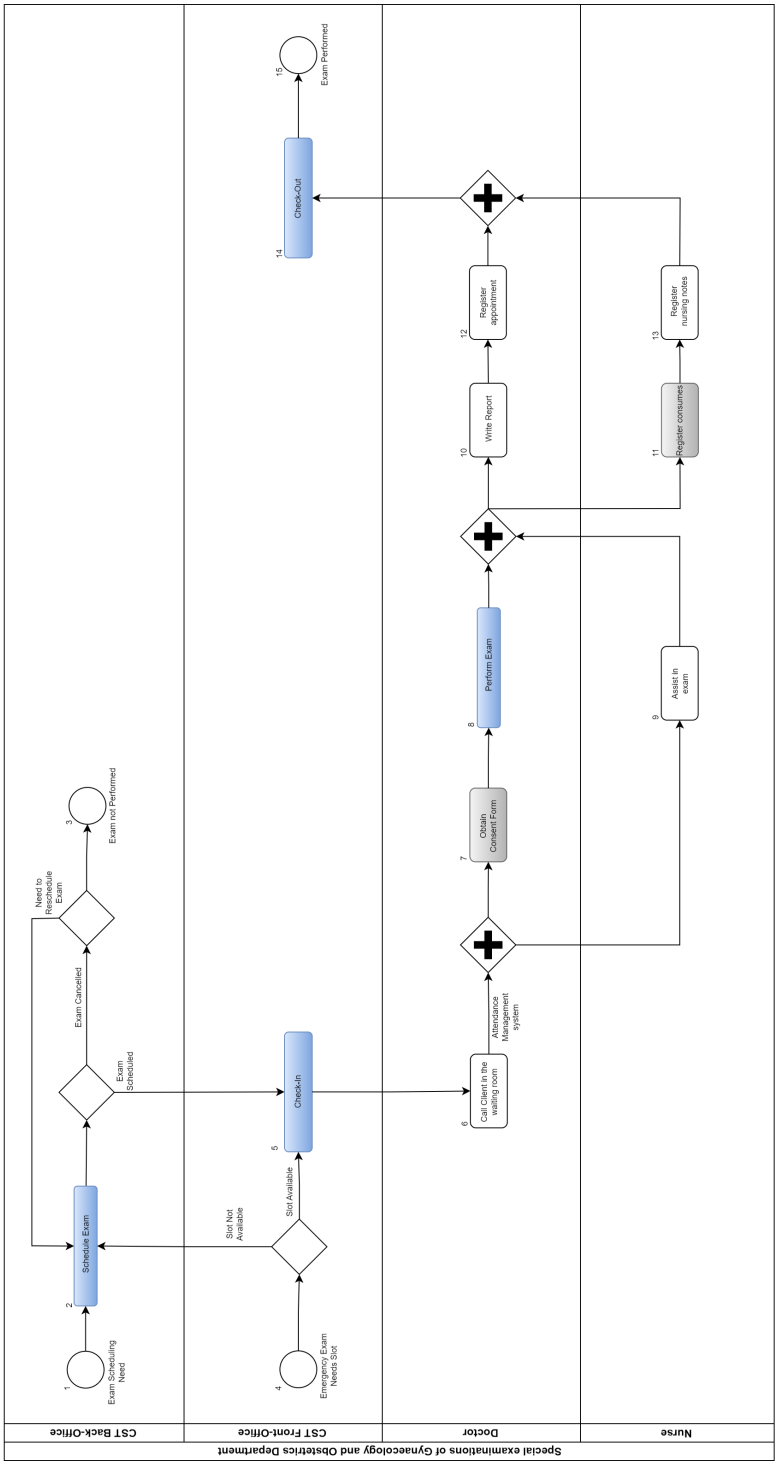


Figure B.1: BPMN To Be: Macro Process

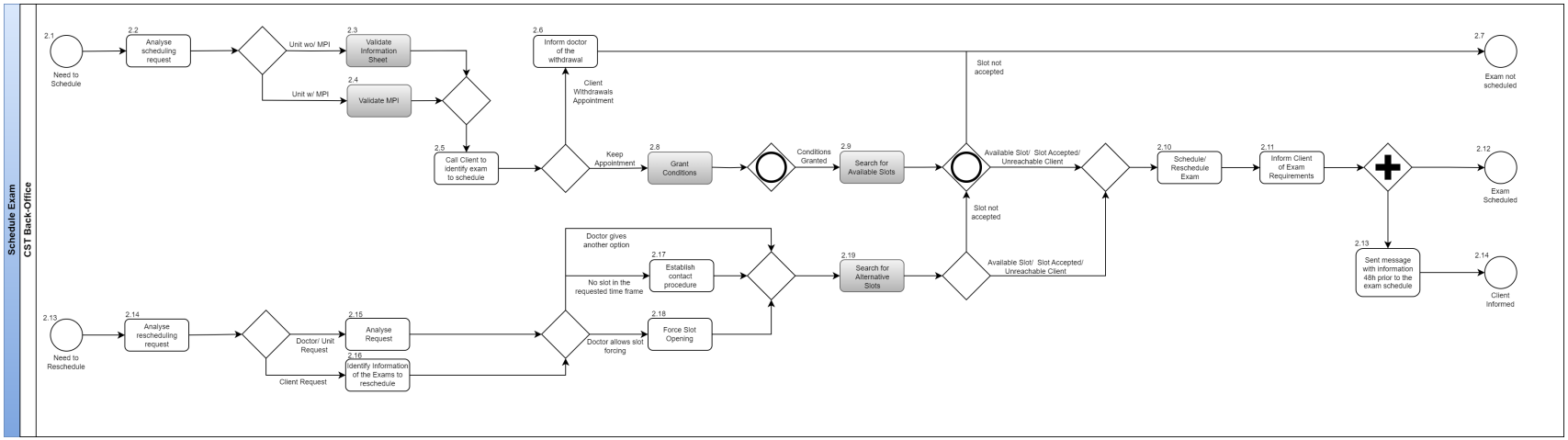


Figure B.2: BPMN To Be:2. Schedule Exam

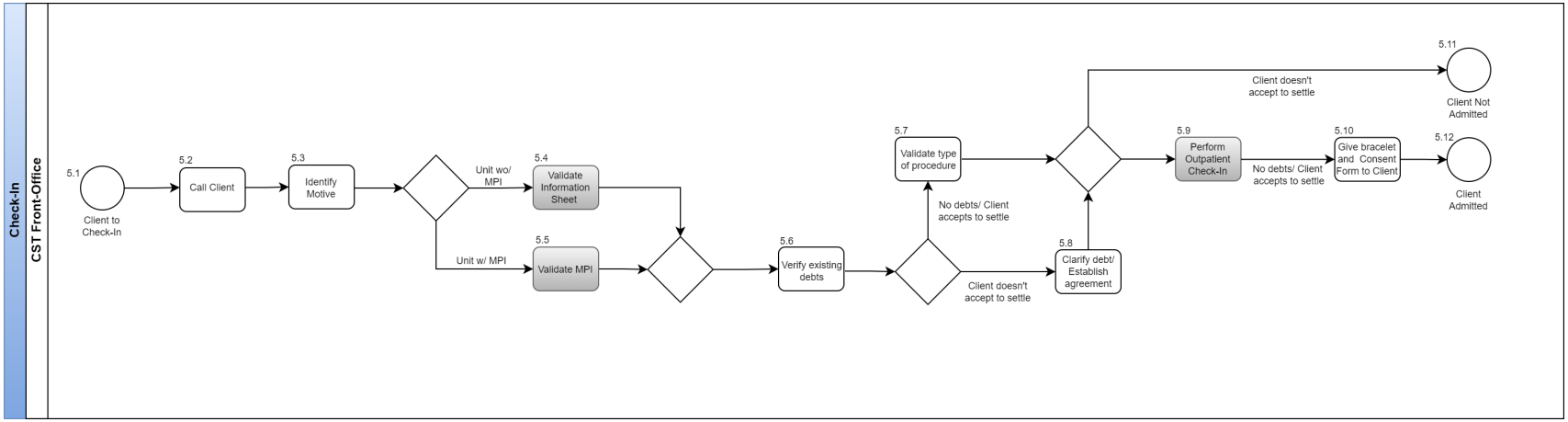


Figure B.3: BPMN To Be: 5. Check-In

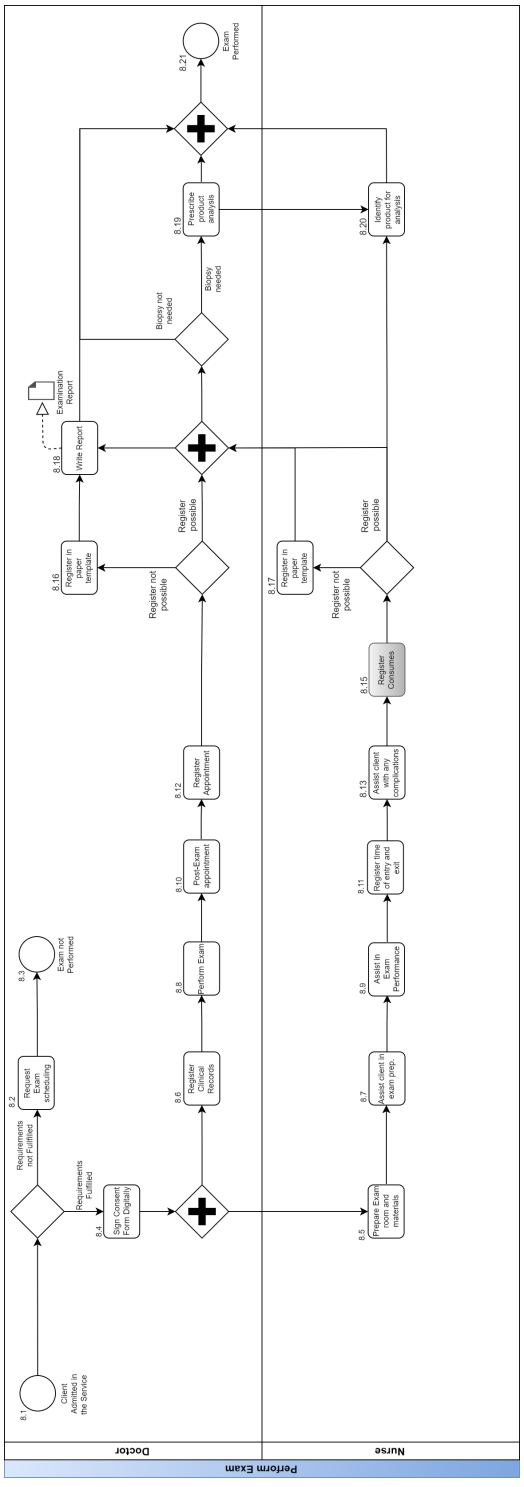


Figure B.4: BPMN To Be: 8. Perform Exam

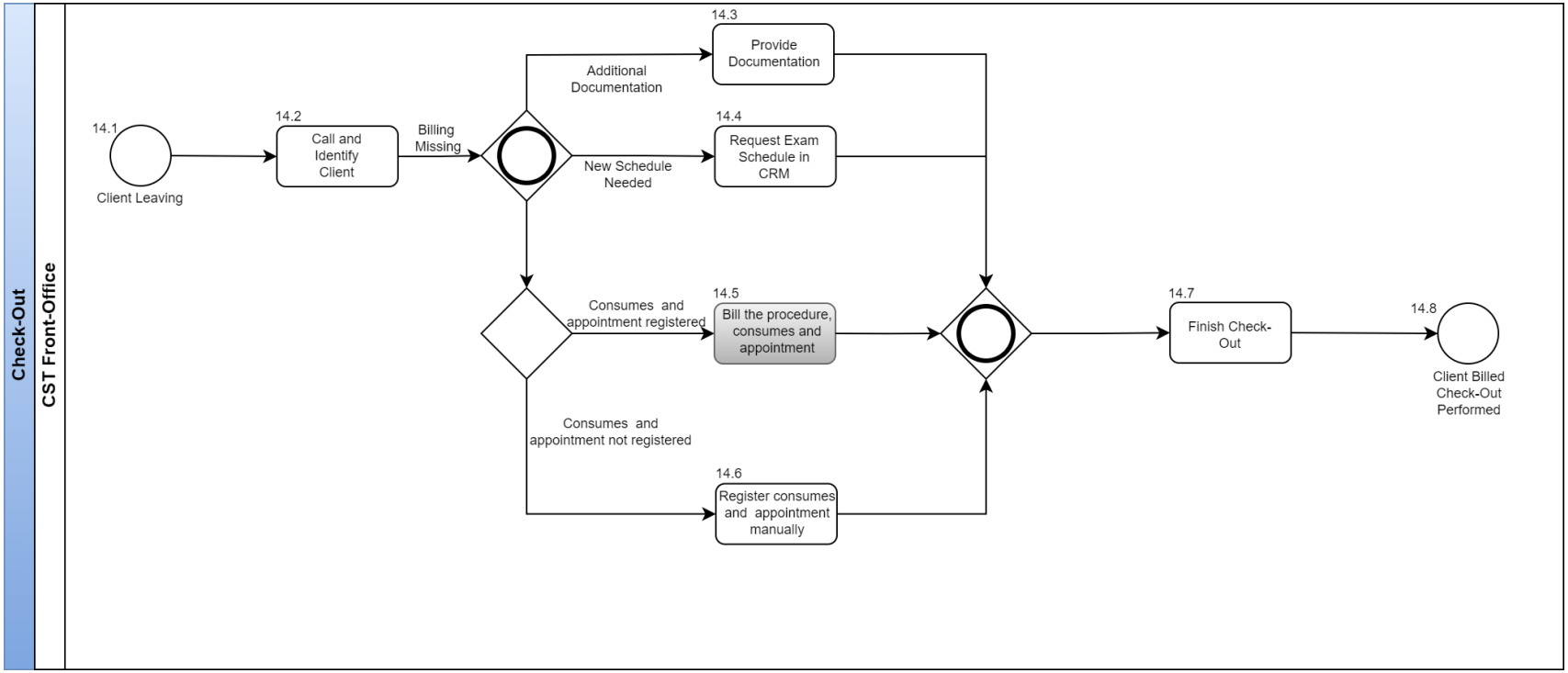


Figure B.5: BPMN To Be: 14. Check-Out

Appendix C

One-Way ANOVA and LSD Test

C.1 Doctors Variability

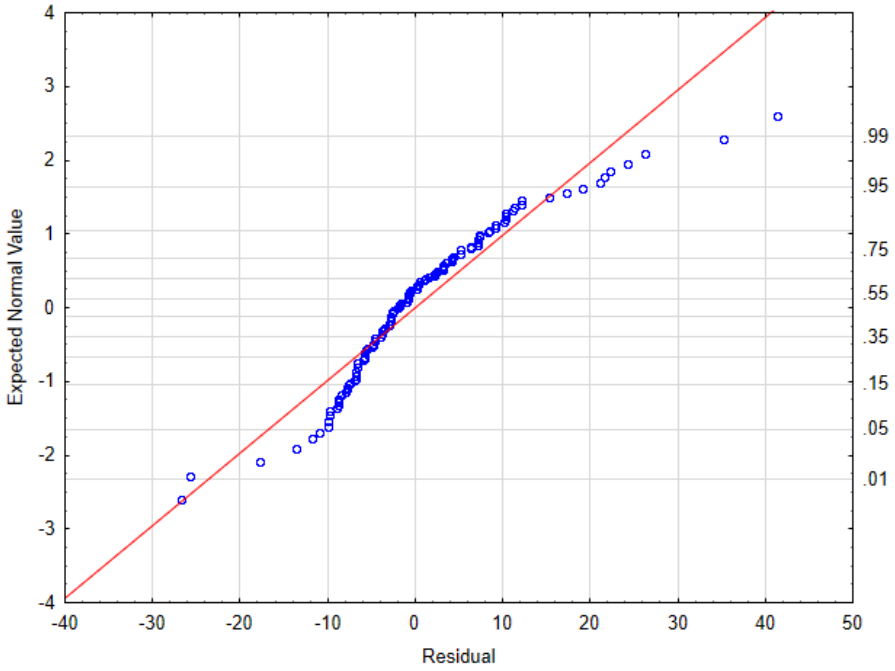


Figure C.1: Doctors Variability - Verifying the normality of the data

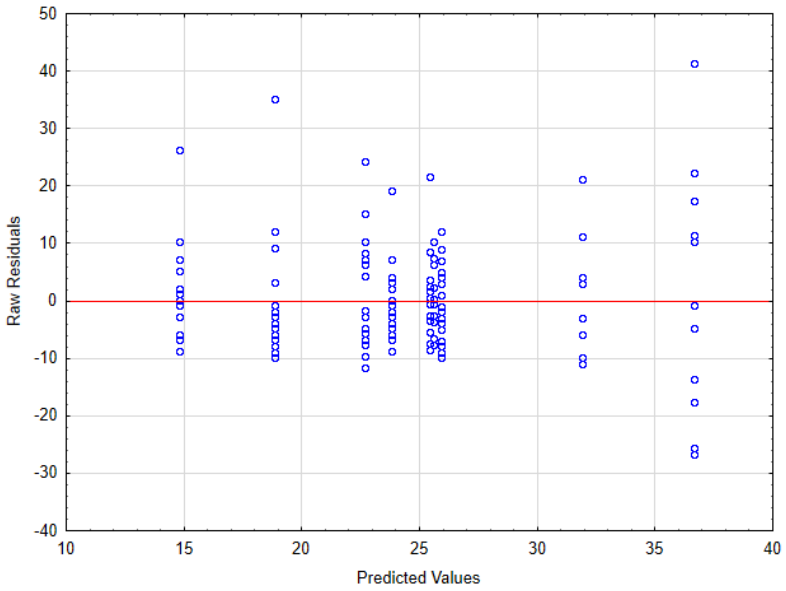


Figure C.2: Doctors Variability - Residuals Values

C.2 Procedures Variability

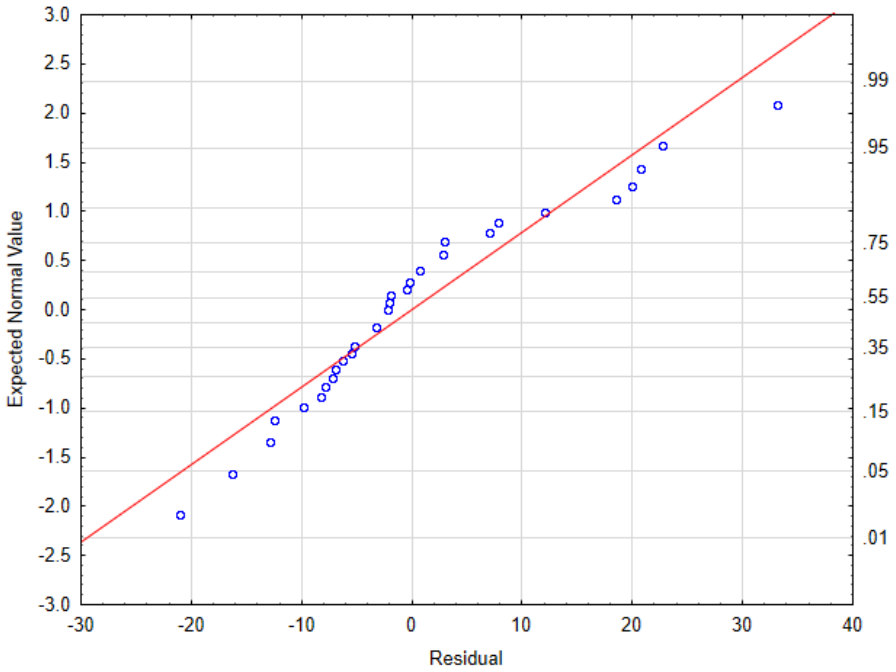


Figure C.3: Procedures Variability - Verifying the normality of the data

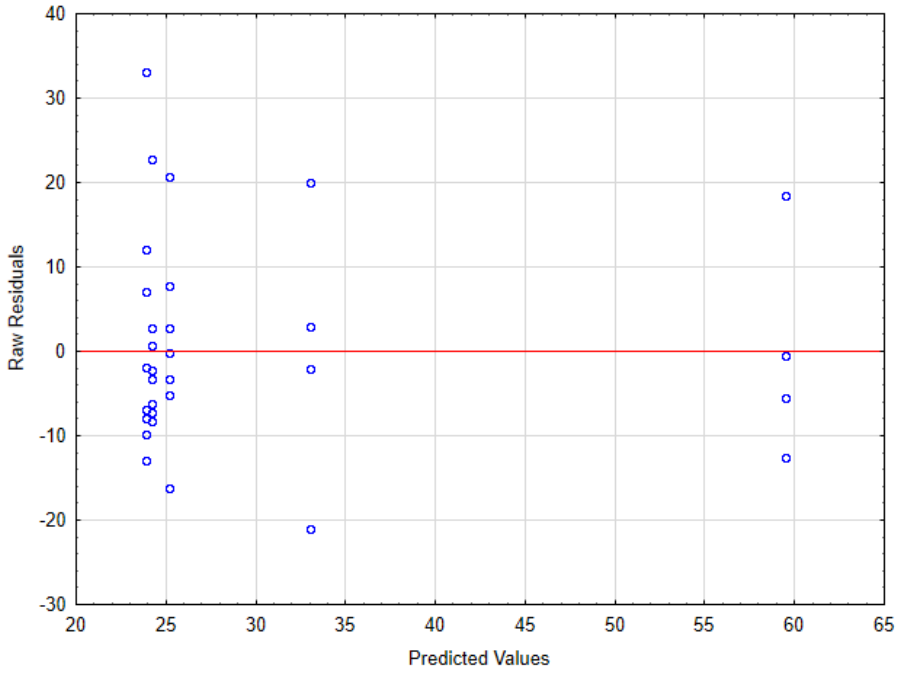


Figure C.4: Procedures Variability - Residuals Values

C.3 Rooms Variability

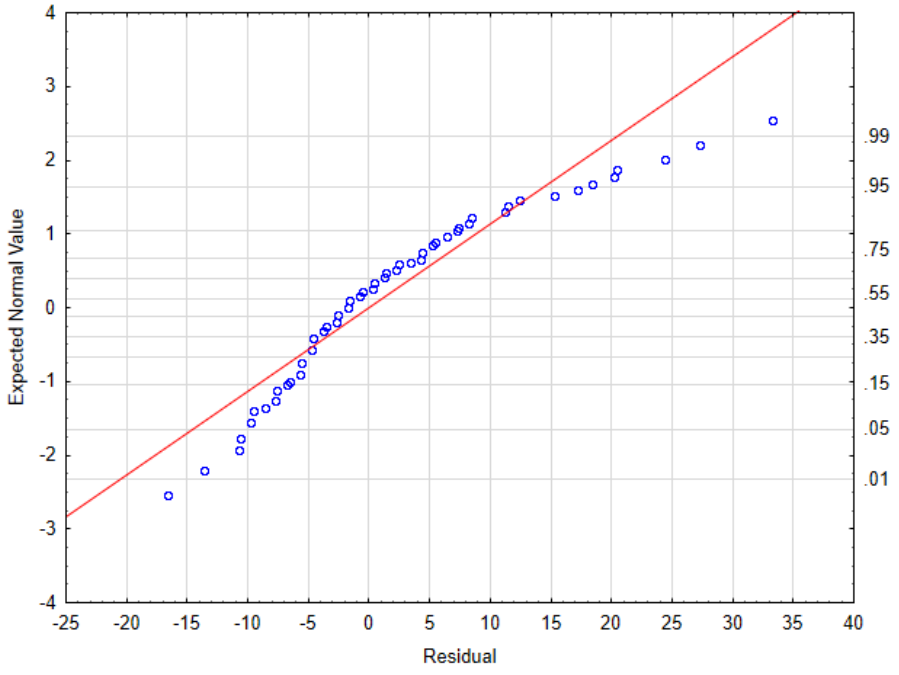


Figure C.5: Rooms Variability - Verifying the normality of the data

C.4 LSD Test

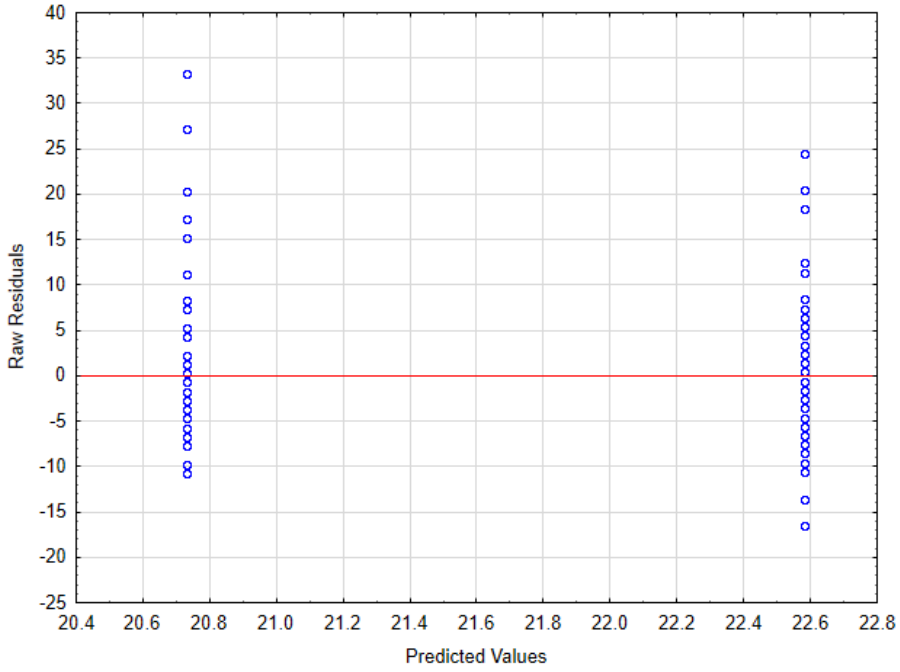


Figure C.6: Rooms Variability - Residuals Values

Table C.1: Values of the LSD Test on the Doctor Variability ANalysis

Doctors	LSD	Means Difference	Doctors	LSD	Means Difference	Doctors	LSD	Means Difference	Doctors	LSD	Means Difference
D1-D2	6,16	7,05	D2-D3	7,82	13,04	D3-D4	7,96	17,11	D4-D5	6,33	7,92
D1-D3	7,82	5,99	D2-D4	6,33	4,07	D3-D5	7,82	9,19	D4-D6	6,94	10,65
D1-D4	6,33	11,12	D2-D5	6,16	3,85	D3-D6	8,33	6,46	D4-D7	7,26	21,89
D1-D5	6,16	3,20	D2-D6	6,79	6,58	D3-D7	8,59	4,78	D4-D8	7,09	10,84
D1-D6	6,79	0,47	D2-D7	7,12	17,82	D3-D8	8,45	6,27	D4-D9	6,33	9,02
D1-D7	7,12	10,77	D2-D8	6,94	6,77	D3-D9	7,82	8,09			
D1-D8	6,94	0,29	D2-D9	6,16	4,95						
D1-D9	6,16	2,10									

Doctors	LSD	Means Difference	Doctors	LSD	Means Difference	Doctors	LSD	Means Difference	Doctors	LSD	Means Difference
D5-D6	6,79	2,73	D6-D7	7,67	11,24	D7-D8	7,80	11,05	D8-D9	6,20	1,82
D5-D7	7,12	13,97	D6-D8	7,51	0,19	D7-D9	7,12	12,87			
D5-D8	6,94	2,92	D6-D9	6,79	1,63						
D5-D9	6,16	1,10									

Appendix D

Scheduling, Performance and Occupation Rates by Doctor

Table D.1: Monthly Scheduling Rate by Doctor

Month	D1 (%)	D2 (%)	D3 (%)	D4 (%)	D5 (%)	D6 (%)	D7 (%)	D8 (%)	D9 (%)
Jan.	75.00	-	55.56	83.33	89.74	86.67	25.00	77.78	76.92
Feb.	84.38	-	88.89	78.79	95.99	87.50	25.00	88.89	79.46
Mar.	79.17	100.00	85.19	77.78	93.44	87.50	28.00	77.78	82.81
Apr.	75.00	100.00	88.89	96.97	95.65	95.00	27.50	94.44	84.52
May	81.25	80.00	88.89	63.33	84.78	79.63	27.50	77.78	76.25
Jun.	83.33	-	94.44	71.43	88.14	84.21	45.00	70.37	74.62
Jul.	87.50	90.00	88.89	91.67	91.94	95.00	47.50	50.00	71.33
Aug.	79.17	90.00	84.21	75.76	80.25	87.50	25.00	100.00	75.00
Sep.	81.25	90.00	77.78	83.33	87.27	87.50	38.00	88.89	75.33
Oct.	75.00	70.00	88.89	83.33	87.80	82.50	20.00	66.67	74.62
Nov.	65.63	100.00	84.44	72.73	88.54	90.00	40.00	66.67	70.00
Dec.	70.83	100.00	74.07	95.24	86.05	82.50	25.00	88.89	75.0
Annual	78.35	92.17	84.69	80.88	88.62	86.11	31.43	77.27	76.01

Table D.2: Monthly Performance Rate by Doctor

Month	D1 (%)	D2 (%)	D3 (%)	D4 (%)	D5 (%)	D6 (%)	D7 (%)	D8 (%)	D9 (%)
Jan.	66.67	-	100.00	85.71	92.86	92.31	25.00	85.71	94.00
Feb.	88.89	-	100.00	88.46	95.19	88.57	100.00	87.50	93.26
Mar.	89.47	92.86	100.00	95.24	89.47	91.43	100.00	92.86	92.45
Apr.	91.67	87.50	37.50	84.38	84.85	78.95	90.91	100.00	80.28
May	84.62	75.00	83.33	78.95	92.31	95.35	90.91	85.71	93.44
Jun.	80.00	-	100.00	93.33	90.38	96.88	94.44	89.47	89.69
Jul.	82.14	88.89	90.63	86.36	92.98	89.47	84.21	100.00	97.20
Aug.	94.74	88.89	93.75	100.00	95.38	88.57	80.00	77.78	93.33
Sep.	96.15	77.78	96.43	91.43	92.71	97.14	94.74	100.00	95.58
Oct.	91.67	100.00	100.00	97.14	90.00	87.88	100.00	83.33	96.91
Nov.	90.48	100.00	94.74	91.67	89.41	85.19	100.00	88.89	90.82
Dec.	88.24	92.86	95.00	100.00	89.19	100.00	100.00	100.00	93.33
Annual	88.33	90.57	93.46	91.21	91.22	91.67	93.18	91.50	92.84

Table D.3: Monthly Occupation Rate by Doctor

Month D9	D1 (%)	D2 (%)	D3 (%)	D4 (%)	D5 (%)	D6 (%)	D7 (%)	D8 (%)	D9 (%)
Jan.	50.00	-	55.56	71.43	83.33	80.00	22.50	66.67	72.31
Feb.	75.00	-	88.89	69.70	91.38	77.50	25.00	77.78	74.11
Mar.	70.83	92.86	85.19	74.07	83.61	80.00	28.00	72.22	76.56
Apr.	68.75	87.50	33.33	81.82	81.16	75.00	25.00	94.44	67.86
May	68.75	60.00	74.07	50.00	78.26	75.93	25.00	66.67	71.25
Jun.	66.67	-	94.44	66.67	79.66	81.58	42.50	62.96	66.92
Jul.	71.88	80.00	80.56	79.17	85.48	85.00	40.00	50.00	69.33
Aug.	75.00	80.00	78.95	75.76	76.54	77.50	20.00	77.78	70.00
Sep.	78.13	70.00	75.00	76.19	80.91	85.00	36.00	88.89	72.00
Oct.	68.75	70.00	88.89	80.95	79.27	72.50	20.00	55.56	72.31
Nov.	59.38	100.00	80.00	66.67	79.17	76.67	40.00	59.26	63.57
Dec.	62.50	92.86	70.37	95.24	76.74	82.50	25.00	88.89	70.00
Annual	69.21	83.48	79.15	73.77	80.84	78.94	29.29	70.71	70.57

Table D.4: Monthly Occupation Rate with Non Scheduled Exams by Doctor

Month	D1 (%)	D2 (%)	D3 (%)	D4 (%)	D5 (%)	D6 (%)	D7 (%)	D8 (%)	D9 (%)
Jan.	87.50	-	77.78	73.81	114.10	80.00	45.00	77.78	72.31
Feb.	84.38	-	94.44	69.70	127.59	80.00	55.00	77.78	80.36
Mar.	83.33	100.00	92.59	75.93	116.39	80.50	60.00	77.78	81.25
Apr.	75.00	100.00	44.44	93.94	107.25	85.00	47.50	116.67	72.62
May	84.38	110.00	74.07	50.00	101.09	75.93	42.50	77.78	79.38
Jun.	75.00	-	97.22	85.71	113.56	81.58	67.50	74.07	70.77
Jul.	78.13	80.00	80.56	91.67	104.84	95.00	55.00	77.78	71.33
Aug.	83.33	90.00	84.21	84.85	96.30	77.50	45.00	77.78	72.50
Sep.	87.50	70.00	83.33	83.33	97.27	87.50	66.00	105.56	76.00
Oct.	78.13	70.00	88.89	88.10	110.98	80.00	40.00	55.56	76.92
Nov.	75.00	115.79	80.00	78.79	116.67	76.67	60.00	66.67	65.00
Dec.	70.83	114.29	70.37	104.76	112.79	82.50	55.00	100.00	77.50
Annual	79.88	97.39	82.74	80.64	108.99	81.02	53.81	81.82	74.69

Appendix E

Waiting Times and Exam Times

Table E.1: Data Set 1 - Waiting Times

Doctor	Average of Waiting Time	Overall Average	Overall Standard Deviation
D1	00:24:06		
D2	00:15:13		
D3	00:41:40		
D4	00:25:40		
D5	00:36:11	00:27:58	00:08:06
D6	00:29:46		
D7	00:32:32		
D8	00:16:47		
D9	00:29:44		
Total	00:30:42		

Table E.2: Data Set 1 - Exam Times

Doctor	Average of Exam Time	Overall Average	Overall Standard Deviation
D1	00:14:49		
D2	00:14:40		
D3	00:17:58		
D4	00:11:08		
D5	00:14:47	00:18:01	00:04:22
D6	00:18:08		
D7	00:25:53		
D8	00:15:43		
D9	00:20:27		
Total	00:17:48		

ANNEX I

DPMO Conversion to Sigma Level

Table I.1: Sigma Level to DPMO Conversion

Sigma Level	DPMO	Sigma Level	DPMO	Sigma Level	DPMO	Sigma Level	DPMO	Sigma Level	DPMO
0.00	933193	1.20	617911	2.40	184060	3.60	17864	4.80	483.4
0.05	926471	1.25	598706	2.45	171056	3.65	15778	4.85	404.1
0.10	919243	1.30	579260	2.50	158655	3.70	13903	4.90	336.9
0.15	911492	1.35	559618	2.55	146859	3.75	12224	4.95	280.3
0.20	903200	1.40	539828	2.60	135666	3.80	10724	5.00	232.6
0.25	894350	1.45	519939	2.65	125072	3.85	9387	5.05	192.6
0.30	884930	1.50	500000	2.70	115070	3.90	8198	5.10	159.1
0.35	874928	1.55	480061	2.75	105650	3.95	7143	5.15	131.1
0.40	864334	1.60	460172	2.80	96800	4.00	6210	5.20	107.8
0.45	853141	1.65	440382	2.85	88508	4.05	5386	5.25	88.4
0.50	841345	1.70	420740	2.90	80757	4.10	4661	5.30	72.3
0.55	828944	1.75	401294	2.95	73529	4.15	4025	5.35	59.1
0.60	815940	1.80	382089	3.00	66807	4.20	3467	5.40	48.1
0.65	802337	1.85	363169	3.05	60571	4.25	2980	5.45	39.1
0.70	788145	1.90	344578	3.10	54799	4.30	2555	5.50	31.7
0.75	773373	1.95	326355	3.15	49471	4.35	2186	5.55	25.6
0.80	758036	2.00	308538	3.20	44565	4.40	1866	5.60	20.7
0.85	742154	2.05	291160	3.25	40059	4.45	1589	5.65	16.6
0.90	725747	2.10	274253	3.30	35930	4.50	1350	5.70	13.3
0.95	708840	2.15	257846	3.35	32157	4.55	1144	5.75	10.7
1.00	691462	2.20	241964	3.40	28717	4.60	968	5.80	8.5
1.05	673645	2.25	226627	3.45	25588	4.65	816	5.85	6.8
1.10	655422	2.30	211855	3.50	22750	4.70	687	5.90	5.4
1.15	636831	2.35	197663	3.55	20182	4.75	577	5.95	4.3
								6.00	3.4