TÉCNICO LISBOA

Improving Surgical Outpatient Flow and Throughput in a Hospital

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Thesis to obtain the Master of Science Degree in

Biomedical Engineering

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December 2021

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Preface

The work presented in this thesis was performed at the company Grupo Luz Saúde (Lisbon, Portugal), during the period March-Jun 2021, under the supervision of Dr. Cristina Mesquita. The thesis was supervised at Instituto Superior Técnico by Prof. João Lourenço.

Acknowledgments

I would like to thank my supervisor Dr. Cristina Mesquita for giving me the opportunity to integrate the Berlin Project and for all the guidance given to me throughout my work. I would also like to thank my supervisor Professor João Lourenço, for the support given to me in the elaboration of the Dissertation and on the simulation model.

To all the professional staff from the *Hospital da Luz Lisboa*, thank you for welcoming me and for your patience and help in the collection of the data.

To all my friends, thank you for all the company throughout these years. It has been quite a journey, full of late nights studying, coffee breaks and unique experiences. I think we can finally go to sleep.

To my family, thank you for the support throughout my life. To my father, thank you for always caring for me (and sorry for all the headaches). To my sister thank you for always being there for me, and for all the sushi dinners. To my grandparents, to my aunt and late uncle, thank you for all the support, specially in the saddest times. And finally, to my mother, thank you for always being close to me. I am sure that you would be proud of my journey.

Resumo

A melhoria contínua de um hospital é fundamental para reduzir custos associados a ineficiências. No *Hospital da Luz Lisboa*, os doentes de cirurgia ambulatória (DCA) realizam a admissão pelo Hospital de Dia Cirúrgico (HDC) e os doentes de cirurgia de internamento (DCI) pelo quarto da ala de internamento (QAI). Contudo, alguns DCI, com admissão no dia da cirurgia, entram pelo HDC. A entrada destes doentes pelo QAI representa uma ineficiência visto que o quarto está ocupado quando o doente estiver na cirurgia e no recobro. A alteração da entrada dos DCI, com admissão no dia da cirurgia, para o HDC foi estudada, considerando os recursos necessários para o fluxo de DCA. Primeiro, foi realizado o mapeamento das atividades para compreensão das causas de atraso no fluxo de DCA. Os dados referentes às atividades hospitalares foram recolhidos e analisados, e uma simulação foi desenvolvida.

Foram estudadas três hipóteses, com foco: no cenário atual; na alteração da entrada dos DCI com admissão no dia da cirurgia; num cenário semelhante ao anterior, mas com um valor específico de chegadas diárias. Os resultados mostraram que, nas duas primeiras hipóteses, não é necessário realizar nenhuma alteração dos recursos no circuito. Contudo, na terceira hipótese, seria necessário a introdução de cinco novas boxes, um cadeirão, um aumento do número de funcionários do HDC e um alargamento do horário de funcionamento do departamento. Estas medidas melhorariam o fluxo de DCA e permitiriam a alteração da entrada de DCI com admissão no dia da cirurgia (aumento da eficiência).

Palavras-chave: Doente de Cirurgia Ambulatória, Doente de Cirurgia de Internamento, Alocação de Recursos, Tempos de Circuito, Simulação

Abstract

The continuous hospital's improvement is fundamental to reduce costs associated with inefficiencies. In *Hospital da Luz Lisboa*, the surgical outpatients (SO) perform the admission through the Day Surgery Hospital (DSH) and the surgical inpatients (SI) through the inpatient ward bedroom (IWB). However, a few SI with admission on the surgery's day enter through the DSH. The entrance of these patients through the IWB presents an inefficiency since the bedroom will not be available during the patient's surgery and recovery. The alteration of the SI with admission on the surgery's day entrance to the DSH was studied, considering the resources needed to improve the SO flow. First, the mapping of all the activities was performed to understand possible causes for the outpatient flow delay. The data involving the hospital activities was collected and analysed, and a simulation was built.

Three hypothesis were studied focusing on: the current scenario; the alteration of the SI with admission on the surgery's day entrance; a scenario similar to the previous one but with a specific number of daily patient arrivals. Results showed that no resource alterations are needed in the circuit for the first two hypothesis. However, it was observed that in the third hypothesis an increase of five boxes, one chair and of the staff of the DSH had to be added, alongside with the extension of this department's schedule. These measures will improve the SO flow and allow the alteration of the SI with admission on the surgery's day entrance (increasing the efficiency).

Keywords: Surgical Outpatient, Surgical Inpatient, Resource Allocation, Circuit Time, Computer Simulation

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Acronyms

AD	Anderson-Darling
AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
CDF	Cumulative Distribution Function
DSH	Day Surgery Hospital
ED	Emergency Department
$H1$	Hypothesis 1
$H2$	Hypothesis 2
$H3$	Hypothesis 3
IWB	Inpatient Ward Bedroom
KS	Kolmogorov-Smirnov
OR	Operation Room
$PACU$	Post-Anesthesia Care Unit
PDF	Probability Distribution Function

Chapter 1

Introduction

1.1 Motivation

Over the years, several improvements have been developed for surgical procedures. By focusing in improving the patient's quality of care, hospitals and clinics have developed innovative ways of providing these services (keeping a close attention on how to also develop cost-efficient improvements). The constant improvement of the hospital processes can not only avoid major costs to the hospital but also improve the quality of care given to the patients. Being the Operation Room (OR) one of the major costs to the hospitals, the need for constant analysis on ways to improve the circuits that pass through this department has been given great attention over the years [1, 2]. Several causes for OR delay have been detected, such as the patient delays, the staff delay and the unavailability of resources [3]. Furthermore, over the years the demand for outpatient surgery as been increasing [4]. This type of surgery enables for patients that undergo less complex procedures (or that do not present a complex condition), to not need to stay overnight in the hospital, without compromising the quality of care. Hospitals created departments dedicated to this type of surgery, thus avoiding the need for these patients to occupy a bed in the inpatient ward since there is no need for a long recovery stay in the hospital.

1.2 Topic Overview

Currently, in *Hospital da Luz Lisboa*, the outpatients perform the admission through the Day Surgery Hospital (DSH), being afterwards taken to this department for the recovery before receiving the hospital discharge (on the same day). Inpatients perform the admission through the inpatient ward bedroom (IWB), and after the procedure, they will stay overnight for the recovery. However, there are some inpatients that perform the admission on the same day as the procedure, who will perform the admission through the DSH (majorly patients from the first surgeries of the day), and after the procedure, they will be transported to their IWB.

The current process presents an inefficiency when analysed on a larger scale. Since not all the inpatients, who perform the hospital admission on the surgery's day, enter through the DSH, they will start to occupy their IWB from the moment they perform the hospital admission. However, when the patient goes to the OR, for surgery, the bedroom continues to be occupied (even if the patient is not there). Considering that the patient is in the surgery and in the primary recovery for an average of five hours, this means that during this time the bedroom did not give any value.

This being said, the problem in study is trying to understand which resources alterations are needed in the DSH in order to improve the surgical outpatient flow and to accept the admission of all the inpatients that perform the admission on the same as the surgery, through the DSH. Due to the increasing demand of inpatients that are going to enter through this department, it is important to ensure that the surgical outpatient's flow is not going to be affected.

1.3 Objectives

The main objectives of this Dissertation are to:

- Understand the effects that reallocating the surgical inpatient entrance to the DSH has in the surgical outpatient's flow.
- Identify the bottlenecks in the surgical patient circuit.
- Understand the required resource alteration in the DSH, in order for it to be able to receive a specific daily number of surgical patients, without compromising the surgical outpatient's flow.

The secondary objectives are to understand how the surgical outpatient's flow in *Hospital da Luz Lisboa* can be improved:

- Considering a resource allocation in the current system.
- Considering that all the inpatients that perform the hospital admission on the surgery's day enter through the DSH.

1.4 Thesis Outline

The remainder of this thesis is organized as follows. Chapter 2 presents a brief explanation of the *Grupo Luz Saúde* and of *Hospital da Luz Lisboa* where this study was applied, as well as the Project Berlin, in which the Dissertation was inserted. Chapter 3 shows a review of the background knowledge of the several existing methods for root-cause analysis and auxiliary tools, as well as possible tools for testing the distributions goodness-of-fit. Chapter 4 presents the methodology applied, from the Ishikawa Diagram to the construction of the simulation model. Chapter 5 presents the simulation results for each hypothesis as well as a discussion for each result. Chapter 6 shows the conclusions for the study, and suggestions for possible improvements and applications in future studies.

Chapter 2

The surgical outpatient flow at *Hospital da Luz Lisboa*

2.1 The Organization

Founded in 2000, *Grupo Luz Saúde* is one of the largest private healthcare delivery groups in Portugal. With 28 functioning units all over the country and in the Madeira islands, the hospital group holds 14 private hospitals, one public-private partnership hospital with the Portuguese National Health Service, 11 outpatient clinics, and two senior residences. Their vision focuses on being a reference in healthcare delivery, through ensuring the delivery of specialized and complex services with high quality standards. *Grupo Luz Saúde* claims to be the leader in healthcare innovation and technology in Portugal [5].

Initially, the hospital group was called *Espírito Santo Saúde* and began functioning after the acquisition of the majority participation in the social capital of *Cliria* (Aveiro, Portugal) and of the *Hospital da Arrábida* (Vila Nova de Gaia, Portugal). Shortly after, the group started to expand by acquiring and constructing several hospitals and clinics in Portugal, and in 2003 the *Hospital da Luz Lisboa* started to be constructed (being finalized in 2007) [5].

In 2014 the then Group *Espírito Santo Saúde* enters the capital market, being the first private company from the healthcare sector to be quoted in the Euronext Lisbon. Afterwards the company *Fidelidade - Companhia de Seguros, S.A* acquired 96% of the Group Espírito Santo Saúde, thus becoming the majority shareholder. With this change, the hospital group name was rebranded to *Grupo Luz Saúde, S.A* [5].

With the focus on healthcare innovation and quality, the *Hospital da Luz Lisboa* is a national healthcare reference. From the excellence specialization in areas such as oncology and robotic surgery, to the patient focus architecture, the hospital is committed on providing the best quality care and comfort to the patients [6]. Furthermore, within the *Hospital da Luz Lisboa*, there's also the *Hospital da Luz Lisboa* Learning Health, which is a training, research and innovation center for the healthcare professionals. In 2021, the Group presented a partnership project with the company *NOS* for the implementation of the 5th Generation (5G) mobile communication in the *Hospital da Luz Lisboa*, thus becoming the first Portuguese Hospital using 5G. This implementation will bring new improvements, such as bigger and faster connections between objects and instruments, smaller response time and bigger bandwidth, thus allowing a real time access to necessary data. This technology will not only be useful in the patient care and in surgical procedures, but also in the training of new professional workers [7].

2.2 Processes and Challenges for the Hospital Optimization

2.2.1 Project Berlin

This Dissertation was developed with the Project Berlin. Within this project, two initiatives are focused on the improvement of the surgical patients circuit of the *Hospital da Luz Lisboa*. Currently, outpatients do the admission through the DSH. However, only a few of the inpatients, that perform the admission on the same day as the procedure, enter the hospital through this department. Most of the inpatients go to their bedroom (in the inpatient ward) after entering the hospital where they wait to be called for surgery. When an inpatient with admission on the surgery's day performs the admission through the IWB, the bedroom will be "occupied" for approximately an average of five hours without the patient, thus not providing a value to the hospital. Unlike the DSH, the inpatients rooms are not on the same floor as the OR, making this process inefficient in terms of not only costs but also of human resources (for the transport of the patients). The solution proposed by the Berlin project is that all the inpatients that perform the admission in the same day as the procedure, enter through the DSH (similarly to the outpatients), and after the procedure and primary recover, they will then go to their respective IWB. Furthermore, currently an expansion of the number of Operation Rooms (from 10 to 16) and beds in the Post-Anesthesia Care Unit (from nine to 24) is being performed. This expansion is expected to lead to approximately 120 daily surgeries. This being said, the problem in this study will be to understand the resources required in the Day Surgery Hospital, in order for the surgical outpatients flow to be improved considering the alteration of the entrance point of the surgical inpatients with admission on the surgery's day, and the increase on the number of daily surgeries.

2.2.2 Hospital Organization

Surgical Outpatient vs Surgical Inpatient

When analysing the surgical patient flow and throughput, it is fundamental to distinguish between two types of surgical patients -Outpatient and Inpatient-, taking into account if whether the patient has to stay overnight in the hospital or not. The surgical outpatient is a patient that goes under a not so complex surgery thus not requiring for the patient to be monitored overnight [8]. The surgical inpatient is a patient that goes under a complex surgery (or the patient can have a complex condition) requiring a hospital stay of at least 24 hours, in order for the patient to be properly monitored. The use of ambulatory surgeries for less complex procedures, enables the hospital to discharge the patient on the day of the procedure, thus resulting in a cost-effective solution for the optimization of the use of resources without compromising the quality of care delivered to the patient [9].

Outpatient Circuit vs Inpatient Circuit

In Hospital da Luz Lisboa, depending on the type of surgical patient (outpatient or inpatient) there are different patient flows (Figures 2.1 and 2.2). It is important to note that before 7am and after 9pm the DSH is not functioning, requiring for the inpatients to go mandatory to their IWB, after the hospital admission.

The outpatient circuit (Figure 2.1) begins in the day of the procedure. The patient enters the hospital and goes to the DSH reception where the admission will be performed by the administrative assistants (this moment is represented as the start of the episode). Afterwards, the patient will wait for a medical assistant to admit them into a Box (bedroom in the DSH). In here, a nurse will prepare the patient for the procedure, making sure that all the requirements are fulfilled. When the OR is prepared, it will call the DSH in order for them to transfer the patient. The medical assistant will carry the patient to the Transfer, where an OR medical assistant will then direct the patient to the respective OR. The patient then will receive the anesthesia and the procedure will start. When the procedure is over, the patient will be taken to the Post-Anesthesia Care Unit (PACU) by the anesthetist, the OR nurse and an OR medical assistant. On the PACU, the patient will be monitored until presenting the conditions required to be discharged from the PACU. When such conditions are fulfilled, the nursing team from the PACU will contact the DSH for a medical assistant and a nurse from the DSH to go pick up the patient. In the secondary recovery (in the DSH) the patient will also be monitored until presenting the conditions to be discharged and go home. When such conditions are presented, and if the physician already sent the medical discharge, the patient will be discharged and will go to the DSH reception to finalize the episode with the administrative assistant (end of episode).

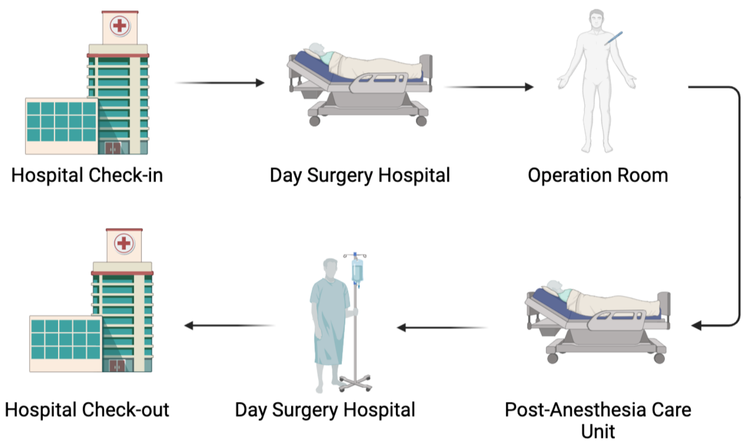


Figure 2.1: Outpatient Pathway.

Unlike the Outpatient, the Inpatient circuit (Figure 2.2) can start on the days earlier to the procedure. When these inpatients enter the hospital, they are admitted in their rooms where they will wait until the day of the surgery. In the day of the procedure, an OR Assistant will transport the inpatient to the Transfer. In contrast, the inpatients that perform the admission on the same day as the procedure, can either enter directly through the DSH (in these cases, the inpatient will be transported to the Transfer by an OR assistant and not by the DSH medical assistant), or be admitted into a room where the patient will wait for an OR assistant to transport them to the OR. Afterwards, the OR and PACU processes are similar do the outpatient ones. However, when the inpatient receives the discharge from the PACU, the patient will be transported by an OR assistant to the respective IWB, where the patient will be monitored overnight until they present the right conditions to get the medical discharge.

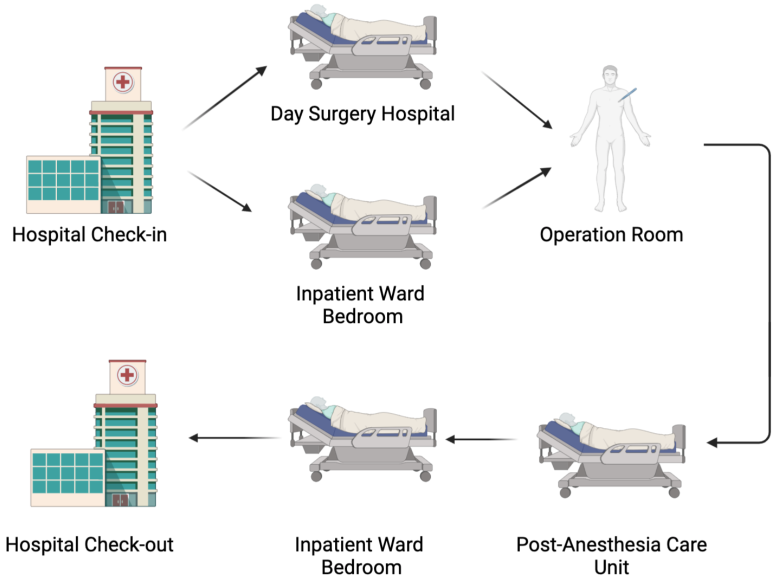


Figure 2.2: Inpatient Pathway.

Chapter 3

Literature Review

Studies have tried to understand the factors that influence the time that the patient takes in the circuit, also referred as patient's episode (all the processes involved from the moment the patient enters the hospital until the moment the patient leaves the hospital). Major attention has been given to indicators such as the patient waiting time in the hospital reception (after performing the admission) due to its influence on the patient's satisfaction in regards to the hospital. To understand the factors that can be related to an increase on the patient's waiting time, Root-Cause Analysis Tools are used to map and understand the process involved in the patient's hospital episode. Although most studies are associated with the optimization of the Emergency Department (ED) (due to the need of a fast response time in assisting the patient) and of the Outpatient Clinic (more specifically to the physicians appointments), it is still possible to adjust these analysis methods to the DSH context. Furthermore, in order to provide a more accurate simulation of the hospital departments performance, a careful analysis of the data must be performed, thus the need for the realization of distribution tests to obtain the distribution that provides the best resemblance to the actual data. In the following chapter, a revision of a few of the methods already used in studies is presented.

3.1 Methods for Root Cause Analysis

A process can be considered as a system that connects a variety of steps in order to achieve a specific goal. Can be the production of a car in a manufacture, a customer shopping in a supermarket or a patient that is going to go under surgery. Within the process, there are several events that, most times, can and should be improved, and for this reason a good analysis of these events is fundamental in every organization. The Root cause analysis involves the analysis of the several events that contribute to a variation or occurrence of an event [10], thus being a good technique to use, since it requires the mapping of the process and the identification of the causes of events. Each Root Cause method has its own configuration, and several methods complement each other. In Table 3.1, several methods and additional tools used in Root Cause analysis are identified, followed by a brief explanation. In the following subsections, three methods-Flowcharts, Ishikawa Diagrams, and Pareto Diagrams- are detailed due to the fact that they can provide a more detailed analysis of the process in study.

Table 3.1: Root Cause Analysis methods and auxiliary tools.

Method/auxiliary tool	Definition
The "5 Whys"	Enables the identification of the causes that lead to an event, by questioning five times the "why" to that occurrence [11]. Considering the example: The patient did not perform the administrative release; (why?) there were no medical administratives available; (why?) he received the medical discharge after the ending of the medical administrative shift; (why?) he only presented the requirements for discharge at that time; (why?) the nurse only went to monitor the patient at that time; (why?) there were not enough nurses for that shift demand on that day.
Affinity Diagram	Enables the organization of the possible causes of an event into groups, allowing to connect all the causes. Although it helps in the identification of possible improvement opportunities and causes, it does not allow the differentiation of secondary causes from the main ones. Furthermore, it does not allow to visually map the events of a process [12].
Flowchart	Allows the identification and representation of the elements in a process in an organized display. Furthermore, enables the identification of possible improvement opportunities in the system. A disadvantage is that it does not allow the identification of causes to an event in the system [13].
Histogram	Allows the identification of the number of times an event occurs in the system [13]. However, it does not allow to visually map the system, or to directly identify the causes of an event.
Ishikawa Diagram	Enables the organization of possible causes of an event into groups. Furthermore, allows a more complete differentiation of the root causes (between main and secondary causes) than the Affinity Diagram. However, it does not allow to visually map the events of a process [12].
Pareto Diagram	Enables the analysis of the contribution of each cause to the occurrence of an event, thus allowing to conclude the most frequent causes. However, it requires the identification of the causes that lead to the event before constructing the Diagram (a good option is to identify the causes with the Ishikawa Diagram) [13].

3.1.1 Flowcharts

Flowcharts are visual tools used to map the several key activities that form a process. This method is typically represented in a vertical order and from the left to the right. This type of chart is characterized for having very few information displayed, thus the need to make it as easy to follow as possible [14]. Furthermore, it uses standard symbols to represent each element of the process (Figure 3.1): the ellipse represents the starting and the ending point of the process, the square represents an activity, the diamond represents a decision (e.g. yes or no decisions), the arrow indicates the flow/direction of the process. Furthermore, by providing a representation of each step of the process, Flowcharts allow the identification of possible improvement opportunities in the process [10]. Depending on the detailed given to it, it is possible to identify redundant activities in the process. Nevertheless, the Flowchart presents some disadvantages, such as by being a visual tool that shows the several processes that occur in a system (and not the causes related to each activity), this method can not provide information regarding the causes that create an event in each activity of the system (e.g. in a hospital context, the user can not extract the cause of delay of the patient in the OR). Nevertheless, the Flowchart provides a schematic visualisation of the whole system and it can serve as a decision support tool to detect possible spots in the system where bottlenecks can occur, and where improvements should be performed [15].

In order to construct a Flowchart, the first step is to understand the process that is going to be mapped, by defining not only the starting point and the ending point, but also all the elements involved in it. Afterwards, each element will be represented by a symbol and with an arrow (to connect each symbol). The Flowchart should be constantly revised in order to modify/update possible changes that occur in the system [16].

Within the several uses of Flowcharts, this method has been used multiple times to describe the processes that occur in a hospital. Morrice *et al.* (2013) built a Flowchart to represent the surgical outpatient process in the University Hospital of the University Health System in San Antonio, Texas, United States of America [17]. Molema *et al.* (2007) used the Flowchart tool to map the patient's flow at a Surgery Department of the University Hospital Maastricht, and of the Endoscopy Department of the Catharina Hospital Eindhoven, The Netherlands, to understand the tasks that had to be performed by the physicians, in order to study the possibility of creating a part time shift for these professionals [18]. As an alternative, the *Hospital da Luz Lisboa* uses Business Process Model and Notation (BPMN) to map the processes in the hospital. This tool is very similar to Flowcharts, having the advantage of enabling the association of the resources to the activities, in a more visual, and easy to understand, way.

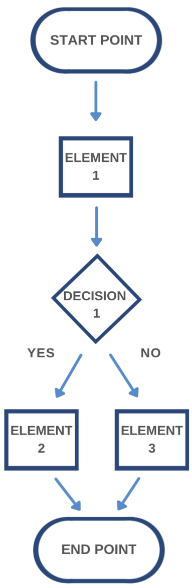


Figure 3.1: Flowchart Example.

3.1.2 Ishikawa Diagram

The Ishikawa Diagram (or Cause and Effect Diagram) is an analysis tool that can assist in the mapping and understanding of the causes that can lead to the occurrence of an event [13]. Developed in the 1960s by Kaoru Ishikawa as a tool for quality control, this method has ever since been used in several fields of the industry. It can also be called fish-bone diagram due to its visual similarity to a fish skeleton (Figure 3.2). In order to create an Ishikawa Diagram, first it is necessary to identify the event/problem in question, and afterwards the event is going to be put in the right part of the diagram (in the head of the fish). Furthermore, an analysis of the several activities related to the event should be performed (methods such as the Flowchart can provide a great utility for this). Following the activity mapping, the delays in each activity should also be mapped, through getting in contact with the people involved with the event and asking for their feedback (this way, they may add missing information thus increasing the detail of the Diagram). After the assembly of the possible causes, a straight line is going to be drawn in the diagram, resembling the main structure of the fish spine, and from this main structure, several diagonal lines are going to be drawn representing the bones of the fish. Each bone represents a category of causes (or the main cause), and from these bones several lines can also be added, representing the causes related to the category (secondary causes). Furthermore, additional lines can be drawn from the secondary causes, adding more detailed to the diagram.

Several studies used the Ishikawa Diagrams to analyse and determine the many causes of problems in the industry sector, majorly in the quality management sector of manufacturing. Due to the constant need for improvement in industries, this method comes as a crucial tool for finding problems, specially in the production line of manufacturing industries [19, 20]. Furthermore, Ishikawa Diagrams are also used many times in the Health sector, as a tool to detect inefficiencies in the hospital. Daliri *et al.* (2019) used the Ishikawa Diagram to analyse the causes that lead to medication related problems in the patients that are being transferred to their houses (after receiving hospital discharge), and to understand the factors that could lead to the overcoming of these difficulties [21]. Asghar *et al.* (2015) used the Ishikawa Diagram to identify the potential causes that lead to inappropriate hospital stay, and by dividing the possible causes in categories, it was possible to observe that the causes that lead to inappropriate stay are much more hospital-related than patient-related [22].

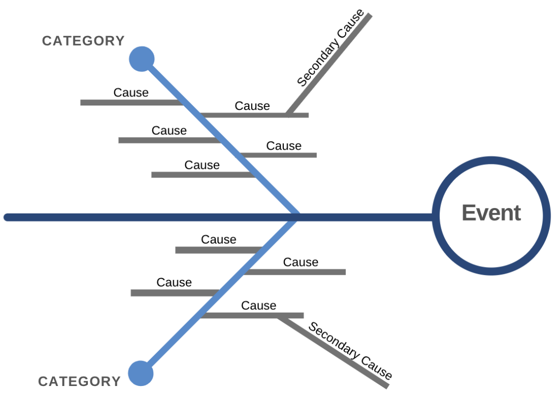


Figure 3.2: Ishikawa Diagram Example.

3.1.3 Pareto Charts

Pareto chart is a graphical representation of the Pareto principle, created by Joseph M. Juran (the principle defines that roughly 80% of all the effects of an event derive from 20% of the causes [23]). Graphically, the Pareto chart is similar to a bar chart, however in this case the bars are sorted in a specific order, following the most frequent cause to the less frequent one, representing the contribution of each cause to the event in study [24]. Furthermore, there is also a trend line in the graph which represents the cumulative percentage. In the Example Chart from Figure 3.3, it is possible to observe that the most frequent cause to the event is the Cause 4, with 80 occurrences and a cumulative percentage of approximately 40%. Pareto charts should not be seen as an error identifier tool, but as a tool to identify the most frequent errors. In other words, the Pareto Chart can not map the causes that led to the occurrence of an event (to do this, the Ishikawa Diagram or the 5 Why's method can be used). Nevertheless, Pareto Charts can be very useful to identify the most important causes, which could indicate on where the changes should first be performed in order to solve the existing problem [24]. Pareto Charts have been used in the industry sector in several studies related with Root-Cause Analysis due to its frequency analysis. A few examples of the application of this method can be seen in the identification of defects in the manufacturing of products [25], in the analysis of workers' safety [26], or even in the improvement of businesses [27]. In the health industry, this tool has been used in many studies related to the identification of the hospital departments where most patient accidents occur [28], and to understand the main causes that lead to delays in the beginning of surgeries [29].

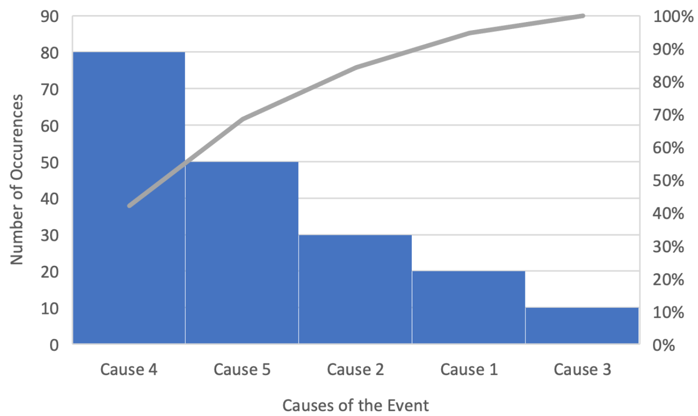


Figure 3.3: Pareto Chart Example.

3.2 Data Fitting Tests

When managing large amounts of data, it is fundamental to represent the distribution that best fits the data in question. The more similar a distribution is to the evolution of the data, the more accurate the simulation will be. There are several tests to obtain the distribution that best fits the data. On Table 3.2, five of the most known goodness of fit tests are explained. Furthermore, two tests -Akaike Information Criterion and Anderson-Darling Test - are detailed in the following subsections, due to the fact that they provide a more close utility for the data in study.

Table 3.2: Data Fitting Tests.

Data Fitting Test	Definition
Akaike Information Criterion	Parametric test. Uses the Log-likelihood function, being able to analyse the information lost when using a specific distribution to represent the evolution of the data. In other words, the smaller the test value, the less information was lost and the best is the distribution to represent the data. Furthermore, for being an information criterion test, it also analyses the complexity of the model [30].
Anderson-Darling Test	Non-parametric test. More often considered as a good test tool to analyse if a given data follows a normal distribution (normality test), being also used in the test of other distributions. This distribution is characterized for giving more emphasis to the tails of the distributions (lower and upper values of the distribution that have a less probability of occurrence) than the other tests [31, 32].
Bayesian Information Criterion	Parametric test. Similarly to the Akaike Information Criterion test, the Bayesian Information Criterion also uses the Log-likelihood function to analyze the goodness of fit of a model. However, this last one gives a higher penalization when evaluating the method, due to taking into account the N parameters of the model. Nevertheless, the BIC is less efficient than the AIC if the best fit distribution is not within the distribution options in study (or if the N value is large) [33].
Chi-squared Test	Non-parametric test. This test is one of the oldest fitting tests, being very known to be used in discrete distributions. Compares the frequency of the fitted distribution with the one from the data in study [34].
Kolmogorov-Smirnov Test	Non-parametric test. This test estimates if a specific distribution fits the evolution of the distribution of a sample, by analysing the maximum absolute difference between the cumulative distribution functions of both distributions [35].

3.2.1 Akaike Information Criterion

When considering a model (in this case, a distribution) to represent a set of data, it is crucial to assure that it does not under-fit or over-fit the information, thus failing to copy the variability that the data might take. In order to avoid this type of errors, there are specific tests to estimate how good the data fits the distribution- Information Criterion. The Akaike Information Criterion (AIC), which was formulated in 1973 by the Japanese mathematician Hirotugu Akaike [30] is one of these tests. It provides a careful analysis of the model performance as well as taking into account the complexity of it, this way the Akaike Criterion enables the comparison between different models in order to assure that the chosen model is able to predict the variability of the data (e.g. considering a comparison between distributions to represent a set of data, depending on the variability of the data there's only a few distributions that can copy the evolution of the data in a very similarly way) [30]. The AIC tests analyses the possible models that are going be used to represent the evolution of the data, as well as the variables presented in the data of the study, and provides a score for each model. Since the score of the model is given as a penalization of the complexity of the model, the one with the lowest AIC score is considered to be the most goodness of fit model for the set of data in study [34]. Considering that this test uses a logistic regression, it can be computed using the Equation (3.1), where K refers to the number of parameters in the model and the L represents the maximum Likelihood function of the model. The Likelihood function of a parameter with a specific value represents the likelihood (or the probability) of a function, with that specific parameter, to obtain the expected observed data [36]. In other words, firstly the maximum of the Likelihood function for each model is considered, and afterwards the AIC applies the Logarithm to each function. The model that is going to be chosen is the one with the largest Logarithm value (since it is going to balance with the complexity of the model) [37]. For a small number of observations, the AIC can be written as a second-order equation (Equation (3.2)), where N is the number of observations [36].

$$AICValue = 2K - 2Ln(L) \tag{3.1}$$

$$AICcValue = AIC + \frac{2K(K+1)}{N-K-1} \tag{3.2}$$

Although the AIC and the Bayesian Information Criterion (BIC) are very similar, the BIC provides a bigger penalization to the model than the AIC, which may lead to over-fitting of the data (when the K value is very large). [33] The AIC test has been used in a few healthcare studies [38, 39], showing the efficiency in the use of this criterion in this sector.

3.2.2 Anderson-Darling Test

Created in 1952 by the statisticians Theodore Wilbur Anderson and Donald A. Darling, the AD Test is a statistical test that provides an analysis of whether or not a distribution follows the evolution of a certain set of data. Unlike the AIC and BIC tests, the AD is a non-parametric test (considers that the set of data does not have parameters) similar to the Kolmogorov-Smirnov (KS) and the Chi-squared tests, being known to be good alternatives to both of them. Furthermore, the AD gives more weight to the tails than the KS does [40]. In the beginning of the AD test, there are two hypothesis - the distribution in study fits the data; or it does not -. To validate the hypothesis, the test can be performed using the the Equations (3.3) and (3.4) [41, 42], in which the N represents the sample size, the F represents the Cumulative distribution function (CDF) of the distribution that is being evaluated, and the Y is the -th value of the sorted data.

$$A^2 = -N - V \tag{3.3}$$

$$V = \sum_{i=1}^{N} \frac{(2i-1)}{N} \times (Ln(F(Y_i)) + Ln(1 - F(Y_{N+1-i}))) \tag{3.4}$$

When testing, the AD uses the distribution in study (e.g. Normal or Exponential) to compute critical values (for this reason, each distribution has specific critical values). This could represent a disadvantage due to need of computing the critical values for each distribution in study (there is only few distributions with the critical values already computed) [42]. Nevertheless, it allows an increase in the sensitivity of the test. If the test value is bigger than the critical value for the distribution, then the distribution does not follow the data evolution [42].

The most typical distributions where the AD test is applied are the Log-Normal, the Exponential, the Weibull and the Logistic distribution, being majorly applied in the Normal distribution. The AD test has been applied in healthcare-related studies, specially as a test to determine if a data follows a normal distribution [43–45].

3.3 Distributions

Whether to describe the evolution of the arrivals in a hospital or the service time that a machine takes to build a product, distributions are used to best describe and predict the evolution of the known data. When computing the Data fitting test, several distributions can be compared in order to find the best ones for the study. In Table 3.3, it is possible to observe a few distributions examples and how they can be used in the industry.

Table 3.3: Distributions.

Distribution	Definition
Exponential	One-parameter continuous distribution, used in the study of positive data (especially in arrivals, e.g. arrival of a product to a storage) [46]. Normally used alongside with the Poisson distribution when computing the arrivals.
Gamma	Two-parameter continuous distribution, used in positive data values. Has two parameters: the shape and scale parameters, and when the shape parameter equals 1, the distribution is similar to the Exponential distribution. Enables to predict waiting like in queues (e.g. how much time a person has to wait in the line of the supermarket, considering that there is an x number of people in front) [47].
Log-Normal	Two-parameter continuous distribution. The parameters are the Mean and Standard Deviation. Recommended over the Normal distribution, due to the fact that in cases such as the time of service (where the sample can have a very small Mean value and a very big Standard Deviation, the Log-Normal distribution considers that the smallest value that the distribution can have is zero (instead of negative values) [48]. It is used in hospital length of stay or to describe the load values of a material.
Pearson V	Two-parameter continuous distribution that is used to describe the duration of tasks. Used as an alternative to the Log-Normal distribution to describe patients length-of-stay in the Hospital [49].
Poisson	Stochastic One-parameter discrete distribution that best describes the quantity of events that occur in a defined time period. Very often used in the estimation of patient arrival to the hospital or in the arrival of requests to a company, alongside with the Exponential Distribution [50].
Triangular	Three-parameter continuous distribution. The parameters are the Lower value of the data, the mode, and the higher value of the data. The shape of the distribution curve resembles a triangle. [51] Very often used when there is low information available to describe the demand of the process time [52].

3.3.1 Exponential Distribution

The Exponential distribution (also known as the generalized Exponential distribution) belongs to the Exponential Weibull distribution family [46]. This is a continuous distribution (the random variables can assume any value of the distribution), being majorly used in the measurement and representation of the duration time until the occurrence of a specific event (e.g. the time pattern of costumer arrivals to a supermarket) [53]. The Probability Distribution Function (PDF) Equation is given by Equation (3.5) [54] where the β is a positive scale parameter (used in the stretching of the function representation in the graph), and represents the mean of the function. This parameter is also known to be the inverse of the λ parameter.

$$F(x) = \frac{1}{\beta} \exp\left(\frac{-x}{\beta}\right) \text{, with } x \geq 0; \lambda > 0 \tag{3.5}$$

The previous Equation was related to the scenario where the probability of the distribution is bigger than x. However when the probability of the distribution is less or equal to x, the function considered is the CDF (Equation (3.6)) [54] [53].

$$F(x) = 1 - \exp\left(\frac{-x}{\beta}\right) \text{, with } x \geq 0; \beta > 0 \tag{3.6}$$

The Exponential Distribution is commonly associated with the Poisson Distribution, since this last one enables the prediction of the number of events that occur in a specific time interval. This way, considering that in a study the customer arrivals to a supermarket follow a Poisson distribution, then the interarrival time can be described by an Exponential distribution [55]. Studies have seen its utility in the analysis of lifetime related data, being able to replace other distributions such as the gamma and Log-Normal distributions [46].

3.3.2 Gamma Distribution

The Gamma distribution is a two-parameter continuous distribution. It is very used since it considers only positive values (similar to the Log-Normal distribution) [47]. This distribution is used in several studies to analyse the expected time that one has to wait for an event (e.g. the time that a customer has to wait in the supermarket line considering that there is a x number of customers ahead of him) [47].

The distribution PDF is given by Equation (3.7) [54], where α is the shape parameter and β is the scale one (both of the parameters are positive).

$$f(x) = \frac{x^{\alpha-1} \times \exp\left(-\frac{x}{\beta}\right)}{\Gamma(\alpha) \times \beta^{\alpha}} \text{, with } x > 0 \tag{3.7}$$

where the Gamma function (Γ) is given by

$$\Gamma(x) = \int_0^{\infty} t^{x-1} \exp(-t) dt \tag{3.8}$$

Depending on the value assumed for α, a family of distributions can be considered. For example, the Exponential distribution is part of this family, for $\alpha = 1$. Moreover, when the shape parameter takes the value of a $\frac{n}{2}$ (where n is an integer) and the scale parameter takes the value of 2, it is known has the chi-square distribution.

The CDF is given by the Equation (3.9) [54].

$$F(x) = 1 - \exp\left(-\frac{x}{\beta}\right) \sum_{i=0}^{\alpha-a} \frac{\left(\frac{x}{\beta}\right)^{i}}{i!} \text{, with } x > 0 \tag{3.9}$$

This distribution has been used in studies to describe the time evolution pattern, such as the infectious time regarding the spread of a disease [56]. In the healthcare sector, the Gamma distribution has been seen as a good arrival pattern estimation [57], and also to describe service times [58].

3.3.3 Log-Normal Distribution

The Log-Normal is a two-parameter continuous probability. This distribution is the Logarithm of the Normal distribution. For this reason, a random variable that follows this distribution can only have positive values [59]. This characteristic is very important, specially in certain cases of study, such as measuring the evolution of patient flow times, where the values can not be negative [60]. Furthermore, when the data in study has a very small mean value and a very big standard deviation, the Normal distribution would consider negative values (at least in the left tail of the distribution), but the Log-Normal distribution would consider that the minimum value that the distribution can have is 0.

To better understand the Equations that allow the calculations of the Log-Normal Distribution, it is important to first consider a normally distributed variable X=Ln(y). Then it is possible to compute the PDF of a random variable Y by considering:

$$f_Y(y) = \frac{1}{\sqrt{2\pi}\sigma_X} \times \exp\left(\frac{-1}{2}\left(\frac{Ln(y)-\mu_X}{\sigma_X}\right)\right)^2 \text{, with } 0 < y < \infty \tag{3.10}$$

where σ_X is the standard deviation of the normal distribution X, and μ_X is the expected value. Both these values can be computed considering the Equations (3.11) and (3.12) [60].

$$\sigma_X = \sqrt{Ln\left(\left(\frac{\sigma_Y}{\mu_Y}\right)^2 + 1\right)} \tag{3.11}$$

$$\mu_X = Ln(\mu_Y) - \frac{1}{2}\sigma_X^2 \tag{3.12}$$

Several studies use the Log-Normal distribution, specially due to its only positive values. In the healthcare sector the Log-Normal has been showed to be a very good distribution to represent the Length-of-stay of the patients in the hospitals [61] and the duration of surgical procedures [62].

3.3.4 Pearson V Distribution

The Pearson V distribution is a two-parameter continuous distribution, that belongs to the Pearson distribution family. This family of distributions was first proposed in 1895 by Karl Pearson, in order to demonstrate that the sample is not always required to follow a normal distribution [63]. The PDF of a Pearson type distribution (or Inverted Gamma distribution) is given as solution of the differential equation presented in Equation (3.13) [63].

$$\frac{d(f(x))}{dx} = \frac{(x-a)f(x)}{b_0 + b_1x + b_2x^2} \tag{3.13}$$

For the specific case of the Type V Pearson, the PDF can be given by the Equation (3.14) [54], where α is the shape parameter and the β is the scale one.

$$f(x) = \frac{x^{-(\alpha+1)} \exp{(-\frac{\beta}{x})}}{\beta^{-\alpha}\Gamma(\alpha)} \text{ , with } x > 0; \alpha > 0; \beta > 0 \tag{3.14}$$

Moreover the CDF is given by the Equation (3.15), where the F_{Gamma} corresponds to the Gamma distribution CDF (Equation (3.9)) with parameters (α;$\frac{1}{\beta}$) [54].

$$F(x) = 1 - F_{Gamma}\left(\frac{1}{x}\right) \text{ , with } x > 0 \tag{3.15}$$

Studies have considered this distribution as fitted to describe the duration of tasks (e.g. the time a customer takes to shop in a supermarket) [54]. In the healthcare sector, the Pearson V distribution has been used to describe patient's Length-of-Stays, proving that can be a good alternative to the Log-Normal distribution [49].

3.3.5 Poisson Distribution

The Poisson Distribution is a one parameter discrete distribution (predicts the occurrence of individual events) [53]. The PDF is presented in Equation (3.16) [54], where $x \geq 0$ and the λ represents the shape parameter that predicts the mean number of events that occur in a specific time interval (e.g. when $\lambda = 5$ the mean number of events is 5).

$$p(x; \lambda) = \frac{\exp{(-\lambda)} \times \lambda^x}{x!} \tag{3.16}$$

When the probability of the distribution is less than x, the cumulative distribution function is given by Equation (3.17) [54].

$$F(x; \lambda) = \sum_{i=0}^{x} (\frac{\exp{(-\lambda)}\lambda^i}{i!}) \tag{3.17}$$

Since it is a stochastic distribution, the Poisson Distribution has a big role in the industry, being used in several studies such as to predict the occurrence of accidents in the workspace [64, 65] . Furthermore, this distribution also has major applications in the healthcare sector, such as for describing the arrival of patients to the hospital, enabling to predict the patient' flow that hospital should expect [66–68].

3.3.6 Triangular Distribution

The Triangular distribution is a three-parameter continuous distribution. The distribution is characterized for having the PDF with a triangular shape, being the three parameter that constituted the distribution, the lower limit (minimum value of a given set of data), the mode (the most likely value from the set of data), and the upper limit (maximum value of the set of data) [52].

Considering that the lower limit is represented with an "a", the mode with a "c" and the upper limit with a ”b”, the PDF of the Triangular Distribution is given by Equation (3.18) [52].

$$f_X(x) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)} & \text{if } a \leq x \leq c \\ \frac{2(b-x)}{(b-a)(b-c)} & \text{if } c \leq x \leq b \\ 0 & \text{Otherwise} \end{cases} \tag{3.18}$$

The CDF of the Triangular Distribution is given by Equation (3.19) [52].

$$F_X(x) = \begin{cases} 0 & \text{if } x \leq a \\ \frac{(c-a)(x-a)^2}{(c-b)(c-a)^2} & \text{if } a \leq x \leq c \\ 1 - \frac{(b-c)(b-x)^2}{(b-a)(b-c)^2} & \text{if } c \leq x \leq b \\ 1 & \text{if } t > n \end{cases} \tag{3.19}$$

The triangular Distribution is used very often when there is not a lot of information available in the study [52]. In the healthcare sector, this distribution has been used in several studies such as in the analysis of risk of infection (in the representation of the patient’s visitors time evolution and nurse visits) [69], and in the representation of the activity’s time of the nurse and physician in a ED in order to analyse the effects of patient waiting time, when replacing the nurse triage by a physician triage [70].

3.4 Patient Waiting Time

When considering the surgical outpatient episode, there is a major factor that influences the duration of this patient in the hospital - the waiting time in the hospital waiting room. The waiting time after the hospital admission is an indicator of how long the patients have to wait in order to be assisted. In cases such as of an ED, the waiting time in the waiting room is a crucial factor, that if long, can have negative impact on the patient’s health condition, or lead to the patient to be unsatisfied by the hospital service and leave to go look for assistance in other hospitals [71]. Furthermore, patients tend to prefer the Private Health Institution then Public ones, due to expecting to receive faster and better healthcare services [72]. There are several studies that established a relation between the waiting time and the hospital organization, or in other words, a longer waiting time can represent a bad management of the hospital [70]. Some observed that it could be related to delays from the physicians, extended time in an appointment (leading to a delay in the following appointments), lack of material resources (e.g. devices or even rooms for patients to be assisted), or even the lack of human resources to provide the care to the patients. Bahadori *et al.* (2014), observed the effect of changing the number of staff in an outpatient department pharmacy, which lead to a decrease on the patients waiting time from 40 minutes to approximately 13 minutes [73]. The National Academy of Medicine (United States of America), considered essential for a primary care center (and for any hospital unit) to ensure that the waiting time for 90% of the patients, that had a scheduled appointment, to be less than 30 minutes [74]. Furthermore, several studies analysed the level of satisfaction of the patients in relation to their waiting time in the hospital reception. Howard *et al.* (2009) observed that the patients in a primary care center gave a satisfactory rating when the waiting time for the appointment was less than 10 minutes, but not a so satisfactory rating when the waiting time was less than 20 minutes [75]. Furthermore, Campbell *et al.* (1994) performed a patient satisfaction study where it was observed that patients tend to show dissatisfaction when they had to wait more than 15 minutes to be assisted [76]. Since there were not found any studies specific for waiting times in the surgical outpatients departments (specially patient satisfaction studies), the most reasonable maximum waiting time for this department is the 30 minutes referred by the National Academy of Medicine (United States of America) [74]. The waiting time can be monitored differently, depending of the hospital department itself. In an ED, the waiting time can be monitored from the moment the patient enters the hospital until the triage is performed (in this moment the patients will receive a bracelet with a color, depending on how urgent their condition is), can also be from the moment the triage is completed until the moment the patients are assisted by a physician, or even both waiting times together. In the case of a surgical outpatient in a DSH, the waiting time can be considered from the moment the patient enters the hospital until they perform the admission, from the moment they perform the admission until the moment the patient is called to be admitted in a bed by a medical assistant, or both waiting times.

The increase of waiting lines in the hospital reception can also lead to unnecessary costs to the hospital. Considering that the waiting lines lead to having patients still in the DSH after its supposed closing hour, would result in having to pay the health professionals for the extra working hours (or by working past the end of their shift). For these reasons, an efficient organization of both human and material resources can not only reduce the time in circuit of the surgical outpatient, but also improve the experience of the patients (and thus their satisfaction).

Several studies analyse the patient flow in order to detect the possible reasons that lead to the increased waiting time in the hospitals. The major causes that were suggested to lead to this problem were: the inefficient setting of patient scheduling time (leading to occurrence of large agglomerations of patients in certain times of the day) [77]; the lack of resources in order to give response to the patients (including the lack of space in the medical installations) [78]; and the lack of human resources to give response to the demand, being the latest one of the most observed causes of delay, specially in the ED and Outpatient Departments [73, 79].

Chapter 4

Simulation Model Development

Being the focus of this Dissertation the improvement of the surgical outpatient flow in *Hospital da Luz Lisboa*, given the alteration on the entrance of the inpatients that perform the admission on the same day as the surgery, the surgical outpatient circuit mapping was performed using a Flowchart. Afterwards, the possible causes for the delay of these patients were identified using an Ishikawa Diagram. Moreover in this Chapter, the three hypothesis for the simulation and the indicators that will be given as the simulation output, that will be used to understand the effects of the changing scenarios in the simulation, are defined. Furthermore, the data collection and analysis, as well as the simulation construction are also presented in this Chapter.

4.1 Surgical Outpatient Circuit Mapping

4.1.1 Flowchart

To understand the processes performed by the surgical outpatient, a flowchart was constructed taking into account not only the information given by the health professionals from *Hospital da Luz Lisboa*, but also by considering the observed on-site. This flowchart will be fundamental for the accurate design of the outpatient circuit on the simulation software. The flowchart in Figure 4.1 illustrates the outpatient circuit by mapping all the activities that the outpatients have to undergo during their hospital stay. Just like it was previously referred in Chapter 2, in *Hospital da Luz Lisboa* the outpatient circuit is characterized by three departments -the DSH, the OR and the PACU-, in the preoperative, the intraoperative and postoperative phase. Furthermore, the flowchart enables the detection of possible places where bottlenecks can occur, being this points relevant for the development of the simulation. When observing Figure 4.1, four possible bottleneck can be observed:

- Between the outpatient entrance in the hospital and the moment the patient is admitted in a DSH box.
- Between the finalization of the patient preparation in the DSH and the moment the patient is transported to the Transfer.

- Between the end of the procedure and the transport of the patient to the primary recovery (in PACU).
- Between the discharge of PACU and the transport of the patient to the secondary recovery (in DSH).

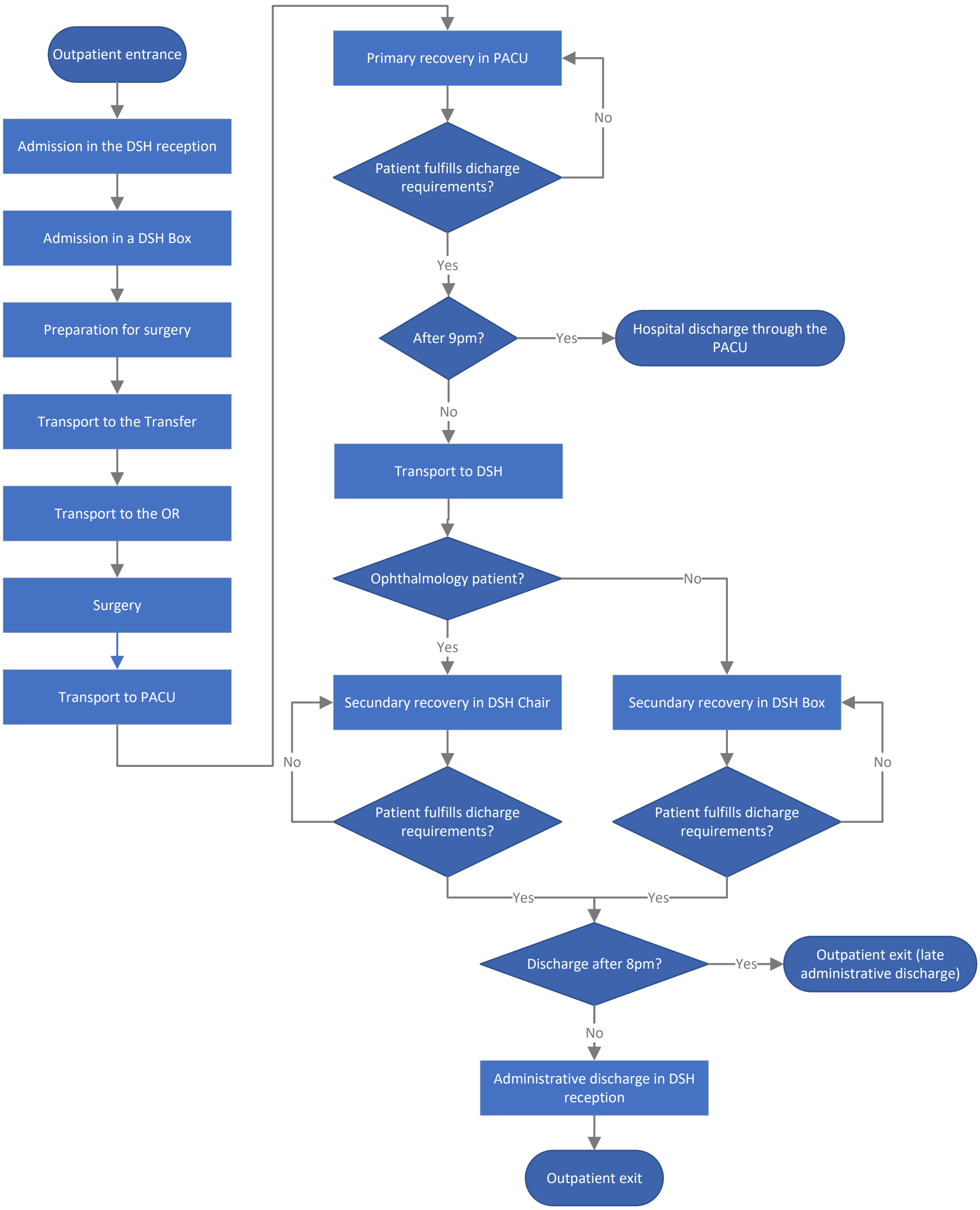


Figure 4.1: Surgical outpatient circuit flowchart.

4.1.2 Ishikawa Diagram

After the mapping of the activities in the process, it is important to understand the causes that can lead to the delay of the surgical outpatient circuit time. For this reason, an Ishikawa Diagram (or Cause and Effect Diagram) was constructed in order to understand the causes of the problem in study. The delays identified were majorly collected from feedback of the health professionals that work in the departments, along with the possible causes identified on-site. This Ishikawa diagram will allow to understand which factors should be improved in the simulation that is going to be developed in order to improve the surgical outpatients circuit. From Figure 4.1 it was possible to observe that the problem in study can be divided in three main moments: Preoperative Phase, Intraoperative phase and Postoperative phase. This three moments were considered as the categories or "main branches" in the Ishikawa Diagram from Figure 4.2. Consequently, each category was connected to several secondary causes which are described in the subsections bellow.

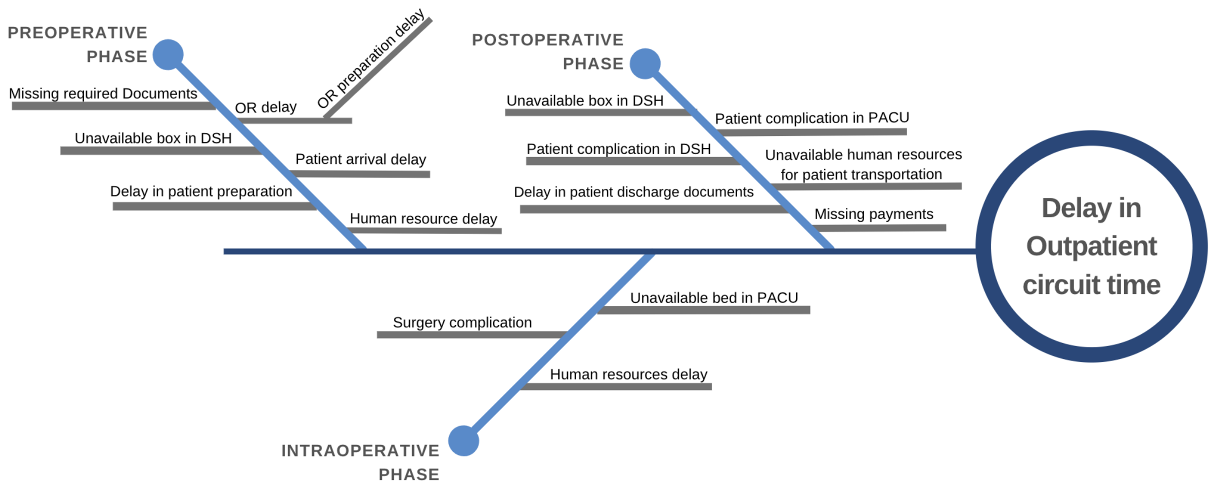


Figure 4.2: Ishikawa Diagram on the causes of delay in surgical outpatient circuit time.

Preoperative Phase

The Preoperative phase covers all the activities the patient must fulfill before the surgical procedure. Although in the simulation the patient episode starts on the moment the patient enters the hospital, the preoperative phase begins much earlier, from the moment the patient schedules the procedure. From this moment on, there are several documents that are required in order for the patient to be accepted for the procedure. One of these documents is the informed consent document, where the patients confirm that they are aware of all the risks and benefits that can come from the procedure and still consent to undergo it. This document must be sign voluntarily and while the patient is conscient. For this reason, the consent must be signed before the patient is sedated (which occurs in the OR). Furthermore, with the COVID-19 pandemic, the hospital requires for patients that are going to undergo surgery to present a negative Polymerase Chain Reaction (PCR) test before the surgery. It was possible to observe that sometimes patients did not have the test (resulting in a canceled surgery) or were still waiting for the result (which, when it was performed in the hospital, the patients were admitted in the DSH Box and wait in there until the result was known). Another reason for delay that was identified is if the patient does not arrive at the scheduled time at the DSH. *Hospital da Luz Lisboa* schedules the expected arrival time of a patient for approximately 2 hours before the time of the procedure, in case the patient is late (this time can vary depending on the procedure's speciality and on the time of day of the procedure). However, if the OR is ready before the estimated time of the procedure, they may contact the DSH earlier to notify that the patient can be transported to the Transfer. In case the patients are late, this delay may compromise the entire schedule of procedures throughout the day (especially if they are the first patients of the day). If the DSH is in full capacity, there is no space to receive new patients, thus creating a bottleneck on the DSH reception and increasing the circuit time of the new patients. This can occur if there are several patients being admitted at the same time (having a demand value bigger than the available response capacity) or if there are several patients that are returning from the primary recovery (from PACU), or both scenarios combined. If the OR is facing a delay in any of the procedures, the OR can not receive new patients in the Transfer, thus forcing the prepared patients in the DSH to wait in their DSH box. This would result in unnecessary occupancy of the DSH boxes and might lead to a bottleneck from both the new patients in the DSH reception and from the patients returning from the primary recovery. If in the moment the DSH nurse is preparing the patient (already admitted in the box), and there is a complication in the preparation, then not only the OR might have to wait for the patient (if they already contacted the DSH) but also the DSH will have one less nurse available (which during bigger rush hours, it could be a crucial human resource, influencing the number of patients that are prepared for surgery or monitored to be discharged). Finally, there could be a human resource delay in the patient admission, or in the patient preparation, due to being available at the moment (e.g. performing other tasks on that moment).

Intraoperative Phase

The Intraoperative phase of the surgical outpatient circuit contains all the processes that occur from the moment the outpatient enters the Transfer of the OR until the patient leaves the OR for the primary recovery (in PACU). Occasionally, the beginning of the procedure is delayed due to one of the physicians not being available in the scheduled time (e.g. surgeon or anesthetists). This occurs especially in the first surgeries of the day, in which the patients are already waiting in the Transfer, thus resulting in the procedure to begin after the standard hour, which in *Hospital da Luz Lisboa*, the OR begins to operate at 8am (excluding the urgent room which is always functioning in case of an emergency). Furthermore, this delay on the availability of the physician might lead to the delay of the following procedures scheduled throughout the day. Although some procedures can have an expected duration time (depending on the type of specialization), it always varies from patient to patient, so in case a complication occurs during the patient's surgery it can be a cause for an extension in the patient's circuit time. Moreover, this complication would also result in a delay of the circuit time of the following patients of the day. If the surgery is finished and the patient is ready to be transported to the primary recovery, but there are no available beds in the PACU, it could cause a bottleneck and represent a waste of resources (since it is blocking the use of the OR and of the nurses and doctors). Although it is not very common for this to occur, it should not be discarded, and the waiting time between the OR and the PACU should be analysed in the simulation.

Postoperative Phase

The Postoperative phase covers all the processes from the moment the patient arrives to the primary recovery in the PACU (following the surgical procedure) until the moment the patient receives the hospital discharge in the DSH. In this branch of the Ishikawa Diagram, several causes were detected for the delay of the outpatient circuit time. The primary recovery is a very sensitive moment, since a complication with the patient could represent an emergency intervention, resulting in needing to occupy an OR and the allocation of the OR human resources. For this reason, it requires the constant need for a nurse to monitor the patients, guaranteeing their normal recovery. If the patient presents a delay in the primary recovery, the circuit time will extend (and could lead to the blocking of the PACU capacity). Moreover, if the patient fulfills the requirements for PACU discharge, but there is no available box in the DSH, the DSH nurse and medical assistant can not transfer the patient, and the patient will be forced to stay in the PACU until a DSH Box is available. Similarly to the recovery in PACU, the patient secondary recovery time in the DSH varies on several factors such as the type of surgery, the anesthesia used and the patient (each patient takes its own time to recover). However, when there is a complication in the patient's normal recovery (e.g. the requirement to change the bandage), the length of stay of the patient in the DSH will increase (thus occupying a bed longer than expected). This problem is especially critical if the DSH is full of both pre- and postoperative patients, requiring a bigger demand for available beds. One of the requirements for the patient to leave the DSH is to receive the medical discharge (document signed by the surgeon referring that the patient presents the secure conditions to leave the hospital and continue the recovery at home). However, the surgeon can be occupied performing other surgeries, being impossible to go to the DSH to validate if the patients present the discharge conditions. When this occurs, the patients have to wait in their DSH box until the physician is available (which can lead to unnecessary waiting times and reduction of the patients' satisfaction). Afterwards, when the outpatients already received the hospital discharge, they will be guided to the DSH reception, where they will consult with the DSH administrative assistants if there is any anomaly with their process (e.g. to consult if there are any extra payments required). Although this process tends to be fast, in some cases it may extend the patient circuit time and occupy the DSH administrative assistants, making it impossible for them to receive other patients (which sometimes can be crucial).

4.2 Simulation

For this research, the number of required resources was analysed taking into account not only the patients' circuit and waiting time, but also the utilization of the several resources. This being said, the software *Simul8* (www.simul8.com/) was used to create three possible hypothesis, taking into account the feedback of the health professionals of the three departments, and the information collected on-site.

4.2.1 The Software

The *Simul8* software allows one to create a simulation of a process or system, thus enabling to manipulate resources and activities using specific distributions of time. From the several areas the system can focus on, healthcare is very used, especially in the analysis of possible ED scenarios (since it enables the analysis of patient waiting times throughout the circuit and the optimization of patient flow).

4.2.2 Patient Arrivals Hypothesis

Before considering how the surgical inpatient entrance modification can affect the surgical outpatient flow, an analysis of the current surgical outpatient flow should be performed in order to understand how the surgical outpatient circuit can be improved and, if there are any alterations, how they can adjusted for after the inpatient modification. This being said, three hypothesis for the DSH functioning were considered:

- H1. Current Patient flow (only a few inpatients enter through the DSH). The number of arrivals follows distributions computed from the data of 38 days.
- H2. All the inpatients that perform the admission on the same day of the procedure will enter through the DSH. The number of arrivals follows distributions computed from the data of 38 days.
- H3. Daily admission of 120 patients. Sixty outpatients (being 15 ophthalmology patients) and 48 inpatients enter through the DSH, and 12 inpatients enter directly through their IWB.

The first hypothesis is similar to the current scenario: all the outpatients enter through the DSH and only a few of the inpatients that have the admission on the same day as the procedure enter through the DSH (majorly first surgery patients). In this hypothesis, the DSH has 10 Boxes and three chairs, the OR has 12 rooms, and the PACU has 24 beds. The second hypothesis follows the purpose alteration of the Project Berlin (Chapter 2) where all the inpatients admitted to the hospital on the same day of the procedure enter through the DSH. The third hypothesis is a study proposed in the Project Berlin where, since the *Hospital da Luz Lisboa* expanded the OR to 16 rooms, a demand of 120 patients is expected after the construction works are concluded (resulting in approximately 7.5 surgeries per day, per operation room). From the 120 patients, 50% are outpatients (being 15 ophthalmology outpatients and 45 from other specialties), 40% are inpatients that do the admission through the DSH (48 inpatients) and 10% are inpatients that enter directly through their rooms (12 inpatients).

4.2.3 Simulation Output Indicators

The simulation software enables the user to obtain the results of specific indicators for several trials, thus allowing a more accurate analysis. The indicators that will be defined for the simulations to retrieve, are presented in Table 4.1. The indicators are separated for the two types of outpatients - ophthalmology and other specialties - and for the two type of inpatients - inpatients with admission through the DSH and inpatients with admission through the IWB. The average time values will be given in minutes and the utilization rate will be given in percentage (which afterwards will be converted in minutes, considering the duration of the simulation). A definition for each indicator is given in Appendix A (Tables A.1 and A.2).

Table 4.1: Simulation output indicators.

Type	Indicator
Outpatient	Average ophthalmology circuit time
	Average number of ophthalmology patients that complete the circuit before 8pm
	Average number of ophthalmology patients that complete the circuit after 8pm
	Average number of ophthalmology patients that received discharge from PACU
	Average other specialties circuit time
	Average number of other specialty patients that complete the circuit before 8pm
	Average number of other specialty patients that complete the circuit after 8pm
	Average number of other specialty patients that received discharge from PACU
Inpatient	Average inpatient that enter through DSH circuit time
	Average number of inpatients that enter through DSH that completed the circuit
	Average inpatients that enter through IWB circuit time
	Average number of inpatients that enter through IWB that complete the circuit
Waiting times (minutes)	Average time for the hospital admission (DSH reception)
	Average time for the patient admission into a Box
	Average time for the patient to go to surgery
	Average time for the patient to go to the PACU recovery
	Average time for the patient to go to the DSH recovery
	Average time for the DSH administrative discharge (DSH reception)
Resource utilization rate (%)	Average time rate for DSH administrative assistants
	Average time rate for DSH medical assistant
	Average time rate for DSH nurse
	Average time rate for DSH cleaning assistant
	Average time rate for DSH Box
	Average time rate for DSH chair
	Average time rate for OR assistant
	Average time rate for Operation Rooms
	Average time rate for PACU nurse
	Average time rate for PACU medical assistant
	Average time rate for PACU beds

These values will allow to analyse the effects in the allocation of resources (both human and material), and to understand the necessity of resources in the DSH after the entrance modification of the surgical inpatient that perform the admission on the same day as the procedure. Furthermore, the indicators will allow to understand which alterations should be perform to reduce the surgical outpatient circuit time. Moreover, it will enable to observe the amount of outpatients that concluded the circuit before the end of the DSH administrative assistants shift, at 8pm (allowing the patient to receive the administrative discharge). If a large number of patients finish the circuit in the DSH after 9pm, an extension of the DSH working hours should be taken into consideration. The waiting times outputs will allow to understand where possible bottlenecks in the circuit can occur (and where alterations should be performed to avoid them).

4.2.4 Data Collection

In order to develop the simulation, three sources of data were considered: the data obtained through the computer records (source 1), the data manually collected by the Nursing team of the DSH (source 2) and the data collected on-site by the researcher (source 3). The first two sources were analysed through the same interval of time of 45 days (between December 2020 and January 2021). The third source was collected during the visits to the DSH and the PACU of the *Hospital da Luz Lisboa* (during the months of March until September). This source was considered due to the lack of specific time activities in the computer and written records. Even though a big wave of COVID-19 cases was registered in Portugal in the month of January 2021 (leading the hospitals to be overwhelmed), it was still possible to obtain a good sample of surgical patients. An analysis of the three sources was performed in order to understand which data source provides the most accurate data to be used in the estimation of the activities distribution times, that will be given as input to the simulation. Since the DSH is only open from Monday to Saturday, Sunday was not considered in the studies. Furthermore, by analysing the number of surgeries that occur in each weekday (Figure 4.3) it is possible to observe that the number of surgeries that occur on Saturday decreases drastically when compared with the remaining weekdays. For this reason, the records of the surgeries performed on Saturdays were not considered to the research as it would influence the simulation and underestimate the number of arrivals per patient. Moreover, it is possible to observe in Figure 4.3 that there is a high number of surgeries of inpatients with entrance through the IWB. This elevated value is due to the fact that there are patients that were hospitalized during the weekend and had to wait until Monday for undergoing the surgery. Furthermore, the ophthalmology outpatients were considered differently from the other specialities outpatients, in the simulation, due to the fact that these patients occupy the DSH chairs in the DSH recovery (unlike the other specialities outpatients that occupy the DSH boxes).

It was observed that the source 1 had more complete and accurate information regarding the preoperative phase and the intraoperative phase of the patients than source 2, and for this reason, this source was considered for the estimation of the patient interarrival times distribution, for the duration of the surgeries and for the duration of the recovery in the PACU. From these three phases, the source 3 contains far less records than the other sources due to the smaller number of patient samples collected (not being a trustful source to retrieve the data regarding the patient arrival, and the duration of the procedure and primary recovery). Nevertheless, this source provided the data regarding the time duration of the patient in the DSH reception (both before and after the procedure), the time duration of the activities performed by the Nurse and the Medical assistant in the DSH (before and after the surgery), and of the activities performed by the Nurse in the PACU recovery. This information could not be obtained from either source 1 or 2. Moreover, source 3 allowed to estimate the time duration of the transport of the patient from the DSH to the Transfer and from the PACU to the DSH.

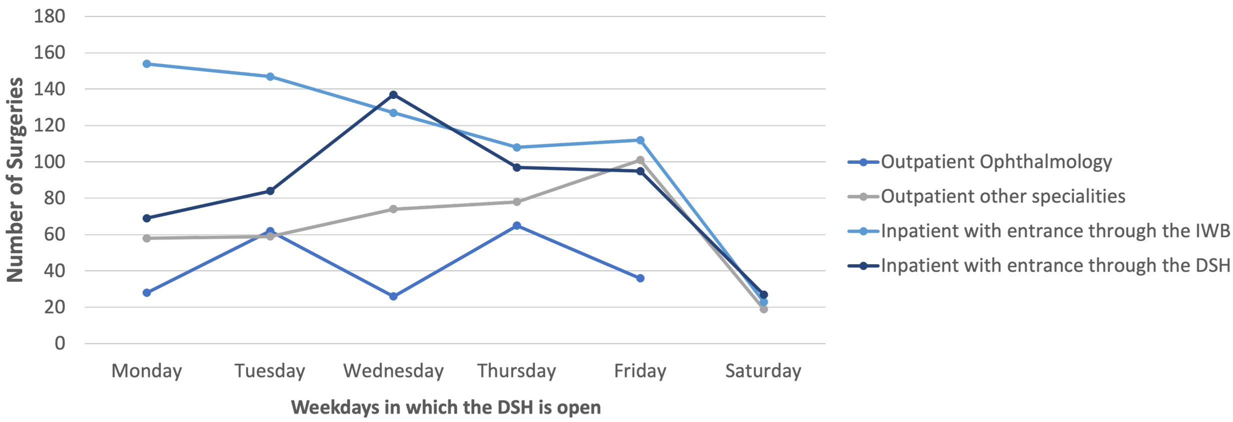


Figure 4.3: Number of surgeries per weekday during the 45 days.

4.2.5 Construction of the simulation model

In order to estimate which input time values should be given to the simulation, a data analysis was performed to understand which distribution best fitted the data sample. Although there are several goodness-of-fit tests, such as the Anderson-Darling, or the Kolmogorov-Smirnoff, in order to obtain a more precise analysis, the Information Criterion methods are more trustful. For this reason, the Akaike Information Criterion was considered to be the best choice for the distribution fitting test [34]. Using the Software *@RISK* from the company *Palisade* (www.palisade.com/risk/), it was possible to estimate the best distribution for the available data. The software uses the maximum likelihood function to determine the best distribution. Since the *Simul8* Software has only a few range of distributions that the users can use, from the top best goodness of fit distributions (computed by the *@RISK* software), the one with the best score, and that is also available to use in the simulations software, was considered. Alongside with the score, the top score distribution was also graphically visualized to understand if the distribution did follow the evolution of the real data. In some activities, such as the surgery time of the inpatients that enter through the IWB in hypothesis 1, the distribution did not follow correctly the data evolution (making the first patients to only be less than 5 minutes in the OR). If this occurred, the following distribution with the best score was analysed and used to replace the original distribution. The results of the estimations computed for the values that were calculated by the *@RISK* software, alongside with the size of the samples are presented in Table 4.2. The values of the parameters of the distributions are presented in Appendix B (Tables B.1 and B.2).

Table 4.2: Distributions fitting results.

Type of patient	Variable	Sample size	Distribution
Not specific	Admission in the DSH reception	8	Exponential
	Admission in a box (transportation)	10	Exponential
	Admission by the DSH Medical Assistant	8	Log-Normal
	Preparation by the DSH Nurse	16	Triangular
	Box cleaning	17	Exponential
	Patient transport to Transfer	12	Exponential
	Patient transport to PACU	6	Exponential
	Patient monitored by PACU Nurse	6	Exponential
	Bed change by PACU medical assistant	5*	Exponential
	Outpatient transport to DSH	5*	Exponential
	Administer discharge in DSH reception	10	Exponential
Outpatient (ophthalmology)	Interarrival time	216	Log-Normal
	Surgery time	215	Pearson V
	PACU recovery time	209	Exponential
	DSH recovery time	213	Pearson V
Outpatient (other surgeries)	Interarrival time	369	Exponential
	Surgery time	364	Pearson V
	PACU recovery time	359	Pearson V
	DSH recovery time	346	Gamma
Inpatient (through DSH) (H1)	Interarrival time	482	Exponential
	Surgery time	473	Gamma
	PACU recovery time	427	Pearson V
Inpatient (through IWB) (H1)	Interarrival time	648	Exponential
	Surgery time	632	Pearson V
	PACU recovery time	578	Pearson V
Inpatient (through DSH) (H2)	Interarrival time	998	Exponential
	Surgery time	632	Pearson V
	PACU recovery time	913	Pearson V
Inpatient (through IWB) (H2)	Interarrival time	132	Gamma
	Surgery time	124	Gamma
	PACU recovery time	92	Pearson V

The * symbol on the values of Table 4.2 indicates that the sample size has the minimum size required for the *@RISK* software to compute the distribution. The distributions used in hypothesis 3 were the same used in hypothesis 2.

4.2.6 Simulation Patient Moments

As previously referred, the focus of this study was to understand what resource changes the *Hospital da Luz Lisboa* needed to make in order to relocate the entrance point of the surgical inpatients with the admission on the same day as the surgery, from the IWB to the Day Surgery Hospital. For this, the optimization of the surgical outpatient circuit is essential (since this patient's circuit passes through the

DSH in the preoperative and postoperative phase). For this, the passing of the patient through the DSH, the OR, the PACU and again through the DSH were analysed. In this subsection, the requirements for each step of the circuit simulation will be defined. The shifts of the human resources were provided by the head nurse of each department. Although the DSH is only operating from 7am to 9pm, the simulation is defined to begin at 7am and end at 0am (in order to make sure that all the patients are able to finish the circuit and to analyse the possibility of extending the functioning time of the DSH). Moreover, in Appendix C, the human resources shifts that were given as input to the simulation are presented.

Day Surgery Hospital (Preoperative Phase)

In the simulation, the DSH was divided in Preoperative and Postoperative phase, to enable the simulation software to differentiate between both the circuit phases. In the Preoperative (Figure 4.4), three patient entrances were defined- only outpatients of ophthalmology, outpatients from other specialities, and inpatients who performed the admission through the DSH-, being each one defined with an interarrival time distribution adjusted to the data extracted from the computer records (Table 4.2). Furthermore, in each entrance the patient receives a numerical label that will help in the rooting out options along the simulation. The Label ”Patients” is given in the following order:

1. Outpatient from the ophthalmology speciality.

2. Outpatient from other speciality (excluding the ophthalmology speciality).

3. Inpatient with the admission through the DSH.

4. Inpatient with the admission through the IWB.

In each entrance point, a constraint for the number of patients was given to avoid a larger number than the expected. The constrain values were determined taking into account the maximum value of patients that arrived to the DSH in the 38 days in study, and are presented in Table 4.3. Furthermore, a constraint for the arrival period of the patient was also given to the simulation, since after a certain hour, there are no arrivals registered. This last constraint is given in minutes and is counted from the moment the simulation begins (e.g. the ophthalmology outpatients arrivals occurred until 5pm, which is 600 minutes after the beginning of the simulation, at 7am).

Table 4.3: Simulation constraints for the ophthalmology outpatients (A), other specialities outpatients (B), inpatients through the DSH (hypothesis 1) (C), inpatients through IWB (hypothesis 1) (D), inpatients through the DSH (hypothesis 2) (E), inpatients through IWB (hypothesis 2) (F).

Entrance Point	A	B	C	D	E	F
Maximum number of patient arrivals	16	22	23	31	37	7
Maximum period of arrival (minutes)	600	630	720	750	-	-

Afterwards a queue was defined in order to understand the hospital reception waiting time, before the patient performs the administrative admission. Afterwards, three activities for the admission were defined, each associated to the resource ”DSH administrative assistant” and with a distribution computed using the *@RISK* Software. It is important to note that the reception of the DSH also serves as the reception for the preoperation anesthesia appointments. However, the flow of those patients was not computed in the simulation, due to not being possible to implement this specific flow in the simulation. This being said, the output utilization rate of the DSH administrative assistants can be lower than the reality due to not taking into account the preoperation anesthesia appointments or other taks that DSH administrative assistants perform when there is no patient that needs to perform the admission or to obtain the administrative discharge. Nevertheless, the utilization rate can still provide an important visualization of the effect of an increase demand and the need for more of this type of human resources. Moreover, when the patients finish the admission they will go to a queue while waiting for a DSH medical assistant to admit them into a DSH Box (room). When both a box and a DSH medical assistant are available, there is an activity representing the patient transport from the DSH reception to the Box (this activity is associated to the resource DSH medical assistants) and follows a computed time distribution (Table 4.2). When in the Box, the patient will have a group of three activities - the welcoming by the DSH medical assistant, followed by the preparation of the patient by the nurse, and the waiting in the Box until the OR contacts the DSH staff in order to signal them that the patient can be transported to the Transfer. Each group is defined to only allow a patient at a time in it, avoiding that a patient is admitted into a box that is still being occupied by another patient. When the patient leaves the box, a cleaning activity of the box is activated and is associated to the resource ”DSH cleaning assistant”. The simulation considers this as a breakdown of the activity, and is defined to be activated every time a patient passes through the activity. If the breakdown is activated before the patient finishes the activity, the patient will be able to finalize the activity and only afterwards the cleaning of the box will begin. No new patients will be received in the box until it is cleaned and available again. There are 10 box groups in the simulation at this moment of the patient circuit, each composed of the following resources: one DSH medical assistant, one DSH nurse, and the activity of the box that the patient is occupying (in this activity, the patient only requires the resource of the box where they are). These box groups are activities connected together, in the simulation, allowing for the user to compute how many patients can be in the group at the same time. Furthermore, it was defined that when the patients enter the boxes, they will grab the resource associated to the box, in order to avoid conflict with the recovery patients that are arriving to the recovery in the DSH (in the postoperative phase). In the end of the DSH stay, the patients will let go of this resource.

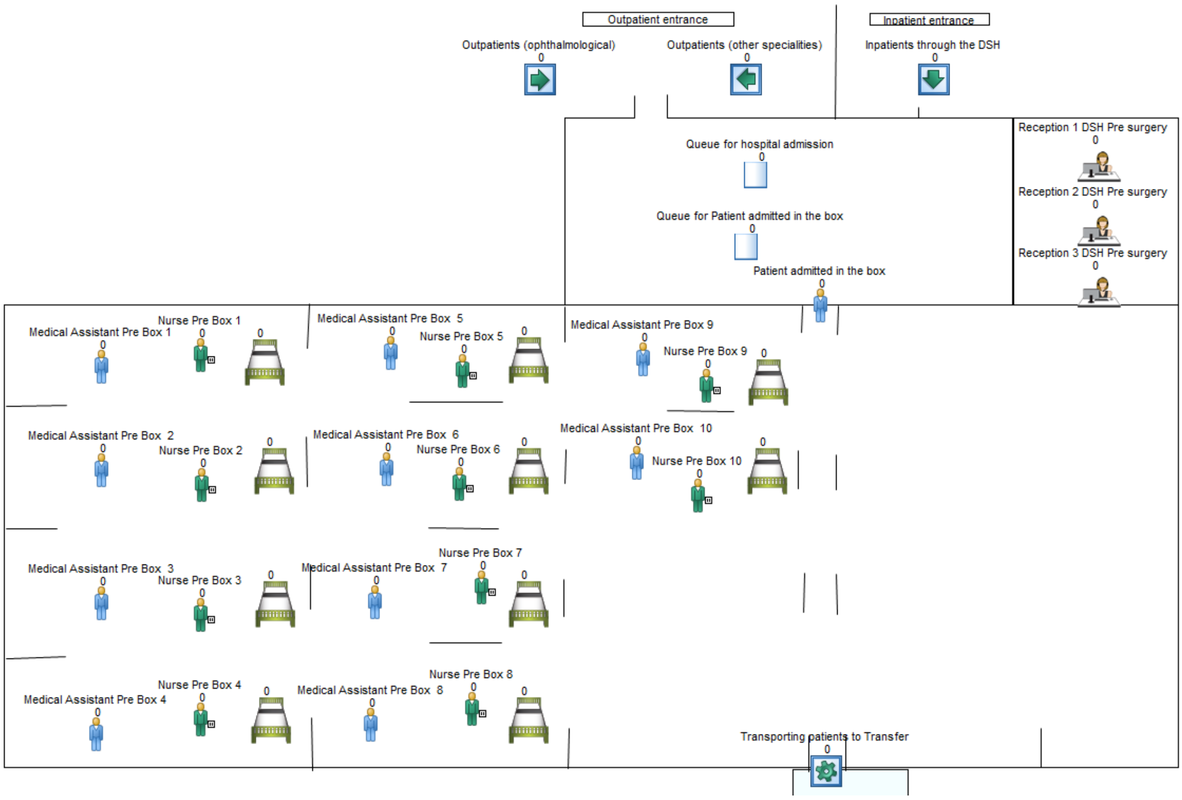


Figure 4.4: Simulation of the Day Surgery Hospital in the preoperative phase.

Operation Room

When the Transfer contacts the DSH in order to notify that the patient can be transported to the Transfer, an activity was defined to represent the transport moment. Depending if the patients are outpatients or inpatients, the resource that will perform the transport is the DSH medical assistants or OR assistants, respectively (Figure 4.5). When in the Transfer, the patients will join a queue that symbolizes the patients stay in the Transfer until they are transported to their Operation Room. The queue was computed with a limit of eight patients (maximum capacity available on the Transfer), and the waiting time of the queue will allow to understand the amount of time that the patients have to wait in the DSH (before going to surgery), since the patients are only transported to the Transfer when an OR is available (or almost available). This will enable the detection of bottlenecks in this moment of the circuit. Moreover in this department, another entrance spot was defined for inpatients that enter through the IWB. These patients are transported by an OR assistant into the queue of the Transfer. An activity is defined between the entrance point and the Transfer queue, to require the resource OR assistants. However, no time was defined for the transport, since it was not possible to collect this information (by requiring the OR assistant resources, it is possible to understand if there is a moment when no inpatients can be transported from the DSH to the Transfer, since all the OR assistants are transporting the inpatients from the IWB to the Transfer). When an OR is available and ready, the patient will be transferred into it for the procedure. Since in the *Hospital da Luz Lisboa* the OR has a standard beginning time at 8am, the resources "Operation Room" are defined to not receive any patients before this hour. The OR activities time varies, depending of the value of their ”Patients” label (Table 4.2). When the procedure is finished, the patient will be directed to another queue, in the simulation. This queue only allows a person at a time, and, similar to the queue in the Transfer, it will provide the waiting time between the OR and the PACU. There are 12 OR activities in the simulation, each associated to the resource ”Operation Room” and each is defined to follow a cleaning time with a Triangular distribution. The OR cleaning time was the only data of the patient circuit that was not possible to measure. The only thing known is that it can vary between 10 to 15 minutes (for this reason, a Triangular distribution was considered for this activity time). The cleaning of the OR is performed by the resource ”OR medical assistants” and is activated after each patient passes through the OR (similar to the boxes of the DSH).

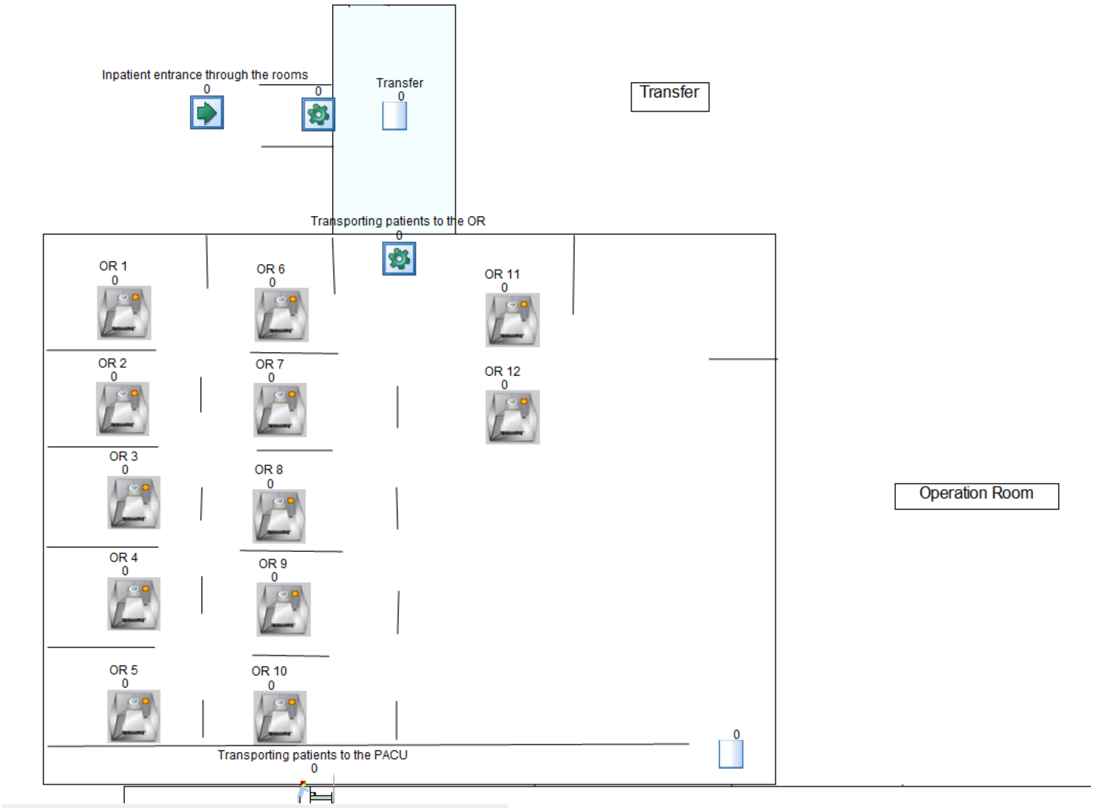


Figure 4.5: Simulation of Operation Room.

Post-Anesthesia Care Unit

For the PACU section of the simulation, 24 groups of activities were defined, each representing a PACU bed (Figure 4.6). The group is constituted of the PACU nurse and of a PACU bed. The nurse will monitor the patient, and analyse if the patient has the conditions for the PACU discharge. The resources associated to the activities are the ”PACU nurse” and the resource ”PACU bed x”, where x is the number of the bed (range between 1 to 24). The second activity of the group is the time the patient actually stays in the bed recovering (without needing the use of the nurse resource), the distribution associated to the evolution of this time varies, depending of the patient (Table 4.2). The second activity of the group is only associated to the resource ”PACU bed x”. Similarly to the DSH groups, the PACU bed groups are computed in order that only 1 patient at a time can be in the group (avoiding that a new patient enters a bed that is still being occupied). The time of the activity ”Nurse PACU” was obtained from the on-site measures (average time of 24.17 $\pm$ 11.63 minutes). Afterwards, this 24.17 minutes of the PACU nurse monitoring were subtracted to the values of the patient’s PACU length-of-stay, from the computer records (source 1), thus enabling the separation of the time the patient is using the PACU nurse and the time the patient is only occupying a bed. When the patients finish their recovery, and present the discharge requirements, they will receive the PACU discharge. Afterwards, the patients will be directed to an activity (that has not time distribution associated), and from this activity (Figure 4.7), depending on the type of patient, and on the ”Patients” label value associated to them in the entrance point, they will go to:

1. Ophthalmology outpatients will go back to the DSH.
2. Other specialities outpatients will go back to the DSH.
3. Inpatients with the admission through the DSH will go to a bedroom in the Inpatient Ward.
4. Inpatients with the admission through their IWB will go back to their bedrooms in the Inpatient Ward.

Considering that the outpatient only receives the PACU discharge after 9pm (which is the closing hour of the DSH), the patient will not be transported to the DSH. For this, a constraint was defined in the simulation to direct the patient to a end point, representing the patient’s hospital discharge directly from the PACU. The constraint was defined in minutes, counting from the beginning of the simulation (more specific 840 minutes).

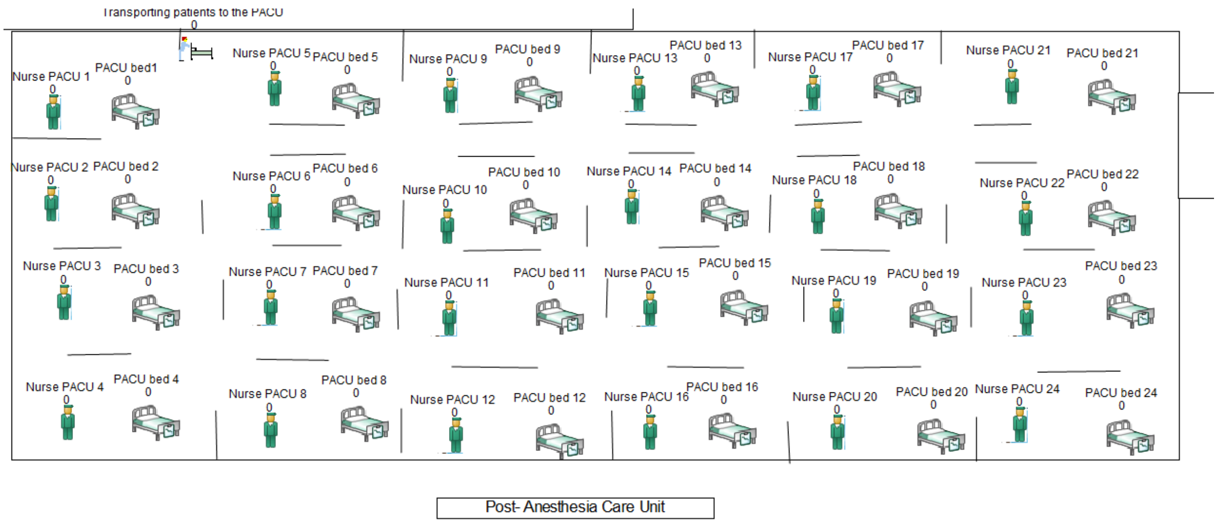


Figure 4.6: Simulation of Post-Anesthesia care unit simulation.

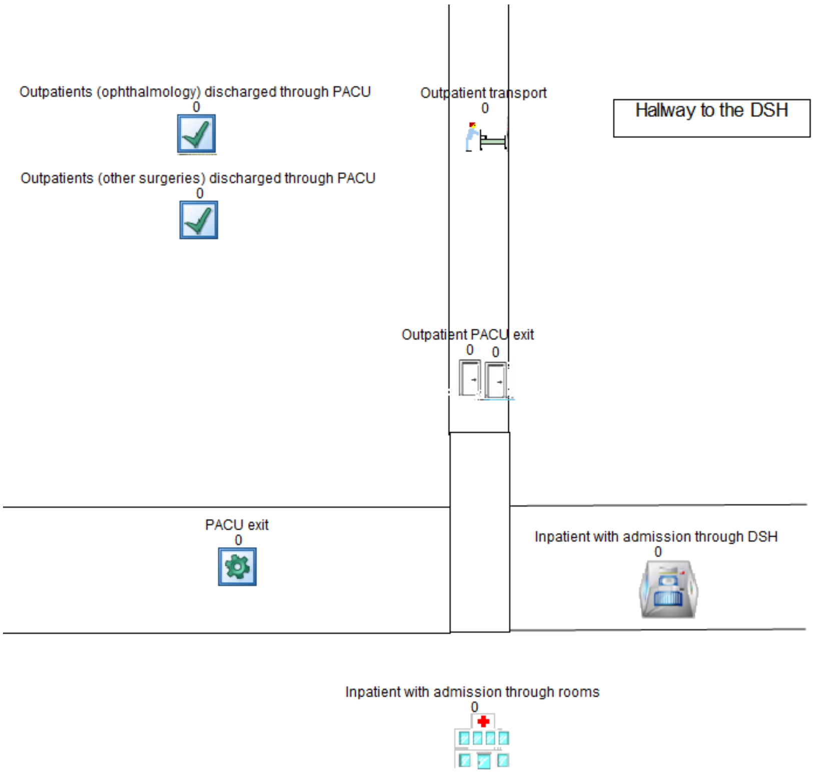


Figure 4.7: Simulation of Post-Anesthesia care unit simulation exit and hallway to DSH.

Day Surgery Hospital (Postoperative Phase)

When the outpatient receives the PACU discharge in the simulation, and if the discharge is before 9pm, the patient will be conducted to a queue that will enable the user to monitor the waiting time between the PACU and the DSH. Furthermore, the outpatients will be transported back to the DSH with a time distribution associated to them and with two resources - a DSH nurse and a DSH medical assistant. Depending on whether the ”Patients” label indicates that the outpatients are from the ophthalmology speciality or not, they will be directed into a chair or a box, respectively (Figure 4.8). There are 10 groups of activities representing the DSH boxes, each box is using the same resource than the box in the preoperative phase in order to avoid two patients using the same resource (e.g. the box 10 in the DSH-preoperative phase is using the same resource ”BDSH10” that the box 10 in the DSH-postoperative phase is using). Furthermore, there are three groups representing DSH chairs, that are only used for the ophthalmology patients recovery. Each group is computed to only accept a patient at a time, and has an activity associated to the DSH medical assistant (e.g. to bring the patient something to drink and eat), and an activity related to the DSH nurse, which represents the patients being monitored and also analysed to see if they gather the proper conditions for DSH discharge. Both the activities have time distributions associated, which were calculated using the data collected on-site (source 3). Furthermore, the average time spent in these two activities were obtained from the on-site measures (for the ophthalmology outpatients is 9.69 ± 2.97 minutes and for the other speciality outpatients is 12.69 ± 5.27 minutes). These values will be subtracted to the remaining time of the activity representing the recovery that will be spent on the Box/chair, following a time distribution obtained from the DSH nurses records (source 2). Similarly to the preoperative phase DSH, it was defined that when a patient passes through a box/chair, a breakdown is activated and the box has to be cleaned by the resource ”DSH cleaning assistant”, following a calculated time distribution. When the patients present the proper conditions for discharge, they will receive the medical discharge and go to the DSH reception (to receive administrative discharge). Depending on the time the patient received discharge, three possible pathways were defined:

- If the discharge occurs before 8pm, the patients will be directed to a queue where they will wait for a DSH administrative to be available (to take care of the administrative discharge). After the administrative discharge, they will be directed to a specific exit point (depending on the type of outpatient).
- If the discharge is between 8pm and 9pm, the patients will go directly to the exits ”Ophthalmology outpatients exit before 9pm” or ”Other speciality outpatients exit before 9pm”, depending on the ”Patients” label value.
- If the discharge is performed after 9pm, depending on the ”Patients” label value, the patients will go directly to the exits ”Ophthalmology outpatients exit after 9pm” or ”Other speciality outpatients exit after 9pm”.

The time distributions used in the activities of this moment were determined using the software *@RISK*, and the results are listed in Table 4.2.

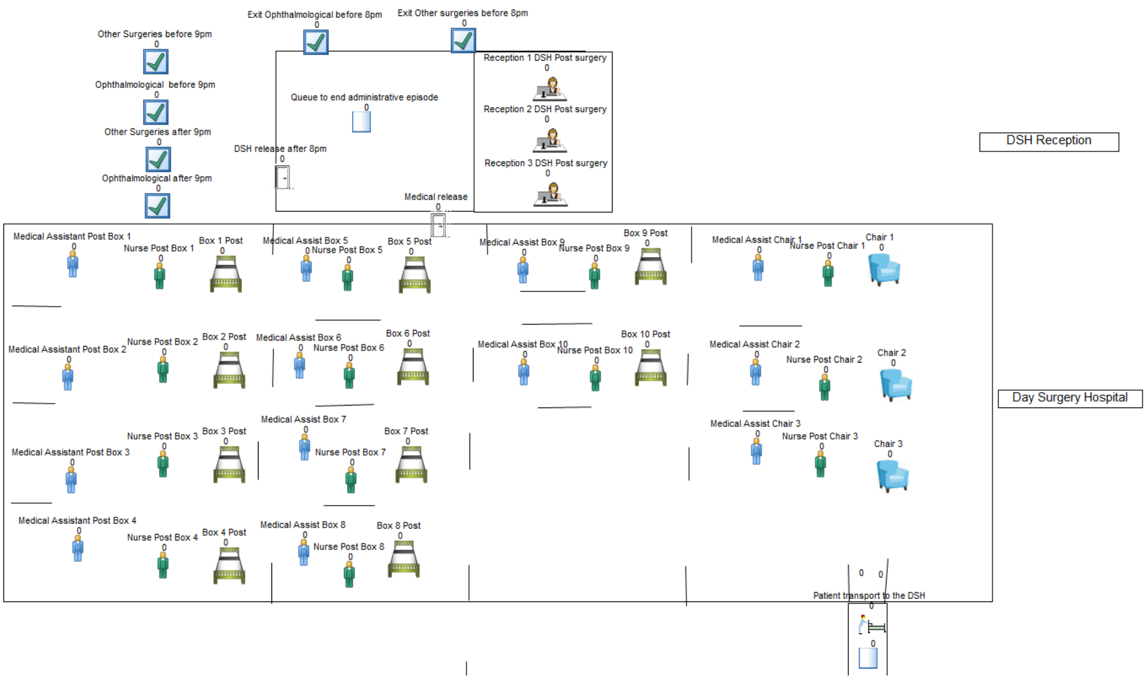


Figure 4.8: Simulation of Day Surgery Hospital Postoperative phase.

Chapter 5

Results

In the following chapter, the output results obtained for each hypothesis were analysed taking into account the variations in the material resources and in the human resources. The main indicators that were taken into account were the circuit time of outpatients that ended the circuit before 8pm, the number of outpatients that ended the circuit before and after 8pm, and the utilization rate of the several resources. Furthermore, the waiting time in the DSH reception (after admission) and the waiting time in the DSH to be transported to the OR were also considered as important indicators. According to studies already performed in the analysis of patient's satisfaction and waiting time in the hospital reception (after hospital admission), the ideal waiting time in the hospital reception, after admission, is 30 minutes or less [74–76]. In Figure 4.2 it was possible to notice that most concerns to the delay of the patient's circuit are associated to the lack of resources (material and human) in the several departments of the circuit moments. For this reason, an analysis of the variation of these resources was performed, allowing to understand the effects that this modification has in the circuit time of the outpatients that finish the circuit before 8pm.

5.1 Hypothesis 1

The hypothesis 1 consists on the current functioning of the DSH, following the resource numbers that were referred in the previous section (Figures 4.4 - 4.8). It was possible to compute the current average circuit time for outpatients (from the ophthalmology speciality and other specialities) that finish the circuit before 8pm (still being able to receive the administrative discharge by the DSH administrative assistants at the proper time). In Figure 5.1 these average circuit times are presented for 50 simulation tests. It was possible to observe that the average circuit time for ophthalmology outpatients varies between 150 minutes and 300 minutes, and for other speciality outpatients varies between 300 minutes and 500 minutes.

In order to validate the veracity of these results, the real circuit time of the outpatients was computed taking into account the computer records, which are presented in Appendix D (Figures D.1 and D.2). Although there are a few underlinings in the circuit time values, it was possible to observe that the range time is very similar to the ones obtained in the simulation, contributing to its validation.

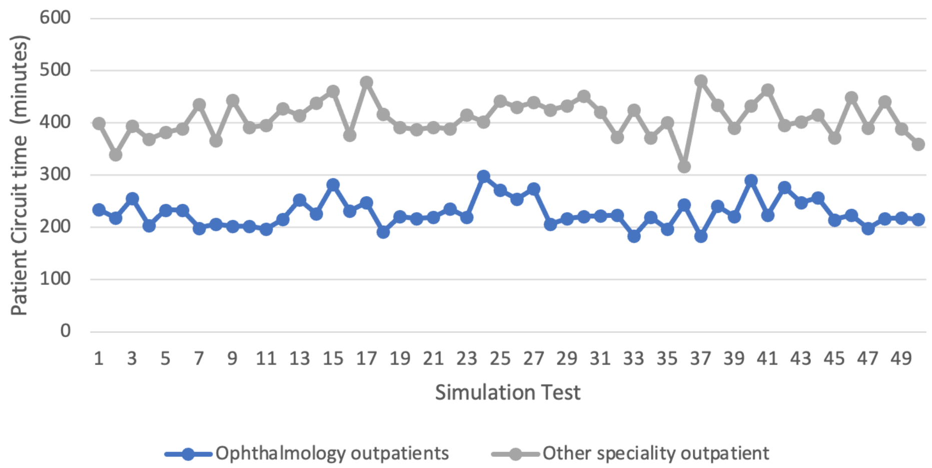


Figure 5.1: Average circuit times of outpatients that finish the circuit before 8pm, for the current scenario (H1).

Furthermore, the expected arrival of patients to the DSH was computed taking into account the computer records of the admission time of 1069 patients. In Figure 5.2, the number of arrivals through 38 days is presented. As it can be observed, there is a large demand of patient arrivals in the first periods of the morning, followed by a quick reduction. In the beginning of the afternoon, a small increase in the patient arrivals is observed again, followed by a reduction until the middle of the afternoon. After 6pm there are no records of patient arrivals. Moreover, it is possible to observe that there is a larger amount of inpatient arrivals in the morning and a larger amount of outpatient arrivals in the afternoon. This occurs because, currently, most of the inpatients that are indicated to perform the admission through the DSH, are first surgery patients (first patients to occupy the OR).

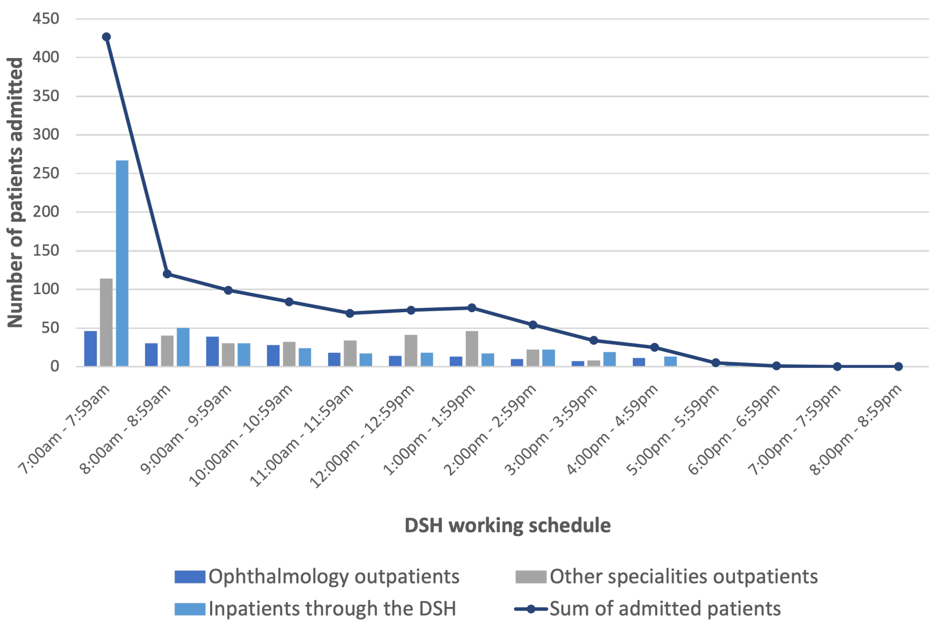


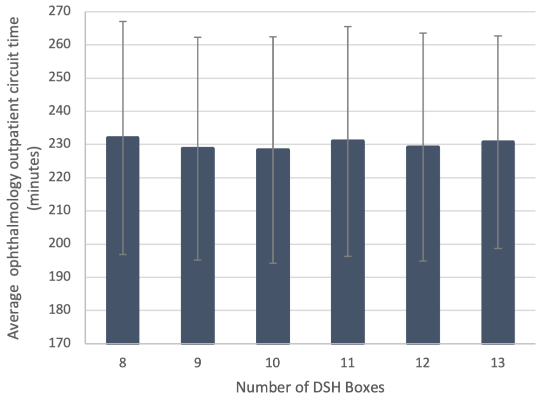
Figure 5.2: Patient arrival through the DSH working schedule (H1).

Variation of material resources

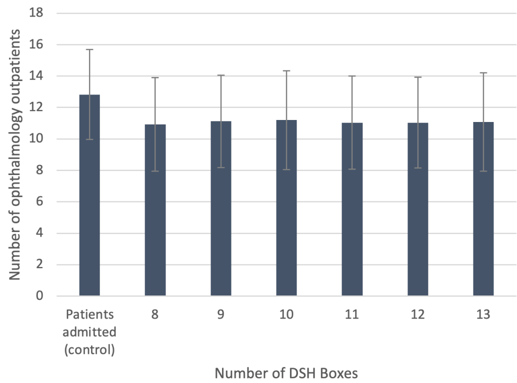
In the Ishikawa Diagram (Figure 4.2), one of the most identified causes for the delay of the surgical outpatient circuit is the lack of available boxes in the DSH, ORs or PACU beds. For these reasons, several scenarios were considered in order to understand the effects in the reduction of the average circuit time, and also to detect possible unnecessary resources that can be removed without compromising the circuit time. Firstly, an analysis on the effect of the variation of DSH box number was performed. It was expected that with the increase on the number of available boxes, there would be a decrease in the patients circuit time. In the Figure 5.3 the DSH variation was analysed for the two types of outpatients. The ophthalmology outpatients were considered differently from the other specialities outpatients, since they occupy the DSH chairs in the DSH recovery (unlike the other specialities outpatients that occupy the DSH boxes).

As it can be observed in Figure 5.3 (a), the variation on the number of DSH boxes does not present a significant variation in the average patient circuit time, since the current resources are able to give response to almost every patient that arrives to the DSH. Furthermore, it is possible to observe that a decrease on the number of boxes would represent a slight increase on the circuit time (due to the DSH having less available space to receive patients). Moreover, it is important to note that the slight increase in the average circuit time of the ophthalmology outpatient, for the scenario of 11 DSH boxes, can be explained by the variation in the distribution used to describe the patients time in the preparation activities. For example, with more boxes, it is possible to receive more patients in the DSH, and if inpatients or other speciality outpatients perform the preparation faster than the ophthalmology outpatients, they will occupy the OR faster, thus forcing the ophthalmology outpatients to wait in the DSH box a little longer than with the other scenarios, causing a slight increase in the ophthalmology outpatients circuit time. Moreover, since the ophthalmology outpatients only use the DSH box when they are being prepared for surgery (preoperative phase), it was expected that an increase in the DSH box number would not represent a critical effect on this type of outpatients circuit time (except if the number was inferior to the current, possibly causing a bottleneck on the circuit). The following statement can also be seen in Figure 5.3 (b), where the average number of patients that concluded the circuit before 8pm did not present big changes with the variation on the number of DSH boxes.

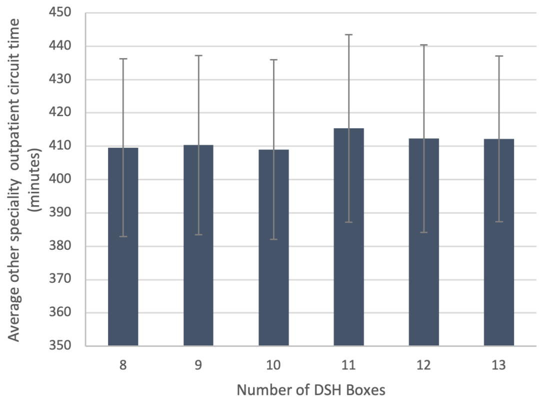
For the other speciality outpatients, it is possible to observe in Figure 5.3 (c) that a decrease in the number of DSH boxes to 8 would represent an increase on the outpatient's circuit time, as expected. Furthermore, it is possible to observe, once again, an increase on the circuit time when there are 11 DSH boxes, being a result of the patient's time variation in the DSH stay. In the simulation, it was not possible to completely mimic the patient's arrival to the hospital (more specifically in the first hours of the day). This can be seen at the beginning time of the OR (8am), since not all ORs are occupied. Nevertheless, it still enables to observe that the evolution of the arrivals throughout the day resembles the reality. When collecting service times on-site in the DSH, it was possible to observe that although there was a big demand in the morning, there were still DSH boxes available to give response. So it is expected that an increase on the DSH boxes would not lead to an increase on the number of patients that finish the circuit before 8pm, as it can be seen in the Figure 5.3 (d). It is important to note that in all simulations, the waiting time, after hospital admission, to be admitted in a DSH box was always inferior to 1 minute. In the real scenario, it was observed that for a sample of 31 patients, the average waiting time to be admitted in a box was 8 $\pm$ 7.01 minutes. This differentiation is explained because it is not possible to insert, in the simulation, certain side tasks performed by the DSH staff, such as the moment from when the DSH medical assistants receive the notification of the patient's arrival to the moment when they notify the DSH nurses (in this moment the DSH medical assistants will decide in which room the patient will stay, only afterwards they will go the DSH reception to receive the patients and admit them in a DSH box). Nevertheless, a small waiting time in the hospital reception indicates a good patient management by the team, and leads to a good satisfaction rating by the patients.



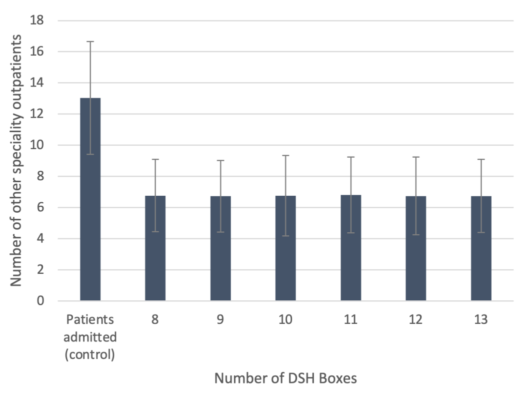
(a) Average circuit time for ophthalmology outpatients that finished the circuit before 8pm, for the several box scenarios.



(b) Number of ophthalmology outpatients that finished the circuit before 8pm, for the several box scenarios.



(c) Average circuit time for other speciality outpatients that finished the circuit before 8pm, for the several box scenarios.

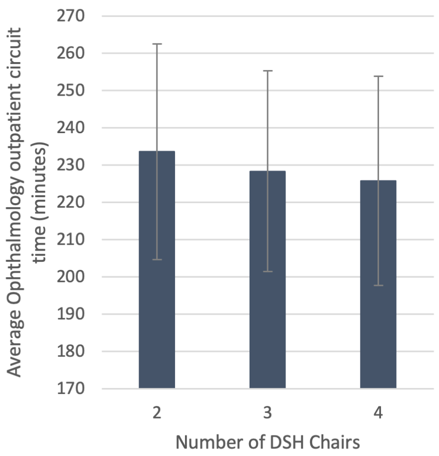


(d) Number of other speciality outpatients that finished the circuit before 8pm, for the several box scenarios.

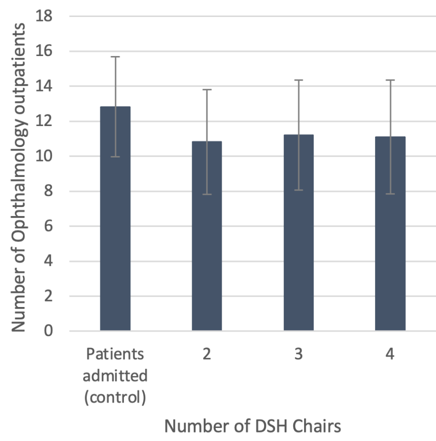
Figure 5.3: Effects of the variation of the number of DSH boxes in the average number and circuit time of outpatients that finished the circuit before 8pm (H1).

The variation in the number of DSH chairs was also analysed and represented in the Figure 5.4. As expected, the decrease in the number of chairs leads to an increase in the average circuit time of ophthalmology patients (due to creating a bottleneck in the system for this type of patients), and an increase in the number of chairs leads to a decrease in the average circuit time (due to having more available chairs for the recovery of these patients) (Figure 5.4 (a)). Moreover, as expected, these variations can also be seen in the average number of patients that finish the circuit before 8pm (Figure

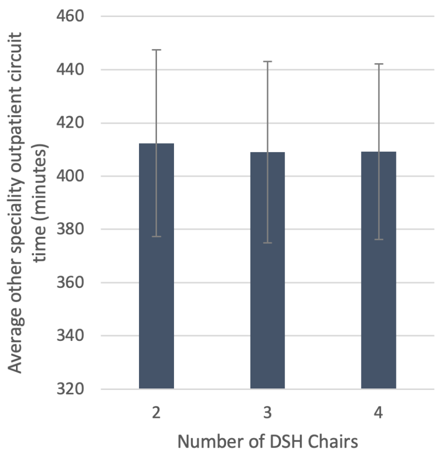
5.4 (b)). With two chairs the average number of ophthalmology outpatients that finish the circuit before 8pm, decreases to 10.82 $\pm$ 2.988 minutes, but with four chairs, the value is very similar to the one with the current number of chairs. Since the DSH chairs are only used in the recovery of ophthalmology patients, a variation in the number of these resources does not present a critical variation in the average circuit time (Figure 5.4 (c)) and in the average number of other speciality outpatients that completed the circuit before 8pm (Figure 5.4 (d)).



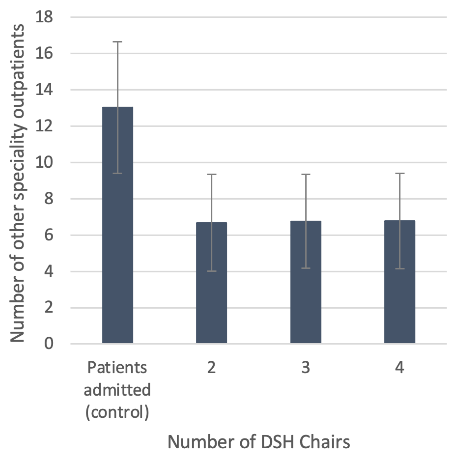
(a) Average circuit time of ophthalmology outpatient that finished the circuit before 8pm, for the several DSH chair scenarios.



(b) Number of ophthalmology outpatients that finished the circuit before 8pm, for the DSH chair scenarios.



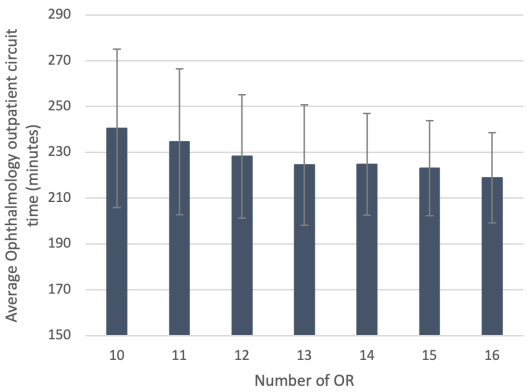
(c) Average circuit time of other speciality outpatient that finished the circuit before 8pm, for the several DSH chair scenarios.



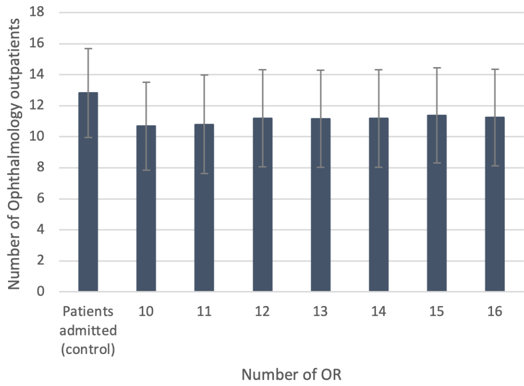
(d) Number of other speciality outpatients that finished the circuit before 8pm, for the DSH chair scenarios.

Figure 5.4: Effects of the variation of the number of DSH chairs in the average number and circuit time of outpatients that finished the circuit before 8pm (H1).

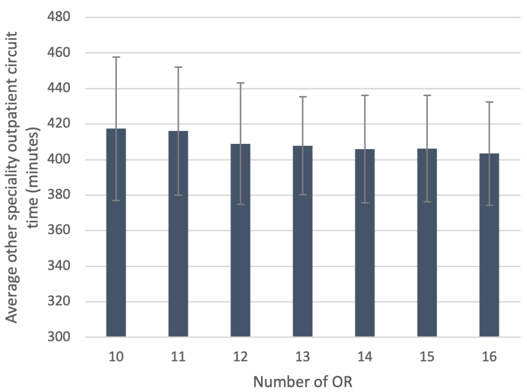
Initially, the OR had 10 rooms (plus one emergency room), however with the new expansion plan, six more rooms were approved to be constructed (resulting in a final value of 16 OR, plus one emergency room). When the computer records were collected, there were already 12 OR functioning. In order to understand the effects that the OR expansion has in the average circuit time of the outpatients, with the current patient demand, several simulations were performed, varying the number of OR between 10 (initial value) and 16 (final value). In Figure 5.5 the effect of these alterations was analysed for ophthalmology and other speciality outpatients that concluded the circuit before 8pm. Since an increase in the OR would result in an increase in the available resources to give response to the patient demand (specially in the moments of bigger demand), it is expected that not only the circuit times decrease with the increase of the OR number, but also that more outpatients will be able to finish the circuit before 8pm. As expected, in Figures 5.5 (a) and (c), the outpatients average circuit times decrease with the increase in the number of OR. However, in the Figures 5.5 (b) and (d) it is also possible to observe that an increase in the OR would not present a variation in the scenarios with more than 12 OR. In Figure 5.5 (d), it is possible to note that there is a smaller average number of other speciality outpatients that finish the circuit before 8pm than expected (the other outpatients exit after 8pm). It is important to refer that since the simulation provides a theoretical approximation of the surgical outpatient circuit, it is possible that in the real scenario, the outpatients would majorly leave before 8pm. Furthermore, it was possible to observe in Figure 5.6 that the average utilization rate of the OR resource is bigger than 50% for 13 OR or less. This being said, and due to the elevated costs that take to keep an OR functioning, the current number of 12 OR would be the most cost-efficient option to respond to the current demand. Furthermore, similar to the variation of the DSH boxes and chairs, the patient waiting time in the hospital reception is smaller to 1 minute in every scenario.



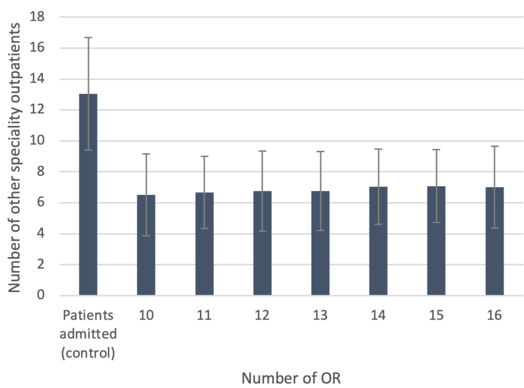
(a) Average circuit time for ophthalmology outpatient that finished the circuit before 8pm, for the several OR scenarios.



(b) Average number of ophthalmology outpatients that finished the circuit before 8pm, for the OR scenarios.



(c) Average circuit time for other speciality outpatients that finished the circuit before 8pm, for the OR scenarios.



(d) Average number of other speciality outpatients that finished the circuit before 8pm, for the OR scenarios.

Figure 5.5: Effects of the variation of the number of Operation Rooms in the average number and circuit time of outpatients that finished the circuit before 8pm (H1).

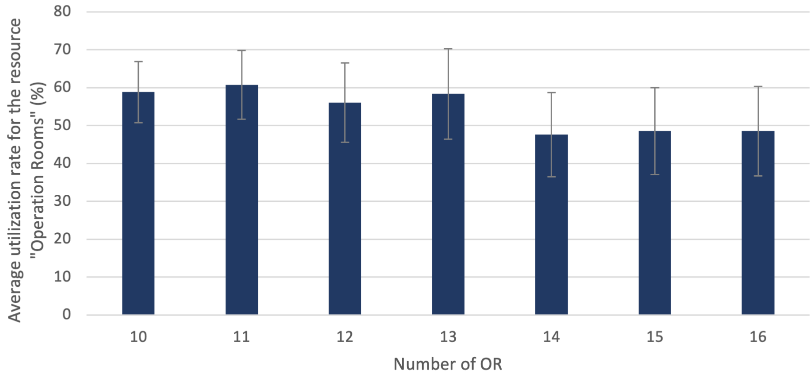
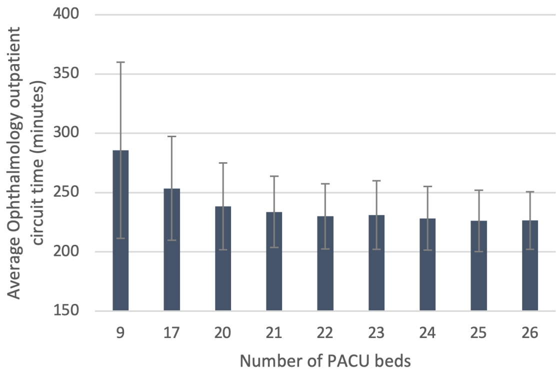
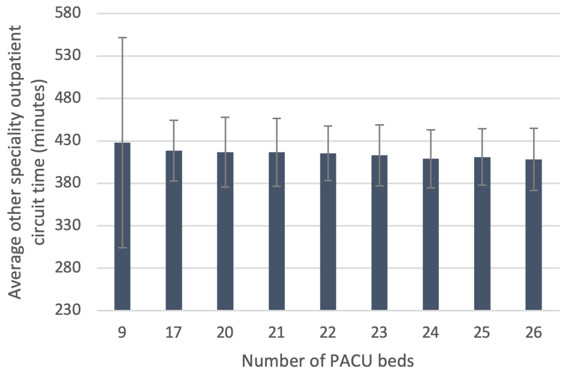


Figure 5.6: Average utilization rate for the resource ”Operation Room” (H1).

Finally, the effects of the variation in the number of PACU beds were analysed for different scenarios. Similarly to the OR, before the expansion plan, the PACU had a smaller number of beds (nine), which was expanded and currently has already 24 beds available for the patients' recovery. It is expected that such an abrupt expansion would result in very different outpatient average circuit time values, as well as with the average number of outpatients that concluded the circuit before 8pm. Furthermore, due to the previously possibility of bottleneck formation (caused by the lower availability of beds in this department), the waiting times in the hospital reception, to be admitted in a box, should also be analysed. It was observed that with a number of PACU beds inferior to 17, the average waiting time in the hospital reception, began to be superior to 15 minutes (e.g. with 16 UCPA beds, one in 50 simulation tests had a waiting time superior to 15 minutes), which although is still within the 30 minute maximum hospital reception waiting time (recommended by the United States of America National Academy of Medicine) [74]), according to Campbell *et al.* (1994) a hospital reception waiting time superior to 15 minutes could lead to patient dissatisfaction [76]. Furthermore, in the scenario with nine PACU beds, from the fifty tests performed, eleven resulted in patients having an average waiting time in the hospital reception bigger than 15 minutes. In Figure 5.7 the circuit time for the two types of outpatients is depicted. As it can be observed, there is a critical reduction from the scenario with nine beds to the scenario with 17 beds. As it was expected, the decrease in the number of available beds leads to an increase in the patient's circuit time. The difference between the scenario with 17 beds and the following ones (20-26) can be best observed in Figure 5.7 (a), where a significant reduction can be seen. Furthermore, it can be observed that after 20 beds the average circuit time tends to be constant. For the other speciality outpatients (Figure 5.7 (b)), the variation of the PACU bed does not influence the average circuit time, however the standard deviation is very high, showing irregularity in the values. Moreover, in Figure 5.8 it is possible to observe the average utilization rate for the several PACU bed scenarios. From nine to 24 beds, the average utilization rate was above 50%. As expected, the average utilization rate tends to decrease, with the increase of the number of PACU beds. This way, for the current demand and taking into account the resources variations performed, it is estimated that 20 Beds would be enough to satisfy the current demand. However, since it is expected an increase in the daily patient demand (hypothesis 3), 24 PACU beds would be better, to be on the safe side.



(a) Average circuit time for ophthalmology outpatient that finished the circuit before 8pm, for the several PACU bed scenarios.



(b) Average circuit time for other speciality outpatient that finished the circuit before 8pm, for the PACU bed scenarios.

Figure 5.7: Effects of the variation of the number of PACU beds in the average circuit time of outpatients that finished the circuit before 8pm (H1).

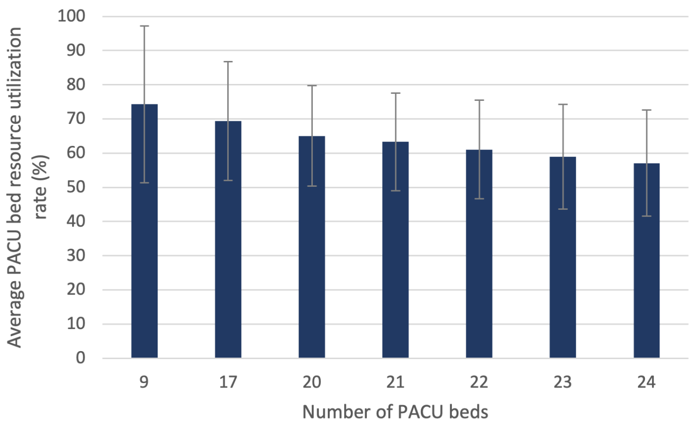
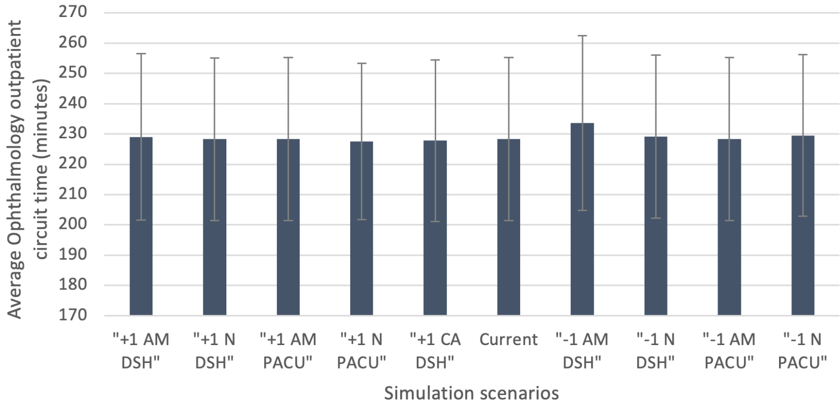


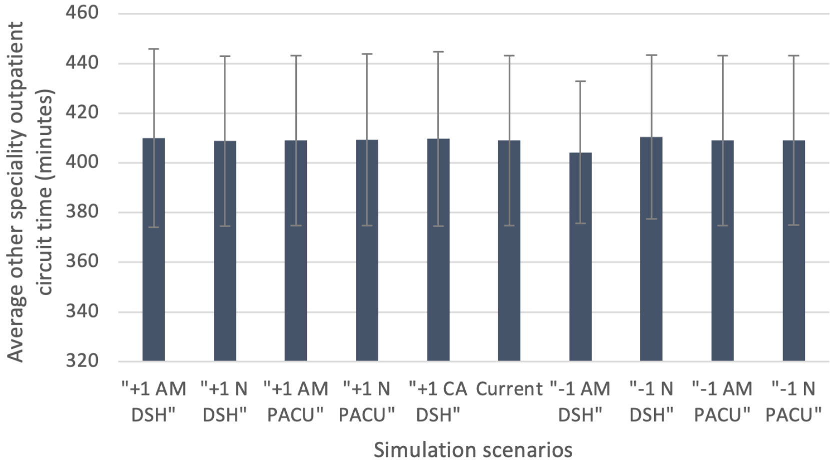
Figure 5.8: Average utilization rate for the resource ”PACU beds” (H1).

Alteration of human resource

Another cause detected in the delay of the surgical outpatient circuit time is the lack of staff to give response to the patient demand (specially in certain parts of the day, such as the first hours of the morning). For this reason, in this section, the effects on the variation of human resources in the three departments of the outpatient circuit were analysed. In Figure 5.9 it is possible to see the effect that the DSH medical assistant resource has in the circuit time of the outpatients that finish the circuit before 8pm. Although the variation of most human resources does not provide a significant effect to the average circuit time, the variation of the medical assistant does. This can be explained by the need of this professionals in several tasks of the simulation, such as to admit the patient in the box (more medical assistants means more patients that can be admitted to the box), to transport the patients to the Transfer and from the PACU to the DSH. An increase in the number of these resources would also result in a higher number of outpatients that finish the circuit before 8pm.



(a) Average circuit time for ophthalmology outpatient that finished the circuit before 8pm, for the several human resources scenarios.



(b) Average circuit time for other speciality outpatient that finished the circuit before 8pm, for the several human resources scenarios.

Figure 5.9: Effects of the variation of the number of DSH medical assistants (AM DSH), DSH nurse (N DSH), DSH cleaning assistant (CA DSH), PACU medical assistants (AM PACU), PACU nurse (N PACU), in the average circuit time of the outpatients that finished the circuit before 8pm (H1).

Overall statements

Through the analysis of the current outpatient flow, it was possible to study the effects of the resources variation in order to reduce the patient circuit time. The results allowed to verify that the obtained average simulation times for the current circuit behaviour are similar to the ones obtained from the computer records of the Hospital. Furthermore, it was observed that a decrease in the number of PACU beds to 20 would not significantly influence the current circuit time and would reduce the cost of having the additional four functioning beds (and increase the utilization rate of this resource). In the study of the influence of the variation of human resources, it was observed that having one more DSH medical assistant in every hour of the DSH schedule could result in a bigger number of outpatients that finish the circuit before 8pm. However, this would require the acquisition of at least two DSH medical assistants, which is not a cost-efficient solution (one from 6:45am to 2:00pm and one from 2:00pm to 9:00pm). In every simulation it was observed that there were always a few outpatients that finish the DSH recovery until a little after 9pm (DSH closing hour), and there were very few outpatients that needed to have the hospital discharge directly from the PACU (only left the PACU recovery after 9pm). For this, an extension on the DSH working time (as well as of the DSH reception) could represent the recovery of more patients through this department, and an increase in the number of outpatients that conclude the circuit with the proper administrative discharge from the DSH reception.

5.2 Hypothesis 2

The second hypothesis focus in the possibility of redesigning the inpatient entrance, in order for all the inpatients that perform the admission on the same day as the procedure, to enter through the DSH, thus avoiding unnecessary use of the IWB (and the high costs associated with the use of this resource). For this, all the distributions for the inpatient arrival and for the service times were computed again, taking into account the modification in the number of inpatients that enter through the DSH. To compute the expected arrival pattern of the inpatients to the DSH, an analysis of the sum of the number of the computer records arrivals was depicted in Figure 5.10, for the 38 days. As it can be observed, in comparison to the patient arrivals sum of H1 (Figure 5.2), now there is a higher inpatient arrival throughout the day, possibly requiring more DSH resources than the current values. Furthermore, similar to the hypothesis 1, it is expected a higher demand in the first hours of the morning and again during the lunch time.

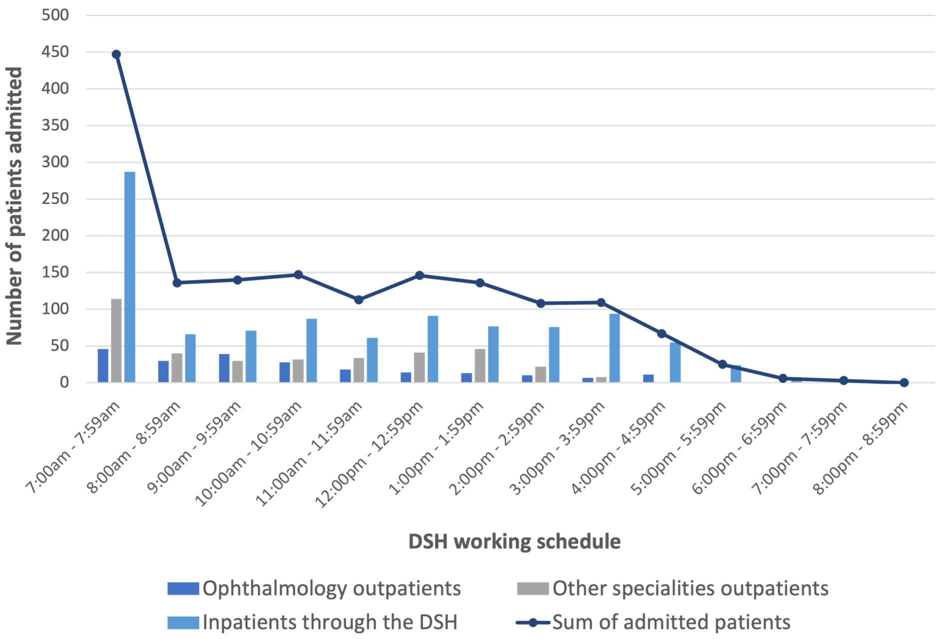
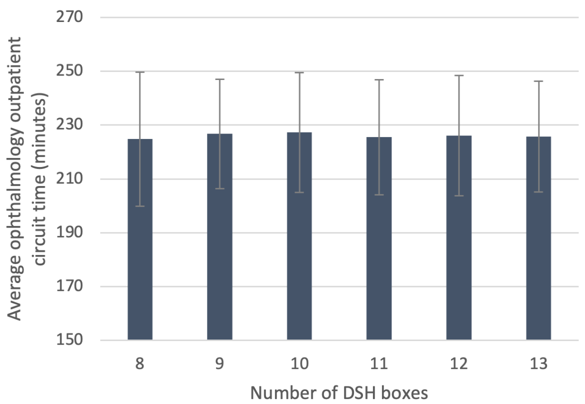


Figure 5.10: Patient arrival through the DSH working schedule (H2).

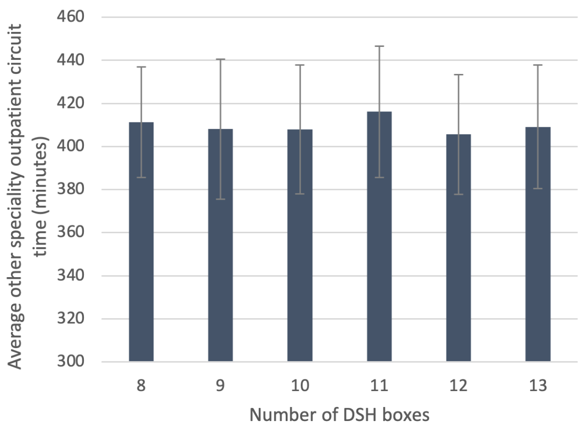
It is important to note that since this modification majorly affects the DSH, the analysis performed for this hypothesis is specially focused in identifying if it is required an increase on the number of the DSH resources, in order to assure most of the outpatients complete circuit before 8pm. Furthermore, the resource variation is also going to be studied, to observe if there is a resource that can be reduced (decreasing the costs). The maximum values for patient arrivals defined for this hypothesis are presented in Table 4.3.

Variation of material resources

As it was referred, this modification on the patient flow affects majorly the DSH, since the OR and the PACU will continue to receive the same patient demand as the current one. The results showed that the circuit time for the ophthalmology outpatients that completed the circuit before 8pm (227.265 $\pm$ 22.274 minutes) and other specialities outpatients that also completed the circuit before 8pm (407.909 $\pm$ 29.928 minutes) is slightly smaller than the obtained for hypothesis 1. Although it was expected an increase in the circuit time due to the overload of patients in the DSH, the distributions used could not completely mimic the demand of patients that arrive in the first hour of the DSH (possibly allowing for the simulation to not detect a bottleneck in these times of biggest demand). Furthermore, the variations in the number of boxes did not present a significant effect on the outpatient circuit time, as it can be seen in Figure 5.11. A small variation can be observed in the other specialities outpatients average circuit time, when the number of DSH boxes is increased to 11, but it is expected to be caused by the variability of the patient service time distributions. Furthermore, the number of outpatients that finished the circuit before 8pm was also analysed, and it was observed that, similarly to the H1, there are several ophthalmology patients that conclude the circuit before 8pm. However there are several other speciality outpatients that concluded the circuit after 8pm, as it can be seen in Figure 5.12 (finalizing the circuit after this hour). It is possible to observe than the increase of the number of DSH boxes does not have an influence is this values.

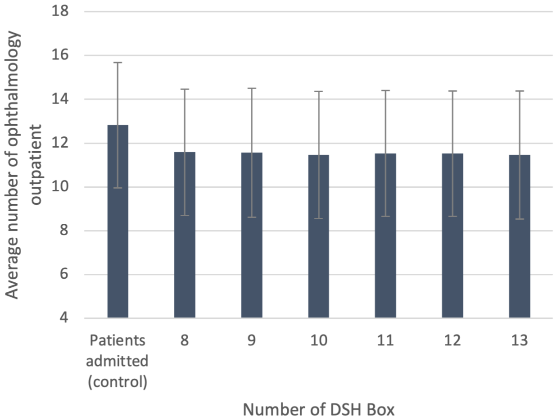


(a) Average circuit time for ophthalmology outpatients that finished the circuit before 8pm, for the several DSH box scenarios.

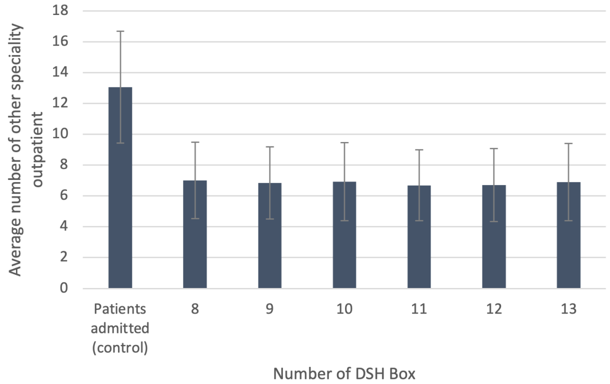


(b) Average circuit time for other speciality outpatients that finished the circuit before 8pm, for the several DSH box scenarios.

Figure 5.11: Effects of the variation of the number of DSH boxes in the average circuit time of outpatients that finished the circuit before 8pm (H2).



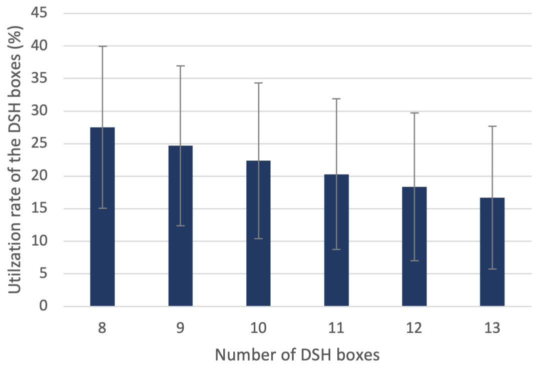
(a) Average number of ophthalmology outpatients that finished the circuit before 8pm, for the several DSH box scenarios.



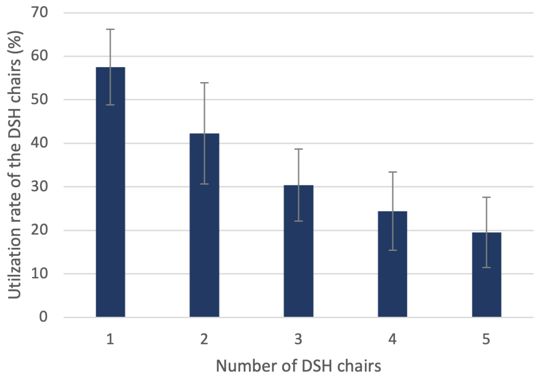
(b) Average number of other speciality outpatients that finished the circuit before 8pm, for the several DSH Box scenarios.

Figure 5.12: Effects of the variation of the number of DSH boxes in the average number of outpatients that finished the circuit before 8pm (H2).

Nevertheless, it is possible to observe the effect of the DSH box variation in this resource utilization rate. In Figure 5.13 (a) it is possible to observe the decrease in the resource utilization rate on the several resource alterations. Considering that the simulation is running 1020 minutes (from 7am to 12am), the utilization can be computed in minutes by multiplying the utilization rate by the simulation duration (e.g. in scenario of just one DSH chair, this resource average utilization rate is $56.789 \pm 9.226\%$, which means that the resource was used during approximately 579 minute). It is important to know that the utilization rate values are computed for the whole simulation, and not only the DSH working system (in other words, since the simulation ends at 12am and not at 9pm, the utilization rate of the DSH boxes can be smaller than expected). From the scenario with 11 boxes or more, the utilization rate decreases very slightly, demonstrating that it is not efficient to expand to more than 11 boxes for the current demand. Furthermore, the morning demand, in the simulation, is smaller than the real scenario (there are slightly less patients entering the DSH in the simulation morning time, when this time presents a higher demand). For this reason, it is not recommended the reduction of DSH boxes (even if in the simulation it can be observed that a reduction on the number of DSH would not influence the outpatient circuit time or the number of outpatients that finish the circuit before 8pm). Moreover, the reduction of DSH boxes can increase the number of outpatients that receive the hospital discharge directly from PACU.



(a) Average resource "DSH box" utilization rate for the several DSH scenarios.



(b) Average resource "DSH chair" utilization rate for the several DSH scenarios.

Figure 5.13: Effects of the variation of the number of DSH material resources in the respective material resource utilization rate (H2).

For the DSH chair variation, as expected, a critical reduction in the circuit time of the ophthalmology outpatient, that finished the circuit before 8pm, is observed in Figure 5.14. The alteration of the chair resource, from one to three chairs (current scenario), as a big effect on this type of patient's average circuit time. However, with more than three chairs, the average circuit time no longer varies. Observing the DSH chairs utilization rate (Figure 5.13 (b)) it is possible to observe that with the increase of the number of chairs in the simulation, there is a notable decrease in the DSH chairs utilization rate, as expected. This being said, no alteration in the DSH chair number is recommended, since it does not present a more efficient solution for the system.

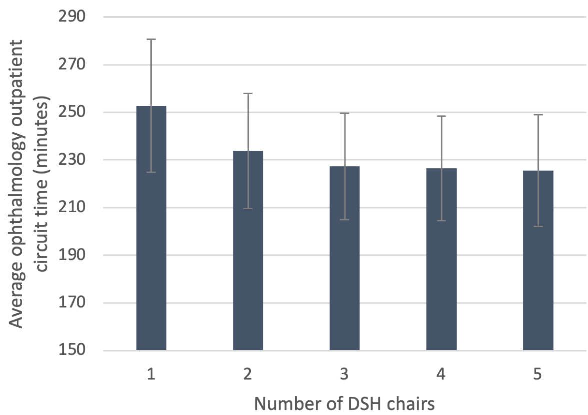
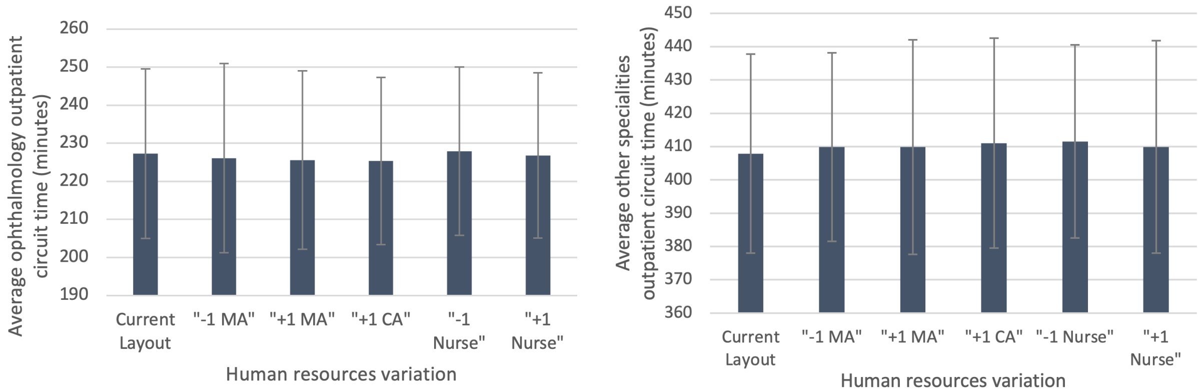


Figure 5.14: Average circuit time for ophthalmology outpatients that finished the circuit before 8pm, for the several DSH chair scenario (H2).

Alteration of human resources

To understand if the increase in the DSH human resources could lead to a decrease in the circuit time, a manipulation of these resources was performed. In Figure 5.15 the results for the simulations are presented. As it can be observed, the increase of a DSH medical assistant or the reduction of a DSH nurse, in each hour of the DSH schedule, leads to a slight increase and decrease in the ophthalmology outpatient average circuit time, respectively. Furthermore, it was observed that the increase of a DSH cleaning assistant in each hour of the DSH schedule, represents a slight decrease in comparison to the current number (in the ophthalmology outpatient average circuit time). Since currently there is only one DSH cleaning assistant, it can occur that a patient can not be admitted into a box, because there is not enough clean and available boxes (for this reason, an increase in this human resource, can lead to a lower circuit time). The comparison between the current resources utilization rate with the resources utilization rate of the variations on Figure 5.15 are represented in Figure 5.16. It is possible to observe that, as expected, by decreasing the number of resources, the utilization rate will increase due to the increase in the overload of patients. Consequently, with the increase of the resources, the utilization rate decreases. One section of Figure 5.16 that is important to refer is the one from the increase of the cleaning assistant resource, since the utilization rate of this resource decreases to half, when compared to the current one. Although its increase leads to a decrease in the circuit time, the decrease on the utilization rate is much bigger, not being an efficient solution for the system. For these reasons, it is not recommended to increase or reduce the current number of DSH human resources, since according to the simulation, it does not provide a cost-efficient solution to the system.



(a) Average ophthalmology circuit time for the several DSH human resource scenarios.

(b) Average other specialities circuit time for the several DSH human resource scenarios.

Figure 5.15: Effects of the variation of the number of DSH medical assistants (MA), nurse, and cleaning assistant (CA), in the average circuit time of outpatients that finished the circuit before 8pm (H2).

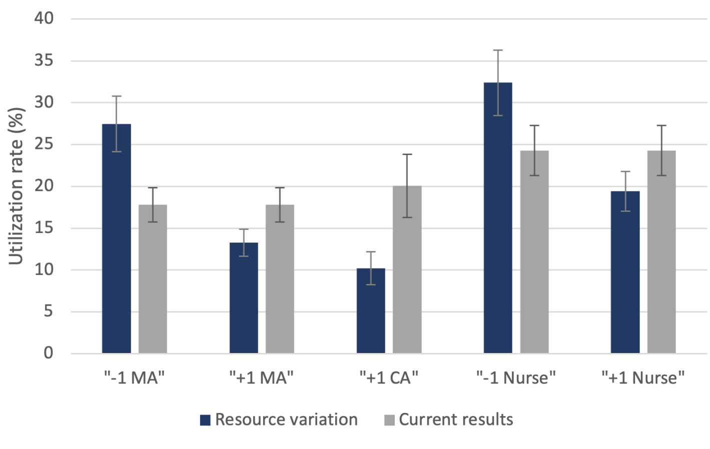


Figure 5.16: Comparison of the current DSH human resources utilization rate with the several variation scenarios (H2).

Overall statements

From the results obtained in the simulation, the change in the current inpatient entrance does not influence the circuit time of the outpatients. It is important to consider that the simulation does not exactly mimic the patient flow arrivals in the first times of the day (at 8am the OR does not begin with all the rooms filled). Furthermore, the effects of the DSH human resources variation in the outpatient circuit time, alongside with the resources utilisation rate, showed that the alteration in the number of any human resource does not provide an efficient alternative to the current number of resources.

5.3 Hypothesis 3

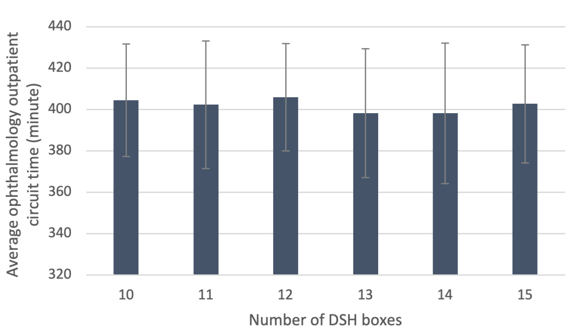
The H3 considers that all the inpatients that perform the admission on the same day as the procedure enter through the DSH, and that a specific number of patients is expected. In this hypothesis, the expansion plans are already concluded, or in other words, there are already 16 functional OR and 24 PACU beds. This hypothesis was specially relevant for the Project Berlin, since it enables to analyse the required expansion that the DSH needs to have in order to be able to respond to the elevated demand that is expected. With the expansion, four OR were built, making it a total of 16 functional OR, with a total expected demand of 120 surgical patients per day, resulting in an average of 7.5 surgeries per OR, per day. From this 120 patients, 60 are outpatients (15 ophthalmology patients and 45 other speciality outpatients), 48 are inpatients that entered through the DSH (all the inpatients that perform the admission on the day of the procedure), and 12 are inpatients that entered through the IWB. In order to obtain the most accurate arrival pattern, specially in the first hours of the day, the percentage of arrival in each hour was estimated. For each type of patient that arrived in the 38 days in study, the sum of arrivals per hour was computed. Afterwards, the percentage of arrivals for each hour was determined in order to understand the weight that the number of arrivals in that specific hour has in the overall number of arrivals. Moreover, depending on the type of patient, the value of expected arrivals for that patient is going to be multiplied by each percentage in order to understand the expected number of patients that will arrive in each hour. The expected values of arrival that were given as input to the simulation are presented in Table 5.1. From this table it is expected that a bigger patient demand should appear in the first moments of the morning and again after lunch (as demonstrated in Figure 5.10). In the simulation, this arrival planner was given as input and the patient arrivals will be distributed in a random way. Furthermore, no maximum arrival was given as a constraint, since the simulation will consider just the values given in the planner. From the simulations it is expected a critical increase, since in some cases the demand is going to grow more than the double of the current demand (e.g. for the other specialities outpatients, the demand is going to increase from a maximum of 22 patients per day, to 45).

Table 5.1: Patient arrival schedule (H3).

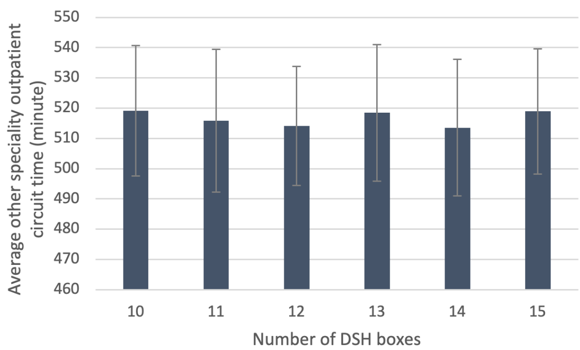
Period	Ophthalmology Outpatient	Other Speciality Outpatient	Inpatient with admission through DSH	Inpatient with admission through IWB
7:00 am-7:59 am	3	14	14	0
8:00 am-8:59 am	2	5	3	1
9:00 am-9:59 am	3	4	3	1
10:00 am-10:59 am	2	4	4	1
11:00 am-11:59 am	1	4	3	1
12:00 pm-12:59 pm	1	5	4	1
1:00 pm-1:59 pm	1	5	4	1
2:00 pm-2:59 pm	1	3	4	1
3:00 pm-3:59 pm	0	1	5	1
4:00 pm-4:59 pm	1	0	3	1
5:00 pm-5:59 pm	0	0	1	1
6:00 pm-6:59 pm	0	0	0	1
7:00 pm-7:59 pm	0	0	0	1
8:00 pm-8:59 pm	0	0	0	0

Variation of material resources

In this hypothesis, the material resources variation was analysed, in order to understand the best resource arrange for this specific demand. Due to the increased demand, it is expected to obtain a higher outpatient circuit time (due to the lack of available resources for the increased patient demand). As it can be observed in Figure 5.17, the average circuit time for both the outpatients that finished the circuit before 8pm is much higher than the average circuit times of the other two hypothesis (and than the computer records). Furthermore, it is possible to observe that the increase on the DSH boxes does not always decrease the outpatient's average circuit time.



(a) Average circuit time for ophthalmology outpatients that finished the circuit before 8pm, for the DSH box scenarios.



(b) Average circuit time for other specialities outpatients that finished the circuit before 8pm, for the DSH box scenarios.

Figure 5.17: Effects of the variation of the number of DSH boxes in the circuit time of outpatients that finished the circuit before 8pm (H3).

Moreover, the waiting time in the DSH reception for this hypothesis was analysed for a large number of DSH boxes (Figure 5.18). As it can be observed, the waiting time in the DSH reception for the current resources, is 106.487 $\pm$ 9.257 minutes, which is much higher than the current real value and than the values recommended in the literature [74]. It can also be observe in Figure 5.18, that for 18 DSH boxes or more, the waiting time in the DSH reception value tends to be constant. These waiting time high values can be explained by the increased number of patients that arrive at the DSH reception at the same time, creating a bottleneck in this sector of the circuit.

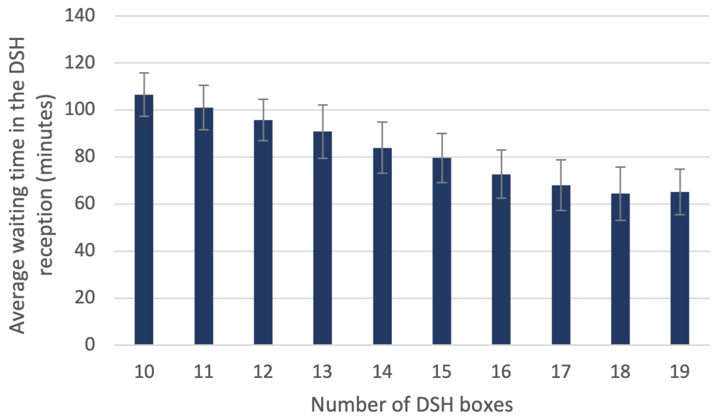


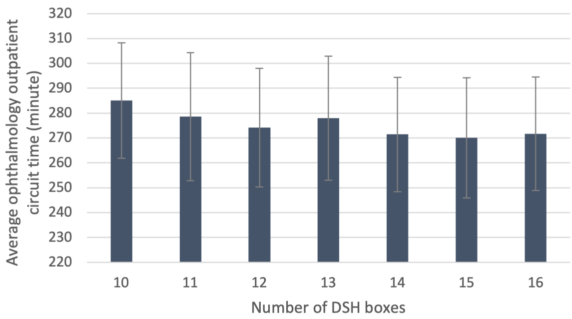
Figure 5.18: Average patient waiting time in the DSH reception for the several number of DSH boxes (H3).

For these reasons, the resource variation is not enough to reduce the outpatients circuit time to values similar to the ones obtain in the real scenario. However, another approach already used in past studies [77] can be used to solve this problem. By changing the schedule of the patient's arrival, long waiting time queues can be avoided. For this hypothesis, the arrivals were estimated taking into account the current patient's arrival pattern, and the specific number of arrivals for each type of patient. When all the inpatients, that performed the admission on the same day as the surgery, enter only through the DSH, the schedule of the procedures will be performed taking into account the capacity of the departments. For example, for the simulation, 14 other speciality outpatients and 14 inpatients arrive at the DSH between 7:00am and 7:59am. If there are only 16 OR, and each start at 8:00am, it is not efficient to put such a high number of patients arriving at this hour. A better patient arrival distribution throughout the day could avoid bottlenecks and decrease circuit times. In the *Hospital da Luz Lisboa*, there are two surgery slots - one from 8:00am to 2:00pm; and another from 2:00pm to 10:00pm. Since the ophthalmology outpatients have a smaller circuit time (due to the fast procedure and recovery), and since the ophthalmology surgeon is scheduled by slots, the new proposed patient schedule will consider that all the outpatients of this type will arrive to the hospital in the first slot of surgeries of the day. The outpatients from the other specialities are also going to arrival only in the first slot of surgeries. This proposed schedule of arrivals is given in Table 5.2. One of the most important alterations made to the current schedule was the decrease in the amount of patients that arrive at 7am, still making sure that all the ORs had enough patients to be fully occupied at 8am. Furthermore, since the inpatients that performed the admission through the DSH, do not recover in the DSH, they were distributed to arrive in the later times of the day. However, the arrivals were carefully distributed, since this type of inpatients can have very complex, and thus long, surgeries (not being good to perform the admission very late on the day). This being said, the inpatients arrivals occur only in the second slot of surgeries of the day (from 2:00pm to 10:00pm). Furthermore, the arrivals of the inpatients with admission through the IWB did not suffer any alteration to the current distribution.

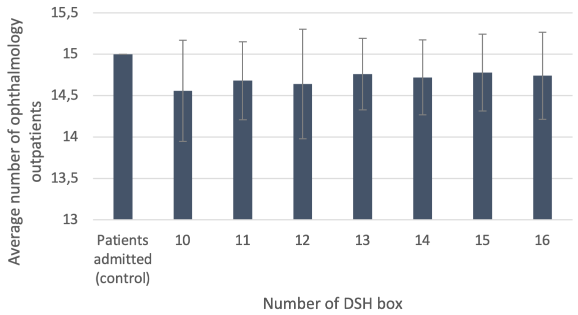
Table 5.2: Proposed patient arrival schedule (H3).

Period	Ophthalmology Outpatient	Other specialities Outpatient	Inpatient with admission through the DSH	Inpatient with admission through the IWB
7:00 am-7:59 am	3	14	0	0
8:00 am-8:59 am	2	5	0	1
9:00 am-9:59 am	3	5	0	1
10:00 am-10:59 am	3	5	0	1
11:00 am-11:59 am	2	5	0	1
12:00 pm-12:59 pm	1	6	0	1
1:00 pm-1:59 pm	1	5	0	1
2:00 pm-2:59 pm	0	0	8	1
3:00 pm-3:59 pm	0	0	8	1
4:00 pm-4:59 pm	0	0	8	1
5:00 pm-5:59 pm	0	0	8	1
6:00 pm-6:59 pm	0	0	8	1
7:00 pm-7:59 pm	0	0	8	1
8:00 pm-8:59 pm	0	0	0	0

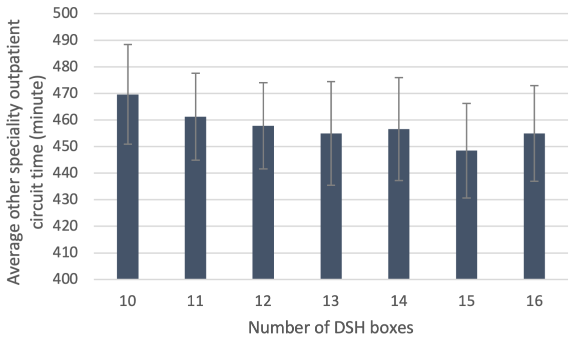
With the new proposed arrival schedule, the impact of the variation of DSH boxes in the number of outpatients that finish the circuit before 8pm was analysed again. Recalling that this research is focused in improving the surgical outpatient flow by ensuring that the DSH has the necessary resources to respond to the expected patient demand, caused by the modification of the inpatient entrance. In Figure 5.19, the average circuit time of the outpatients is depicted again, considering the proposed schedule. It is possible to observe that, on average, most of the ophthalmology outpatients are able to finalize their circuit before 8pm (being able to receive the administrative discharge from the DSH administrative assistants on time), unlike with the previous schedule (Figures 5.19 (b) and (d)). Although the average circuit time for outpatients that finish the circuit before 8pm as decreased compared to the previous schedule (Figures 5.19 (a) and (c)), it is still slightly higher than the values obtained in Figure 5.3. This can be explained by the increase in the number of patients in the circuit. It can also be noted that the average circuit time tends to decrease with the increase of the number of DSH boxes, as expected.



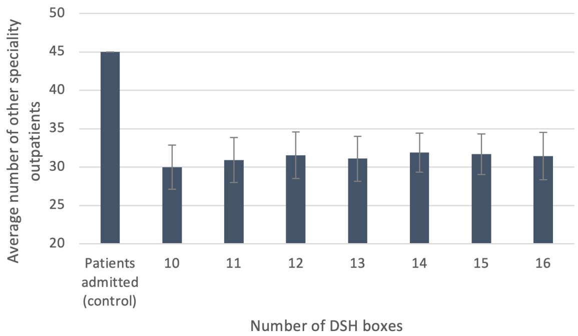
(a) Average circuit time for ophthalmology outpatient that finished the circuit before 8pm, for the several DSH Box scenarios.



(b) Average number of ophthalmology outpatients that finished the circuit before 8pm, for the DSH box scenarios.



(c) Average circuit time for other speciality outpatients that finished the circuit before 8pm, for the DSH box scenarios.



(d) Average number of other speciality outpatients that finished the circuit before 8pm, for the DSH box scenarios.

Figure 5.19: Effects of the variation of the number of DSH boxes in the average number and circuit time of outpatients that finished the circuit before 8pm, for the new arrival schedule (H3).

The waiting time in the DSH reception was also computed, taking into account the new schedule. In Figure 5.20, it is possible to observe the results of the simulation for this analysis. As expected, the waiting time in the DSH reception tends to decrease with the increase of the number of DSH boxes. For 11 and more DSH boxes, the average waiting time in the DSH reception is lower than 30 minutes, which according to the National Academy of Medicine (United States of America), is the maximum recommended time for the patients to wait in a hospital reception [74]. For 14 DSH boxes, the average waiting time in the DSH reception value is lower than 10 minutes. Furthermore, for 15 and 16 DSH boxes, the average waiting time in the reception value is lower than five minutes. This values are more similar to the ones obtained in H1 and H2.

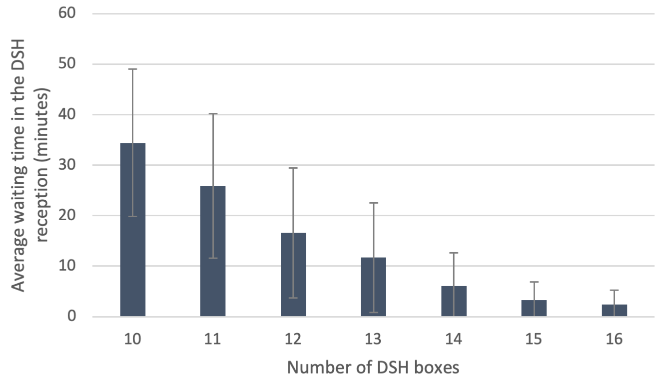


Figure 5.20: Average patient waiting time in the DSH reception for the several number of DSH boxes, with the new schedule (H3).

Another indicator that was analysed was the average utilization rate of the "DSH box" resource. As it can be observed in the Figure 5.21, the utilization rate of the "DSH box" resource is lower than 50% for 16 DSH boxes or more. For these reasons, the most cost-efficient solution would be to have, at least, 15 DSH boxes in the simulation.

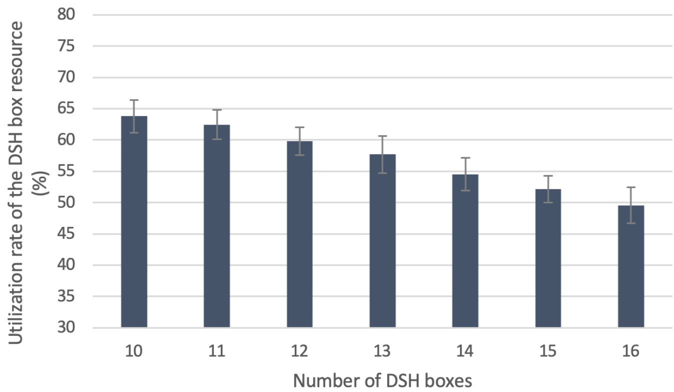


Figure 5.21: Average utilization rate of the "DSH boxes" resources for the several number of DSH boxes, with the new schedule (H3).

After observing that at least 15 DSH boxes are required in the simulation, the necessary number of DSH chairs was analysed. It is important to note that by what was seen in the previous hypothesis, it is expected that the variation of chairs leads to a significant effect in the ophthalmology patients average circuit time (but not in the other speciality patients). As expected, in Figure 5.22 it is possible to observe the effect of the resource variation in the average circuit time of the ophthalmology patients that finished the circuit before 8pm. For the other specialities outpatients, the DSH chair resource variation did not present an effect in the average circuit time of this outpatients. As it can be observed in Figure 5.22, for more than four DSH chairs, the average circuit time tends to not vary.

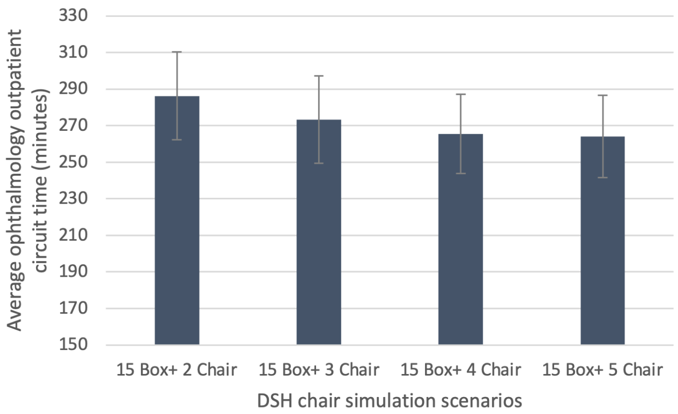


Figure 5.22: Average circuit time of ophthalmology outpatients that finished the circuit before 8pm, for the several number of DSH chairs, with the new schedule (H3).

It is also relevant to understand the utilization rate of this resource, specially since it is only used in the recovery of ophthalmology outpatients. In Figure 5.23, the average utilization rate of the DSH chairs is depicted. As it can be seen, the increase in the number of DSH chairs leads to a decrease on the utilization rate (as it would be expected, since there are more chairs available to the ophthalmology outpatient demand).

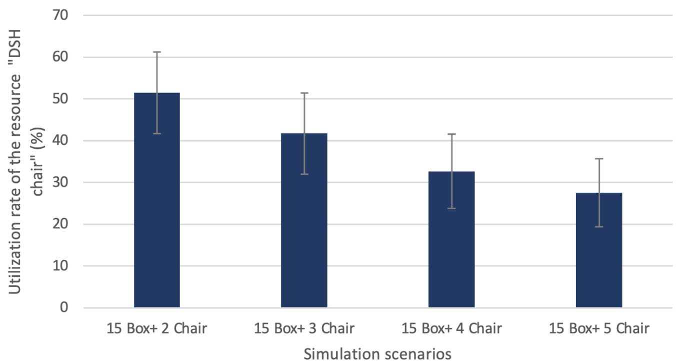
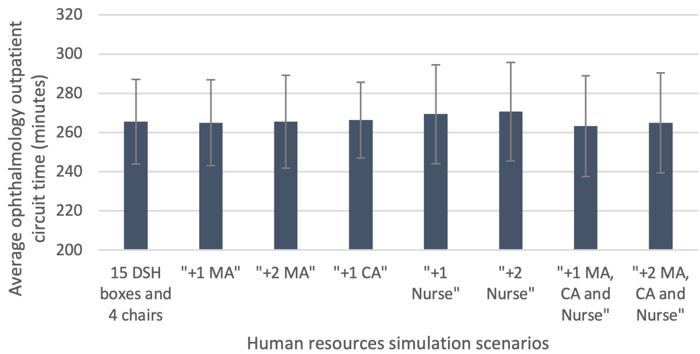


Figure 5.23: Average utilization rate of the resource ”DSH chair”, for the several simulation scenarios (H3).

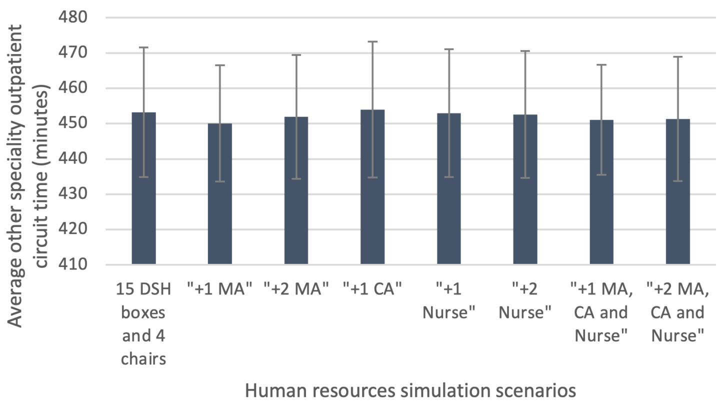
By analysing both Figure 5.22 and Figure 5.23, it is possible to observed that by increasing the number of DSH chairs to four or five, the average circuit time of the outpatients is influenced in a very similar way. However, the resource utilization rate is smaller when there are five DSH chairs. For this reason, the most cost-efficient solution would be to have four DSH chair in the simulation. This being said, it was observed that having 15 DSH boxes and four chairs could lead to a more efficient and reduced outpatient circuit time.

Variation of human resources

Due to the increase in the expected patient demand, an increase in the available human resources in the DSH to admit, prepare, transport and monitor the patients, might be needed. It was observed that the current resources are enough for the current patient demand. However, with the expected patient increase, an analysis on the effects of increasing the DSH staff must be performed. It is important to note that in the proposed schedule, the patients are better distributed throughout the day, thus avoiding the formation of bottlenecks. This being said, there might not be required an increase in the current human resources in the first shift of the morning (which previously were the hours more propitious for the development of bottlenecks), but instead an increase on the later shifts of the day, due to the big demand of inpatients that are going to be admitted in the DSH at that time. For this reason, to the average outpatient circuit time obtained for 15 DSH boxes and four DSH chairs, eight scenarios were simulated (Figure 5.24). This scenarios represent the addition of one or two DSH medical assistants, nurses and cleaning assistants, to the first shift of each resource (most propitious hours for the formation of bottlenecks in the previous hypothesis). As it can be observed, the allocation of more resources on this shift does not influence the outpatients average circuit time. This goes as expected, since there is not a big patient demand variation, compared to the real scenario.



(a) Average circuit time of ophthalmology outpatients that finished the circuit before 8pm, for the several DSH human resource scenarios.



(b) Average circuit time of other speciality outpatients that finished the circuit before 8pm, for the several DSH human resource scenarios.

Figure 5.24: Effects of the variation of the number of DSH medical assistants (MA), nurse, and cleaning assistant (CA) in the average circuit time of outpatients that finished the circuit before 8pm (H3).

Furthermore, it was also observed that a few outpatients did not received the administrative discharge on time (after 8pm). Taking this into account, and considering that there is a large number of inpatients that arrive to the DSH from 2pm to 8pm, an analysis was performed allocating more DSH human resources in the period of 4pm-12am (period when the 48 inpatients are going to be admitted in the DSH, and when there are less human resources). This analysis considers the extension of the DSH working schedule, from 9pm to 12am (and of the DSH reception working schedule, from 8pm to 12am). In Figure 5.25, it is possible to observe the effects that extending the working schedule of the DSH and allocating more human resources has in the average number of other specialities outpatients that finish the circuit. According to the simulation, this expansion would allow for almost all of the 45 other speciality outpatients to finish the circuit, receiving the administrative discharge on time. Furthermore, this alteration would also increase the number of ophthalmology outpatients that concluded the circuit to 15 (which is the total number of this patients that were admitted, representing that all the ophthalmology outpatients that perform the admission, were able to conclude the circuit and to receive the administrative discharge on time). Moreover, as it can be observed in Figure 5.25, the increase of one or two DSH medical assistants, cleaning assistants, administrative assistants and nurses, does not present a variation on the average number of outpatients that concluded the circuit. For this reason, the most cost-efficient solution would be to only allocate one more of each DSH human resource in the period from 4pm to 12am.

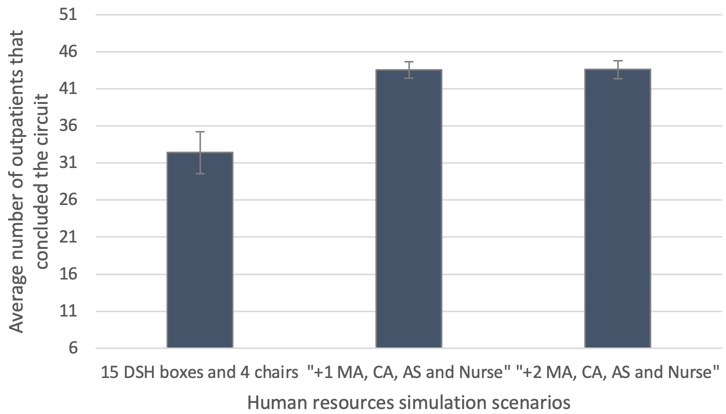


Figure 5.25: Effects of the variation of DSH medical assistants (MA), nurse, cleaning assistant (CA) and administrative assistant (AS), in the average number of other specialities outpatients (H3).

Overall Statements

This hypothesis analysis enabled to understand that the DSH requires at least 15 DSH boxes, four chairs, and one more human resource for the period of 4pm to 12am (one medical assistant, one nurse, one administrative assistant, and one cleaning assistant), in order to have the required capacity for the expected 120 patients. Furthermore, an extension on the DSH and of the DSH reception working schedule would be required to allow more outpatients to receive the administrative discharge on time. The new proposed arrival schedule avoids the formation of bottlenecks in the system, thus reducing the average circuit time of the outpatients. Moreover, the simulation for the proposed solution only detected possible bottlenecks in the DSH reception (before the patient admission in a box), and between the DSH (preoperative phase) and the OR.

Chapter 6

Conclusions

The main purpose of this Dissertation was to understand the required resource alteration in the system, in order for the DSH to be able to receive all the surgical inpatients that perform the admission on the surgery's day, as well as a specific daily number of surgical patients, without compromising the surgical outpatient's flow. The utilization of a simulation model for this Dissertation came as an innovative and relevant decision tool for the surgical patient circuit (and for the hospital) improvement. These type of models allow hospitals to carefully predict and study scenarios, thus decreasing the number of inefficiencies in the system.

In the simulation for the current scenario (H1), it was observed that no alteration is needed for the resource allocation. By what was observed on-site, this result goes as expected, since it was possible to observe that although there are some moments when the DSH is crowded, it still has the necessary resources for the patient demand (not presenting bottleneck effects in the department). Moreover, it was observed that it was possible to reduce the PACU beds from 24 to 20, without influencing the outpatient circuit time. However, due to the expected demand of 120 patients (and due to the inpatient entrance alteration), it is recommended that no alterations are made from the current resources. Furthermore, it was observed that the average outpatient circuit time (for both ophthalmology and other specialities) is very similar to the current real values, contributing to the validation of the simulation.

For the second hypothesis (H2), the entrance point for the surgical inpatients with admission on the surgery's day was already modified. In general, it was not registered any major alteration to the outpatients' average circuit time, although the simulation was not able to correctly mimic the patient arrivals in the first hours (that are expected to be the busiest hours of the day). This being said, no resource alteration is recommended for this hypothesis (current resources are able to satisfy the current patient demand).

For the last hypothesis (H3), it was expected a demand of 120 patients (15 ophthalmology outpatients, 45 other specialities outpatients, 48 inpatients with entrance through the DSH and 12 inpatients with entrance through the IWB). As expected, the current resources in the DSH do not allow an efficient response to the estimated patient demand, presenting outpatient's average circuit time values very high (compared to the current values). To solve this problem, it was observed that changing the schedule of arrivals would decrease the bottleneck in the first hours of the morning. Furthermore, it was observed that increasing the number of DSH boxes to 14, the DSH chairs to four, and having at least one more human resource of DSH medical assistants, nurses, administrative assistants and cleaning assistants from 4pm to 12am, can have a big effect on the reduction of the outpatients' average circuit time, as well as of the patients' waiting time in the DSH reception (reducing to less than five minutes). These alterations require that the DSH extends the working schedule until 12am, in order to assure that almost all outpatients can finalize the circuit and receive the administrative discharge on time. This hypothesis shows the importance of modelling the demand (as well as the resource allocation), to improve a system's efficiency.

This Dissertation allowed a first-hand experience with the work performed in a hospital, specially in the DSH and PACU, contributing to a more detailed simulation model. Furthermore, even with the COVID-19 pandemic, the possibility of collecting the data on-site enabled the use of time-related data that would not be possible to obtain only from the computer records. However, a few obstacles were also found in the construction of the simulation. In some cases, the computed activities distributions did not represent the real scenario. Nevertheless, these obstacles were overcome by computing alternative distributions, that were able to represent the expected values. Furthermore, the lack of studies regarding the maximum recommended waiting time in the hospital reception for surgical outpatients came as a challenge for defining a reference value for this time. For this problem, similar studies for other types of patients enabled the identification of a maximum recommended waiting time in the hospital reception, to be used in the simulation model (30 minutes). In this simulation model, although almost all the activities of the process were successfully mimicked, both H1 and H2 did not mimic very well the arrivals on the first hours of the simulation (arriving slightly less patients than expected).

The results of this study will be used by the company *Grupo Luz Saúde* for the allocation of more resources in the DSH, in order to respond to the new expected patient demand. In future works, the collection of more data would provide more detail to the simulation (specially in the data that only had the minimum required number of samples). Furthermore, it would be very important for the hospital to add more detail to the circuit of the surgical inpatients (for example, the processes that occur in the IWB) in the simulation, in order to find and study more possible opportunity points (such as the inpatient entrance alteration), and to better understand the utilization of the resource "OR assistants". It would also be interesting to develop this kind of simulations for the other hospital departments, and try to connect the several circuits, thus allowing to better distribute the several resources, depending on the demand. Moreover, it would be very relevant to perform a study to understand the ideal outpatient waiting time in the DSH reception, since it was not possible to find this exact value in the existing literature.

Finally, the work performed in this Dissertation revealed the potential that the simulation models have in the systems improvement and the importance of the patient flow improvement to not only increase the patient's satisfaction, but also the hospital efficiency.

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Appendix A

Simulation Indicators Definition

Table A.1: Simulation indicators definition (patient specific type).

Type of indicator	Indicator	Definition
Outpatients	Average circuit time	Average circuit duration from the moment the patient enters the DSH, in the preoperative phase, to the moment the patient exists the DSH, in the postoperative phase (before 8pm)
	Number of outpatients that completed the circuit before 8pm	Number of patients that exit the circuit in the DSH before 8pm
	Number of outpatients that completed the circuit after 8pm	Number of patients that exit the circuit in the DSH after 8pm
	Number of outpatients that received discharge from PACU	Number of patients that exit the circuit from PACU after 9pm
Inpatients (through DSH)	Average circuit time	Average circuit duration from the moment the inpatient enters the DSH to the moment the patient exits the PACU recovery
	Number of patients that completed the circuit	Number of patients that exit the circuit after the PACU discharge
Inpatients (through IWB)	Average circuit time	Average circuit duration from the moment the inpatient enters the simulation in the Transfer to the moment the patient exits the PACU recovery
	Number of patients that completed the circuit	Number of patients that exit the circuit after the PACU discharge

Table A.2: Simulation indicators definition (non-patient specific type).

Type of indicator	Indicator	Definition
Waiting times (minutes)	Average time for the hospital admission	Average duration of the patient stay in the DSH reception, from the moment the patient enters the DSH to the moment the patient performs the hospital admission with the DSH administrative assistant
	Average time for the box admission	Average duration of the patient stay in the DSH reception, from the moment the patient finalizes the hospital admission to the moment a DSH medical assistant admits the patient into a box
	Average time for the patient to go to surgery	Average duration of the patient stay in the Transfer, from the moment the patient enters the Transfer to the moment the patient enters the Operation Room.
	Average time for the patient to go to PACU recovery	Average duration of the patient stay in the OR, from the moment the surgery ends to the moment the PACU can receive the patient
	Average time for the outpatient to go to DSH recovery	Average duration of the outpatient stay in the PACU, from the moment the patient receives the discharge to the moment the DSH can receive the patient
	Average time for the outpatient to receive the administrative discharge	Average duration of the outpatient stay in the DSH reception, from the moment the patient receives the medical discharge to the moment the patient begins the administrative discharge with the administrative assistant
Resource utilization rate (%)	Resource average time rate	Average percentage of time that a resource is being used. Is calculated by the division of the time that the resource was used in the simulation, by the total simulation time (1020 minutes)

Appendix B

Simulation Variables Distributions

Table B.1: Distribution results values for non-specific patients.

Variable	Distribution	Parameters
Admission in the DSH reception	Exponential	M = 5.734
Admission in a box (transportation)	Exponential	M = 0.491
Admission by the DSH Medical Assistant	Log-Normal	M = 3.352; SD = 1.395
Preparation by the DSH Nurse	Triangular	T = 6; M = 6; B = 17.421
Box cleaning	Exponential	M = 3.439
Patient transport to Transfer	Exponential	M = 1.781
Patient transport to PACU	Exponential	M = 3.694
Patient monitored by PACU Nurse	Exponential	M = 22.144
Bed change by PACU medical assistant	Exponential	M = 4.920
Outpatient transport to DSH	Exponential	M = 1.944
Administer discharge in DSH reception	Exponential	M = 2.088

Table B.2: Distribution results values for specific patients.

Type of patient	Variable	Distribution	Parameters
Outpatient (ophthalmology)	Interarrival time	Log-Normal	M = 47.045; SD = 38.399
	Surgery time	Pearson V	α = 5.518 ; β = 157.280
	PACU recovery time	Exponential	M = 42.848
	DSH recovery time	Pearson V	α = 4.914; β = 227.530
Outpatient (other surgeries)	Interarrival time	Exponential	M = 45.760
	Surgery time	Pearson V	α = 10.720; β = 774.270
	PACU recovery time	Pearson V	α = 10.898; β = 1608
	DSH recovery time	Gamma	α = 1.423; β = 86.888
Inpatient (through DSH) (H1)	Interarrival time	Exponential	M = 43.123
	Surgery time	Gamma	α = 1.779; β = 71
	PACU recovery time	Pearson V	α = 14.303; β = 4511.400
Inpatient (through IWB) (H1)	Interarrival time	Exponential	M = 43.781
	Surgery time	Pearson V	α = 4.357; β = 444.270
	PACU recovery time	Pearson V	α = 13.754; β = 3429.400
Inpatient (through DSH) (H2)	Interarrival time	Exponential	M = 24.482
	Surgery time	Pearson V	α = 5.110; β = 625.690
	PACU recovery time	Pearson V	α = 13.577; β = 3709.900
Inpatient (through IWB) (H2)	Interarrival time	Gamma	α = 1.313; β = 139
	Surgery time	Gamma	α = 1.981; β = 59.080
	PACU recovery time	Pearson V	α = 7.293; β = 1577.100

Appendix C

Human Resources Shifts

Table C.1: Human resources shifts.

	Human Resources						
Shifts	DSH administrative assistant	DSH medical assistant	DSH nurse	DSH cleaning assistant	OR assistant	PACU medical assistant	PACU nurse
7:00am-3:00pm	-	2	4	-	1	-	-
7:30am-3:30pm	-	-	-	-	1	-	-
10:00am-6:00pm	-	1	1	-	-	-	-
1:00pm-9:00pm	-	2	2	-	1	-	-
6:30am-2:00pm	-	-	-	1	-	-	-
2:00pm-10:00pm	-	-	-	1	-	-	-
6:45am-3:45pm	3	-	-	-	-	-	-
8:00am-5:00pm	1	-	-	-	-	-	-
11:00am-8:00pm	2	-	-	-	-	-	-
8:00am-4:00pm	-	-	-	-	-	2	6
11:00am-7:00pm	-	-	-	-	-	2	-
3:30pm-11:30pm	-	-	-	-	1	-	-
4:00pm-11:30pm	-	-	-	-	-	2	6

Appendix D

Outpatient Circuit Times Records

D.1 Ophthalmology outpatients

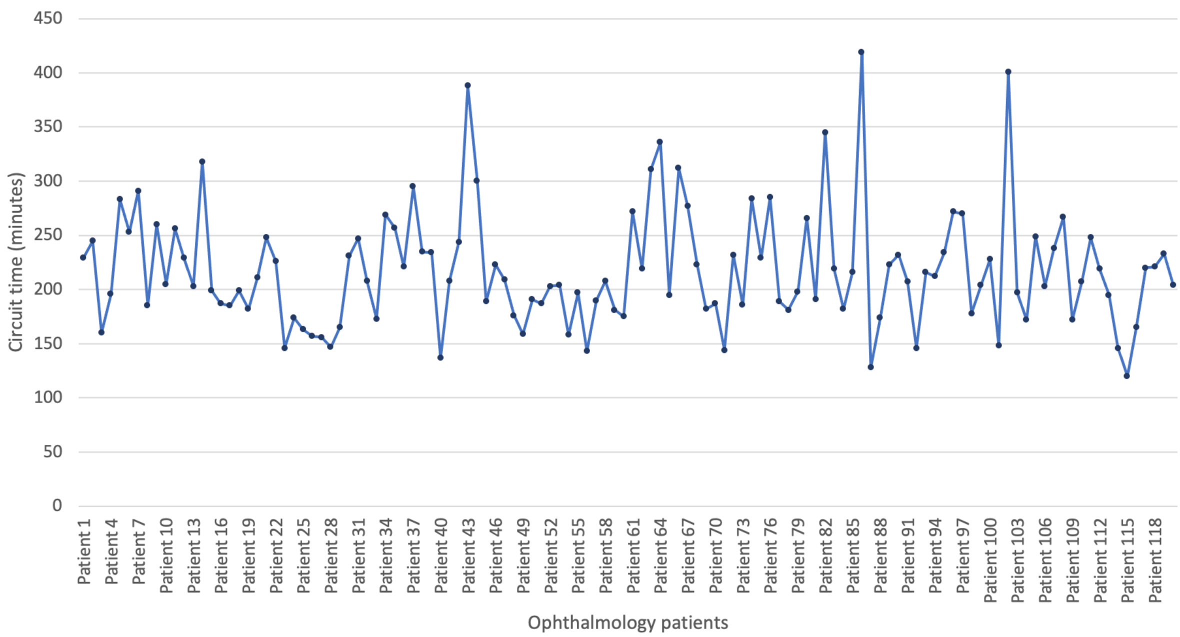

Figure D.1: Ophthalmology outpatient real circuit times (for the 38 days).

D.2 Other speciality outpatients

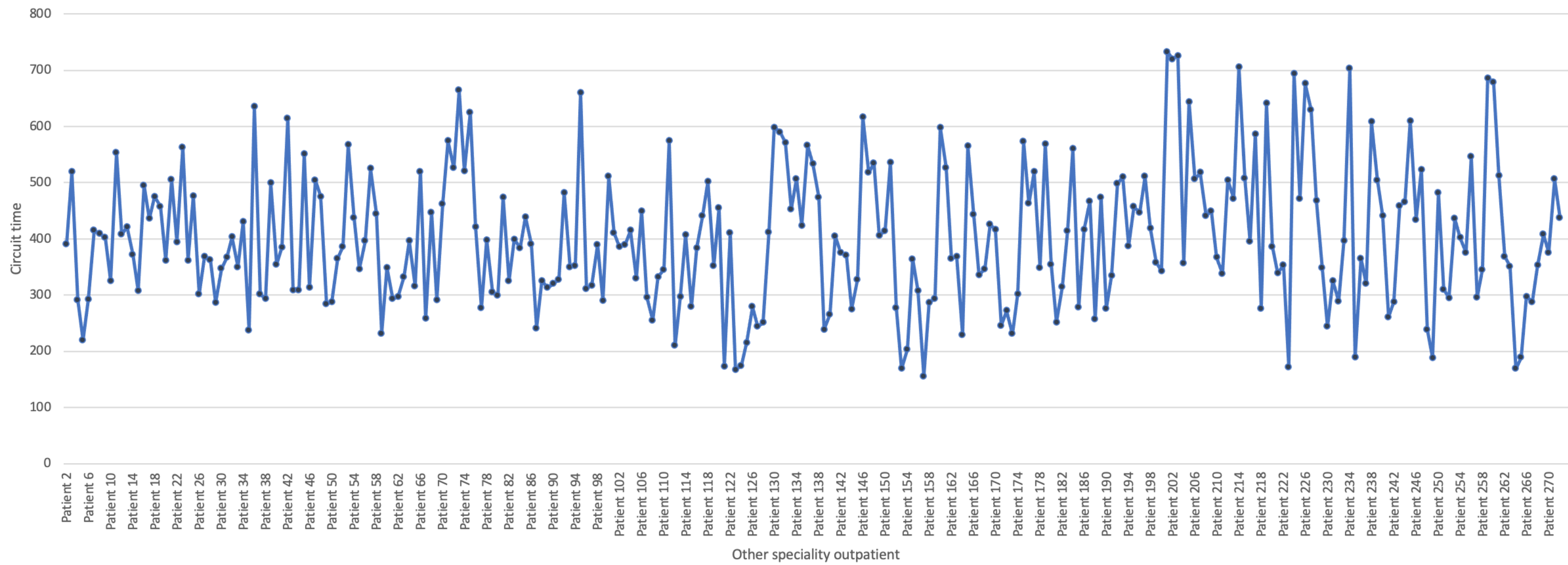

Figure D.2: Other specialities outpatients circuit times (for the 38 days).