Operating Room Planning and Scheduling of Elective Patients
Introducing Surgeon’s Preferences into the Decision Process

Nuno Queiroz Barroso Colaço Ramos

Dissertation to obtain the Master of Science Degree in

Industrial Engineering and Management

Supervisors: Professor Inês Marques Proença
Professor Mónica Duarte Correia de Oliveira
Professor M.D. Lucindo Ormonde

Examination Committee

Chairperson: Professor Carlos Bana e Costa
Supervisor: Professor Inês Marques Proença
Member of the Committee: Professor Maria Eugénia Captivo

October 2018
Acknowledgements

This dissertation would never exist without the contributions of Professor Inês Marques, Professor Mónica Oliveira, and Professor Lucindo Ormonde.

Professor Inês and Mónica, I am grateful for all the motivation throughout this work, and most of all, the time spent and contributing knowledge, and persistence, enabling me to improve this dissertation.

Professor Lucindo Ormonde, a special thanks for the opportunity of allowing me to make this work; and for the kindness of spending time discussing the hospital elective activity with me, and furthermore expediting the required stakeholders to interview.
Abstract

The operating theatre is one sizeable cost-center in hospital day-to-day management, challenging decision-makers planning its activity. This dissertation focusses with the operating theatre planning and scheduling. We propose and apply throughout this work a comprehensive Multi-Methodology to structure elective surgery planning activities at a Portuguese hospital *Centro Hospitalar Lisboa Norte* from stakeholder’s experience. A Multi-Methodology based in a relaxed version of Soft Systems Methods and Process Mapping is proposed.

The data collection is performed on site through semi-structured interviews. Then, to map surgeons and hospital managers knowledge, we use Rich Picture models, CATWOE, and Root Definitions. Consequently, we model a scheduling decision with process mapping. We conclude that stakeholders look towards maximising OR occupation, although find that the actual model governing the hospital elective activity conflicts with their aspirations. Scheduling models embedded into a decision support system could assist stakeholders’ achieving their objectives.

*Keywords*: Operating Room Planning and Scheduling; Surgeon Preferences; Decision Support Model; Multi-Methodology.
Resumo

O bloco operatório é um dos principais centros de custos de um hospital na gestão do dia-a-dia, desafiando decídures no planeamento da sua actividade. Esta dissertação foca-se no planeamento do de bloco operatório e agendamento. É proposto e aplicado no curso do trabalho uma comprensiva Multi-Metodologia para estruturar o planeamento de cirurgias electivas no Centro Hospitalar Lisboa Norte de acordo com as experiências dos participantes. A Multi-Metodologia baseada num relaxamento de Soft Systems Methods e Engenharia de Processos é proposta.

A recolha de dados é realizada por meio de entrevistas semiestruturadas. As expectativas e conhecimento de cirurgiões e administradores hospitalares são mapeados por meio de Rich Pictures, CATWOE e Root Definitions. Consequentemente, foi modelada um processo de decisão de agendamento cirúrgico por engenharia de processos. O estudo conclui que no hospital os participantes visam simultaneamente maximizar o tempo de ocupação do bloco operatório, contudo verifica-se que o modelo de gestão do hospital conflite com as suas aspirações. Modelos de agendamento incorporados em sistemas de apoio à decisão podem assistir participantes a atingir os seus objectivos.

Palavras-chave: Planeamento de Bloco Operatório; Preferências de Cirurgiões; Modelos de Apoio à Decisão; Multi-metodologia
List of Figures

Figure 1: Portuguese Health Expenditure share of GDP (%) ................................................................. 3
Figure 2: Hierarchical decision levels adapted from Guerriero and Guido (2011) .............................. 6
Figure 3: Perioperative system (Erdogan et. al, 2011) ................................................................... 11
Figure 4: CHLN Case Study Multi-Methodology .............................................................................. 26
Figure 5: Proposed Case Study Multi-Methodology ......................................................................... 27
Figure 6: Elective Main Operating Rooms at CHLN per Surgery Type Performed .......................... 33
Figure 7: Surgical Specialties at CHLN included to the case study .................................................. 33
Figure 8: Multi-Methodology Application to CHLN Case Study ...................................................... 34
Figure 9: Surgical Specialties access to main ORs at CHLN ............................................................ 35
Figure 10: Human interdependencies in Scheduling Elective Patients at CHLN ............................. 37
Figure 11: First Rich Picture of the CHLN Elective Scheduling System ........................................... 38
Figure 12: CHLN case study participant’s hierarchy ......................................................................... 38
Figure 13: Rich Picture: Strategic Decision Level at CHLN ............................................................. 40
Figure 14: Master Surgery Schedule Decision Process at CHLN ..................................................... 41
Figure 15: Rich Picture: Operational Decision Process at CHLN ..................................................... 42
Figure 16: Flowchart basic objects ..................................................................................................... 45
Figure 17: Surgeon decision process for Patient Selection Activity .................................................. 46
Figure 18: Decision process of requesting for an additional specialist at CHLN .............................. 47
Figure 19: Surgeon decision node estimating surgical equipment complexity ............................... 48
Figure 20: Surgeon decision node estimating texp coefficient ............................................................ 49
Figure 21: Surgeon decision process estimating patient’s characteristics impact on surgery i . 51
Figure 22: Surgeon decision Process for estimating non-elective activities .................................... 53
Figure 23: Surgeon Advance Schedule Decision Process ................................................................. 54
Figure 24: Surgeon Allocation Schedule Decision Process ............................................................... 55
Figure 25: CHLN characterisation according to descriptive fields .................................................... 56
Figure 26: Surgeon Decision Process Computing Patient Volatility in Surgery Proposal Form ........ 60
Figure 27: CHLN Advance Schedule and Allocation Schedule Surgeon Decision Process .............. 60
List of Tables

Table 1: Surgery Demand indicators between 2006-2015, adapted from ACSS (2016). [TMRG = Maximum Guaranteed Response Time] ................................................................. 4
Table 2: Clustering patient priority level per maximum allowed NHS hospital response time [TMRG = Maximum Guaranteed Response Time] ............................................................... 5
Table 3: Taxonomy based on descriptive fields, adapted from Cardoen et al. (2010) .............. 14
Table 4: Classification Scheme for OR utilisation .................................................................. 15
Table 5: Classification scheme for levelled resources .......................................................... 17
Table 6: Classification scheme for waiting time ..................................................................... 18
Table 7: December 2017: TMRG grouped by Surgical Service at CHLN ............................... 25
Table 8: Catwoe Analysis Description .................................................................................. 31
Table 9: Adapted from (CHLN, 2015) .................................................................................. 33
Table 10: Surgeon feedback over SM main elective rooms unused ...................................... 37
Table 11: CATWOE and Root Definition of the Patient Scheduling Activity ....................... 42
Table 12: Set and Parameter used in models ....................................................................... 47
Table 13: Surgeons actual estimates used at CHLN for non-surgical activities ...................... 53
Table 14: CHLN variability criteria in the Advance Schedule .............................................. 59
Table 15: CHLN characterisation according to descriptive fields ......................................... 59
Table 16: OR planning and scheduling literature covering the advance schedule and allocation ..................................................................................................................... 63
Table 17: CHLN advance and allocation schedule vs. Literature ........................................ 67
Abbreviations

BIP – Binary Integer Programming
CG – General Surgery
CHLN – Centro Hospitalar Lisboa Norte
CV – Vascular Surgery
CT – Thoracic Surgery
DGS – Direção Geral de Saúde
DSM – Decision Support Model
EST – Stomatology
FCFS – First-Come-First-Serve
FIFO – First-In-First-Out
GDP – Gross Domestic Product
ICU – Intensive Care Unit
INE – Instituto Nacional de Estatística
LIFO – Last-In-First-Out
LOS – Length of Stay
LST – Latest Start Time
MILP – Mixed Integer Linear Programming
MSS – Master Surgery Schedule
N – Neurosurgery
NHS – National Health Service
OBS – Obstetrics
OPSS – Observatório Português Sistemas de Saúde
OR – Operating Room
ORT – Orthopedy
OTO – Otolaryngology
PACU – Post Anaesthesia Care Unit
PECLEC – Programa Especial de Combate às Listas de Espera
PSM – Problem Structuring Methods
PV – Hospital Pulido Valente
RDT – Resource Dependant Theory
RP – Rich Pictures
SA – Simulated Annealing
SIGIC – Sistema Integrado de Gestão de Inscritos em Cirurgia
SIGLIC – Sistema de Informação de Gestão da Lista de Inscritos para Cirurgia
SM – Hospital Santa Maria
SSM – Soft Systems Methods
ST – Stakeholder Theory
TMRG – Tempo Máximo de Resposta Garantida
URO – Urology
VNS – Variable Neighbourhood Search
1. Introduction

The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being (World Health Organisation, 2017), as well as a valuable condition to ensure societies productivity and longevity, enabling individuals to deliver more output to society. Delivering healthcare, however, is becoming increasingly complex and challenges governments into action; due to the ageing of population (DGEFA, 2015), alongside the continuously growing demand for healthcare goods, studies have shown that available budget will never be enough to meet all the demands for healthcare goods. Thus, to ensure the functioning of healthcare delivery services, governments need to go through the rationalization of the available resources (Vanberkel & Blake, 2007).

One critical unit within a hospital is the operating room (OR). The OR is extremely relevant in a hospital day-to-day management, given that a high percentage of hospital admissions is due to surgical interventions (Guerriero & Guido, 2011). Furthermore, the OR is one of the main cost drivers in a hospital, as well as traditionally underutilized (Magerlein & Martin, 1978), which implicitly means that efficient OR management can both reduce costs and increase revenues for hospitals. However, managing the OR is a very complex process - because of the current ageing population, health managers must anticipate the increasing demand for surgical services and react with limited resources, while managing conflicting objectives and preferences of its stakeholders (Cardoen et al., 2008). As pointed out by Litvak & Long (2000), while non-elective cases contribute to the huge amount of variability in hospital environments, an important part of the variance can be controlled by well thought-out scheduling policies to elective cases; and variability in the OR scheduling, as positively correlated with inefficiencies (artificial variability), if controlled, enables hospitals to contain the elevated OR running costs and to provide an effective response to the increasing surgical demand. The advantages stemming from efficient OR scheduling systems led the operations research community to cultivate interest in the domain of OR planning and scheduling scope, proposing several applications to support policy-makers with the use of optimisation and simulation models often embedded into decision support systems (Guerriero & Guido, 2011).

This work introduces Multi-Methodology focused on stakeholder knowledge over OR elective scheduling, thereby leveraging the relevance of models and improve the chances of successful implementation, by systematically address key stakeholders and process owners, translating their tacit knowledge into explicit definitions constraining elective schedules.

Several authors in the operations research community propose customised formulations, with performance usually tested against specific historical data. While most authors in literature over-concentrate their efforts into development, OR stakeholders are often left-out, or purposefully avoided from study’s methodology. Conversely, the goal of this work is to purposefully include key stakeholders’ concerns into the process of modelling elective schedules.

Besides tackling the technical interests of the scheduling process, this project is concerned with the role surgeons’ play during the scheduling decision process, in which the argument is that, failing to identify their expectations in the scheduling phase increases the risk of unsuccessful implementation.
This thesis proposes a systematic multimethodology based in Soft Systems methods (SSM) and process engineering, applied to a Portuguese hospital. Ultimately, our goal is to approach stakeholders, build a shared understanding over their tacit knowledge, thereby easing the acceptance of stakeholders to optimisation alternatives by translating their concerns into practitioner’s mathematical formulations. Therefore, an opportunity to address a specific OR setting, include surgeon’s expectations into the elective surgery scheduling process, facilitating the discussion between stakeholders regarding the use of operational research techniques, to converge expectations and optimise processes.

Accomplishing this work, first, we present a literature review covering the scope of OR planning and scheduling, as well as identify the key OR stakeholders, according to what several authors refer in their studies. Furthermore, as this work is concerned with retaining stakeholder knowledge designing models, we also introduce stakeholder theory (ST), resource dependant theory (RDT), and discuss how authors usually perceive and consider surgeon’s preferences in their studies.

Then, we address the proposed Multi-Methodology to undertake at the hospital of study, Centro Hospitalar Lisboa Norte (CHLN), and introduce a section for Problem Structuring Methods (PSM).

Following the literature review and methodological proposal, this work presents the case study application; we address two operating theatre at CHLN, one at hospital de Santa Maria (SM) and one at hospital Pulido Valente (PV). The first methodological step introduces semi structured interviews with certain relevant stakeholders in different surgical groups: hospital managers, surgeon specialists, and surgeon interns. In our work, a Soft Systems approach was relaxed solely to define stakeholder concerns and tacit knowledge at CHLN, enriching our preconceived views from literature, thereby enabling us to model one selected scheduling process, adjusted to how relevant stakeholders experience it. Therefore, we structure the stakeholder knowledge with Rich Pictures and define the problematic situation with CATWOE and Root Definition. Finally, we select a process and model it according to surgeon’s expectations by process mapping, thereby enabling follow-up studies, where authors can adapt to stakeholders confirmed realities. In addition, we conclude this study by reviewing OR planning and scheduling literature against how we characterize the elective scheduling activity at CHLN; and review several studies in similar hospitals, with potential applications from which CHLN could benefit implementing.
2. Context

This chapter introduces the reader to the relevance of having the operations research community exploring approaches alongside healthcare manager’s. Furthermore, an overview of the Portuguese health service, as well as context to the planning and scheduling of elective surgeries is given. In section 2.1., we demonstrate the historical pursue of the Portuguese government and its efforts to increase the elective planning and scheduling operational efficiency; and in 2.2., we introduce the subject of planning and scheduling elective patients.

2.1. Towards Efficiency in the OR

The period of ‘long stagnation’ that shook Portuguese economy at the beginning of century XXI, and from which the country is now slowly recovering has alarmed the European community. The systematic budget deficits in public accounts, alongside the increased dependency on European loans over the years, has led the eyes of public scrutiny into finding where and how public expenses are spent. Given its relative weight as percentage of the gross domestic product (GDP), illustrated in Fig. 1, the healthcare sector has been on the spotlight as one of the main drivers of public spending. Therefore, governments have been trying to enact legislation that promotes cost-containment; and potentiate the National Health Service (NHS) efficiency and effectiveness, inducing a rational use of services and resources, thus controlling expenses (Oliveira et al., 2011).

![PORTUGUESE HEALTH EXPENDITURE SHARE OF GDP (%)](image)

There has been a clear effort to promote efficiency into the NHS with the limited resources at disposal. A sizeable portion of these attempts are directed at public hospitals. They aren’t just inherently complex in planning for service delivery, with high variability, but they also account for a major parcel of health providers annual expenses and demand for healthcare goods (32% in 2013 (INE, 2014)). In the agreement memo between Portugal and the tripartite steering (European Central Bank; European Commission; and the International Monetary Fund) it is clearly outlined the importance of generating additional savings in hospitals expenses (Oliveira et al., 2011).
One example of Portuguese policy-making towards efficiency is found in the surgery waiting list management background of the NHS. Between 1995 and 2004, the number of enlisted patients for surgery started to increase, overwhelming public hospitals waiting lists for surgery. To cope with this problem, multiple programs were launched by the Health Ministry, aimed at reducing the surgery waiting lists (e.g., Programa Especial de Combate às Listas de Espera Cirúrgicas, PECLEC). Basically, its premise was based on monetary incentives to stimulate the execution of additional surgeries under a fee-for-service funding system. However, despite the increased capacity, the number of patients waiting for surgery continued to grow. For instance, when PECLEC was enacted in 2002, there was 123,547 enlisted patients waiting for surgery, with an average waiting time of 571 days, and a minimum and maximum response time of, respectively, 380 days and 1699 days. The number continued increasing, and in 2005 the number of enlisted patients waiting for surgery was 224,000 (Observatório Português dos Sistemas de Saúde – OPSS, 2009). Hence, in 2004, a different strategy was defined with the implementation of SIGIC (Sistema Integrado de Gestão de Inscritos em Cirurgia). SIGIC is the government information system aimed at minimizing the surgery wait list, by efficiently managing it. After the failure of several public interventions, based on increasing capacity to perform surgeries, SIGIC aim is to induce a philosophy of increasing productivity in the health service, through efficiency and resource rationalization (Barros, 2008). The evolution of the wait list according to SIGIC between 2006 and 2015 is presented in Tab. 1

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>List Entrances</td>
<td>451,942</td>
<td>573,527</td>
<td>611,535</td>
<td>624,226</td>
<td>644,178</td>
<td>649,386</td>
<td>662,642</td>
<td>47%</td>
<td>2%</td>
</tr>
<tr>
<td>Enlisted Patients</td>
<td>221,208</td>
<td>162,211</td>
<td>180,356</td>
<td>166,798</td>
<td>176,129</td>
<td>184,077</td>
<td>197,401</td>
<td>-11%</td>
<td>7%</td>
</tr>
<tr>
<td>Median Waiting Time (months)</td>
<td>6.9</td>
<td>3.1</td>
<td>3.3</td>
<td>3</td>
<td>2.8</td>
<td>3</td>
<td>3.1</td>
<td>-55%</td>
<td>3%</td>
</tr>
<tr>
<td>% of Enlisted Patients off TMRG</td>
<td>43.50%</td>
<td>13.00%</td>
<td>15.80%</td>
<td>15.10%</td>
<td>12.80%</td>
<td>12.00%</td>
<td>12.20%</td>
<td>-72%</td>
<td>2%</td>
</tr>
</tbody>
</table>

**Table 1: Surgery Demand indicators between 2006-2015, adapted from ACSS (2016).** [TMRG = Maximum Guaranteed Response Time]

Potential for cost containment, through efficient planning and effective use of resources in hospitals appears in the surgical setting (Magerlein & Martin, 1978). Given the highly innovative and specialized technical equipment used in surgeries, operating rooms are among the most critical resources that generate highest costs for a hospital (Lamiri et al., 2008; Marques et al., 2014a). Furthermore, managers design hospital services with certain capacity over a given time, which if not used, misses the opportunity to generate revenue for the hospital (Ozcan, 2005).

In 2015, Portuguese public hospitals incumbent in the NHS have spent 893,913,814 € in surgical activities, which represented about 29% of the whole hospital budget (Penedo et al., 2015). The increasing relevance of the OR planning and scheduling process on the hospital’s performance, has summon the attention from the operations research community over the years; and given the inherent complexity of these problems, the use of mathematical and simulation models, and other quantitative techniques plays, thus a crucial role (Guerriero & Guido, 2011).
1.2. Planning and Scheduling of Elective Patients

Surgery waiting lists are a necessary mechanism for public health services. Their purpose is to ensure that the cost-benefit rule is achieved; by delaying health care delivery to act as a rationing device, it is accomplished the same effect market price has in private health systems (Testi & Tànfani, 2009). According to Portuguese law, the patient must have surgery within a maximum response time (TMRG), depending on his level of priority (UCGIC, 2005), presented in Tab.2.

The surgery waiting list management poses a difficult challenge to public hospitals, as previously mentioned. Even though patients legally must have surgery within the TRMG, in most hospitals that is not always the case. Therefore, one of the guidelines outlined in the Portuguese National Health plan is the reduction of waiting lists for surgery (Direção Geral de Saúde, 2012). For instance, in Centro Hospitalar Lisboa Norte EPE (CHLN), in October of 2016, only 82.6% of waiting cases were in fact still within the allowed TMRG, an amount of 6.708 patients, out of 8.123 enlisted in SIGIC (CHLN EPE, 2016). To cope with this goal, efficient OR planning and scheduling can increase patient throughput. However, the decision-making process involving the setup of efficient schedules is very demanding.

<table>
<thead>
<tr>
<th>Patient Priority Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMRG (days, hours)</td>
<td>72 hours</td>
<td>270 days</td>
<td>15 days</td>
<td>72 hours</td>
</tr>
</tbody>
</table>

*Table 2: Clustering patient priority level per maximum allowed NHS hospital response time [TMRG = Maximum Guaranteed Response Time]*

OR management requires the coordination of both human, and material resources, so that surgeries can be performed efficiently, cost effectively, and safely (Plasters et al., 2003); and given the complexity, often researchers decompose problems into three well-defined hierarchical decisions across OR planning and scheduling literature - strategic, tactical, and operational (Magerlein & Martin, 1978; (Blake & Carter, 1997); (Cardoen et al., 2008), Guerriero & Guido, 2011), illustrated in Fig.2:

- **Strategic** – High-level stakeholders (usually hospital managers) decide, on long-term, how much OR time to strategically distribute among surgical specialties. This reflects mainly a resource (surgeons) allocation problem, in which the allocation time to surgeons varies according with manager’s goals, e.g., maximise OR utilisation. Thus, OR resource provision for surgeons operating time is settled at the strategic level.
- **Tactical** - OR capacity available to each surgical service for a given horizon. The tactical level concerns the development of a master schedule for a given planning horizon – the master surgery schedule (MSS). In the MSS problem, the OR manager defines the allocation of specific time blocks of each OR to several surgeon groups per day, based on the OR time distribution previously settled at the strategic level, dependant on the OR manager’s objectives (limitations) for the MSS.
- **Operational** - In this phase, decisions are made at the patient level, based upon the previously developed MSS; and has been referred to as a two-stage process – the advance schedule and
allocation schedule problems (Magerlein & Martin, 1978). In the former, a set of patients is selected from the waiting list to have surgery on a future date. In the latter process, the sequence of surgical cases for each day is determined, by defining an available OR and a surgery start time for each surgical case, taking the assumption that all patients are available and prompt for surgery.

![Hierarchical decision levels adapted from Guerriero and Guido (2011)](image)

Many researchers tackle these problems in OR planning and scheduling literature, proposing several methods and mathematical formulations. Although authors adjust and tailor models to their hospitals of study, we see that part of their contributions is often assumption-based, since in many cases, there is no mention of a formal methodology used to include key stakeholders. Thus, given that OR planning and scheduling literature rarely considers modelling surgeon’s preferences, our goal will be to apply a formal methodology to characterize stakeholder’s tacit views when modelling their decision process.

This study aims to apply a robust approach for data collection, treatment, and assessment at Centro Hospitalar Lisboa Norte (CHLN). Our goal is to enable the development of efficient elective scheduling models, by proposing formulations that shape and respect relevant stakeholder’s preferences, avoiding resistance and delayed implementation.

This thesis is focused with the OR planning and scheduling scope. The structure of the following review has two main sections.

First, the scope of OR planning and scheduling problems found in literature has several distinguish characteristics that hinders the process of structuring studies appropriately. Given that difficulty, Cardoen et al. (2010) developed a classification scheme based on descriptive fields, to clarify the statement and scope of the different operating room planning and scheduling problems:

- Patient characteristics (section 3.1)
- Delineation of decision (section 3.2)
- Uncertainty (section 3.3)
- Performance measures (section 3.4)
Considering this as a robust approach to classify literature, we apply their methodology to structure the first part of this review. The main goal of our review approach is to present an organised view over what researchers propose in literature – describing their methods, main assumptions and limitations.

The second part of the following review concerns with the role of one OR key stakeholder, the surgeon. Specifically, we introduce stakeholder theory as well as resource dependent theory (section 3.5). Furthermore, we reference multiple challenges for future research according to several authors and conclude this literature review (section 3.6); and in annex is presented a general description for the reviewed studies, exhibiting their methods, goals, limitations (Appendix A). Also, the classification schemes introduced (Tab.3; Tab.4; Tab.5) are pooled together (Appendix B); and for the ones who have considered surgeon's welfare, a framework is introduced to label the methodologies applied for preferences analysis, as well as the circumstances of validation by the involved stakeholders (Appendix C).
3. Literature Review

This thesis concerns with the use of efficient scheduling methods at hospitals, the underlying decision-making medical teams require in designing elective schedules and identifying how schedules have different impacts on stakeholders' preferences. This chapter provides an explanation covering the different models and approaches authors use in literature.

This thesis considers the application in an actual case study at a Portuguese hospital in Lisbon. The following review assists us in breaking down the problem’s authors find in OR planning and scheduling literature, and validate if and how, they include key stakeholder’s perceptions and concerns, when modelling their preferences.

The material we use on the following review was product of searching in databases as Google Scholar, PubMed, B-on, and ScienceDirect, by using expressions such as “Elective Scheduling Methods”, “Operating Theatre Planning”, “Scheduling Optimisation Algorithms”, “Variability”, “Healthcare management”, “Decision-making”, “Stakeholders” and its combinations.

3.1. Patient Characteristics (α1)

Usually patients are grouped into two classes, elective and non-elective patients. The first class includes patients in a non-urgent condition, for whom surgery can be scheduled in advance; whereas the second patients group need surgery unexpectedly, and thus it is necessary to schedule in short notice (Samudra et al., 2016). Furthermore, although many researchers do not indicate what type of elective patients they are considering, some distinguish between inpatients (conventional) and outpatients (ambulatory). Inpatients refer to hospitalized patients who must stay overnight, whereas outpatients typically enter and leave the hospital on the same day (Cardoen et al., 2008). Compared to an inpatient setting, surgery in an outpatient setting has some characteristic features. For example, outpatient surgery often consists of more standardized procedures (e.g., routine surgeries, minimally invasive procedures); and given that outpatients are not already present in a hospital ward before surgery, their actual arrival time is uncertain (Samudra et al., 2016). To deal with outpatient surgeries, specific rooms may be dedicated to exclusive use of these patients (Castro & Marques, 2015). However, according to Blake et al. (2002) with the increased use of outpatient surgery, the designation of main and elective rooms is now somewhat anachronistic, because many outpatients are now treated in the main operating rooms. Despite this, in general, the hospital reserves the use of the elective rooms for shorter, less complex, outpatient cases. Plenty of studies in literature avoid dealing with non-elective cases (Cardoen et al., 2008). Indeed, there are two common approaches to deal with non-elective cases: either accommodate non-elective cases into the elective schedule, or else channel non-elective patients into dedicated operating rooms (Samudra et al., 2016). According to Litvak & Long (2000), if patients appearing with an emergent or urgent condition are forced to compete with elective scheduled patients for the same rooms, it becomes impossible for the operating theatre to simultaneously satisfy the performance objectives of high utilization and low waiting time for both patient groups. However, by separating these patient groups, and open dedicated rooms for emergencies, additional costs arise, due to staff allocation and maintenance costs (Sperandio
et al., 2014)). In Lamiri et al., (2008), the authors consider OR capacity to be shared among these competing groups, by constructing a Monte Carlo simulation-optimization method, that combines Monte Carlo simulation (to generate random samples of non-elective capacity) with mixed integer linear programming (MILP); their planning target is to assign elective cases to different periods over a planning horizon, to minimize the sum of elective patient related costs and overtime costs of operating rooms. A more simplistic approach was taken by (Vanberkel & Blake, 2007), to increase OR efficiency and elective throughput, they introduced a general rule to the dedicated emergency room in their simulation model. The authors consider some deterministic OR time available to the elective patients – the general rule followed in this study is to use weekday mornings for two or three short elective cases before switching priorities and completing all the non-elective cases for that day.

Some hospitals have operating rooms for the exclusive use of separate patient classes. By doing so, these are automatically excluded from being considered as part of the patients to be scheduled, hence simplifying the underlying model (Aringhieri et al., 2015). However, this may translate into unbalance workload among OR’s, if the time distribution isn’t adequate to serve both demands. On the one hand, exclusive OR’s satisfying emergency cases increases the safety of promptly serving these patients, possibly increasing the unused OR capacity as well; on the other hand, by having separate OR’s for different patient classes, less available capacity is available to accommodate elective cases, and these elective OR’s may become bottlenecks.

Nonetheless, most studies found in the literature limit the scope to the elective patient class. (Beliën et al., 2009) developed a decision support system (DSS) for the MSS problem, that relies on MILP techniques involving the solution of multi-objective linear and quadratic optimization problems, as well as on simulated annealing (SA). In their study, they only account for elective cases; first, they state that it would make little or no sense fitting a probability distribution for both the non-elective arrivals and recovery, given the high unpredictability of these events; and second, since non-elective cases occur unexpectedly, surgery often takes place on days during which the surgeon has no block allotted in the MSS. Despite disregarding non-elective patients, the authors expect to overcome the impact of non-elective variability in bed occupancy, by controlling an important part of the variance through well-thought scheduling policies to the elective cases.

3.2. Delineation of Decision (β)

Classification based on descriptive fields to address OR planning and scheduling problems is not the sole approach found in literature; a popular alternative is to review these problems by the hierarchical decision levels commonly found: strategic, tactical and operational. In the strategic level, OR time is distributed among different surgeon groups; whereas in the tactical level, concerns the development of an MSS, which defines the number and type of available ORs, their working hours, as well as the surgeons which the OR time is assigned to; and the operational level, when elective patients are scheduled, with the definition of a date, an available OR, and a surgery starting time (Guerriero & Guido, 2011). According to Cardoen et al. (2010), this classification is somewhat inappropriate, because the boundaries between the
strategic, tactical, and operational level are seemingly hard to define and hence result in unclear or vague statements. Also, another common distinction is between block scheduling and open scheduling management procedures (Samudra et al., 2016). In block scheduling policies, a block of OR time is allocated to each surgeon or group of surgeons, usually one-half to a full day in length (Ozcan, 2005); and planning can be viewed as being made up of three phases corresponding to the three well known hierarchical decision (Aringhieri et al., 2015). On the other hand, open scheduling policies assign surgical cases, to an available OR, at the convenience of surgeons (Guerriero & Guido, 2011). An empty schedule is filled up with surgical cases in two usually decomposed phases: a first planning stage, during which an operating day is fixed for each surgery. This planning stage is next followed by a scheduling stage that determines the starting time of each operation occurring on a given day, by taking the implementing constraints into account (Roland et al., 2010). Other usually referred scheduling policy is the modified block scheduling, where time blocks may be left open for use, and unused time can be reallocated to a different surgeon’s or surgeon group (Spratt & Kozan, 2016).

Decision delineation regards the reflection onto the following questions:

- $\beta_1$ – To Whom decisions do apply?
- $\beta_2$ - Which type of decisions are made?
- $\beta_3$ - What is the degree of OR integration?

Specifically, researcher’s decisions apply to whom ($\beta_1$)? The research purpose may focus solely on patients, e.g. Tyler et al., (2003); surgeons, e.g. Wright & Kooperberg, (1996); or other medical disciplines, such as nurses, e.g. Lim, (2016) or may in fact relate to hospital interest, e.g. Litvak & Long (2000). In addition, it should be noted that decisions in OR planning and scheduling literature can in fact apply to different entities, a combination of stakeholders to whom the decisions have impact, e.g. Arenas et al. (2002). Furthermore, which types of decision can be made regarding the OR planning and schedule ($\beta_2$)? In this field, one or more elements are combined in the literature. The decision may involve selecting a date for a surgical case, e.g. (Ozkarahan, 2000); assigning an available OR, e.g. (Duma & Aringhieri, 2015); and/or assigning a surgical starting time, e.g. (Franklin Dexter & Traub, 2002). Other studies include OR capacity decisions, e.g. Dexter (1999), and usually focus on assigning OR time to disciplines, which often results in the MSS (Samudra et al., 2016).

Many authors claim the OR as the engine that drives the hospital, (Litvak & Long (2000); Blake et al. (2002); Beliën & Demeulemeester, 2007). In fact, the activities inside the OR have a dramatic effect on other activities within a hospital (e.g., patients undergoing surgery are expected to recover a number of days, thus bed capacity and nursing staff requirements are dependent on the OR schedule (Beliën & Demeulemeester, 2007)), because the overall surgery process involves several activities before, during and after the surgical procedure, including the preoperative, intraoperative and postoperative stages (Erdogan, Denton, & Cochran, 2011), as shown in Fig.3. Thus, researchers face decisions on the level of OR integration they want to include into the scope of each study ($\beta_3$); either account relationships with partaker facilities (e.g., intensive care units (ICU), post anaesthesia care unit (PACU)), in which case the study is labelled as integrated; or study the intraoperative system as an isolated unit. According to
Samudra et al. (2016), when OR planning and scheduling decisions do not incorporate supporting facilities, in which case the OR is studied as an isolated system, improving the OR schedule may worsen the efficiency of those related facilities. Fig. 3 illustrates the various stages patients must undergo within the operating theatre.

![Figure 3: Perioperative system (Erdogan et al., 2011)](image)

3.3. Uncertainty ($\Upsilon_1$)

A key feature of surgery planning and scheduling processes is the coordination of several and multiple activities in an uncertain environment (Guerriero & Guido, 2011). Such uncertainty leads to frequent deviations between what was planned and what was in fact performed (Sperandio et al., 2014), and thus, the ability to cope with uncertainty is an essential part of modern healthcare scheduling (Beliën et al., 2009). Before reviewing the different approaches conducted in literature to account for uncertainty in the OR planning and scheduling process, first one needs to understand which sources drive this phenomenon. As pointed out by Litvak and Long, (2000) even though variability in hospitals environment is significantly accounted for non-elective demand, an important portion of this variance can be controlled by developing efficient OR schedules for elective cases. In their study, they make a distinction between natural and artificial variability. The former, results from the uncertainty inherent to the world of healthcare; the latter, doesn’t occur with randomness nature, it is created from poor scheduling policies. Natural uncertainty in the OR planning and scheduling process has three main sources (Riise et al., 2016):

1. **Surgeries duration** – which are difficult to predict because, for some surgeries, the magnitude of the procedure only becomes apparent once the surgery is already in progress, and additionally the durations often depend on complex factors, e.g. the characteristics of the patient, the surgeon, and the surgical team;

2. **Resource availability** - e.g. bed occupancy, which is difficult to predict due to unexpected patient length of stay (LOS) (Beliën et al., 2006));

3. **Cancellations or arrivals of emergency care patients.**
To deal with variability in the OR, managers must eliminate system’s expense resulting of artificial variability from the OR planning and scheduling processes. By using operations research methods, schedulers must then optimally manage these remaining natural variabilities (Litvak & Long, 2000). In the literature, two different approaches to deal with variability are found – deterministic and stochastic approach. Deterministic planning and scheduling approaches ignore uncertainty, whereas stochastic approaches explicitly incorporate (Samudra et al., 2016) uncertainty into the models. Deterministic approaches are a simplification of the real situation (Marques et al., 2014b); and when uncertainty pertaining to arrival rate, operating time, or LOS are excluded, translates into a serious drawback of the model whose solutions depend heavily on the ability of surgeons to predict these parameters correctly (Testi & Tànfani, 2009).

Magerlein & Martin (1978), identify three methods for estimating procedure times: surgeon’s estimates, OR scheduler’s estimates, and historical averages. Furthermore, Ozcan (2005) states that, although most hospitals often use surgeon’s estimates, only few attempts have been made to validate them, with significant limitations and ambiguous findings. In one instance, Wright & Kooperberg (1996) have carried out statistical analysis to estimate surgical case durations. In their work, the authors sought to compare surgeon time estimates for elective cases with those of commercial scheduling software used in a hospital; and ascertain whether improvements could be made by regression modelling. The study concluded that surgeons provided more accurate estimates than the scheduling software at the hospital of study; and credit this fact to the lack of specificity of the Current Procedural Terminology (CPT) coding in the prediction software in-house coding scheme. Furthermore, some authors propose robust optimisation methods (Addis et al., 2014; Addis et al., 2015; Addis et al., 2016; Gupta & Denton, 2017; Marques & Captivo, 2017). These methods assume that each uncertain parameter belongs to a given convex set, without the need for a further description of its probability distribution functions (which in many cases, hinders parameter statement), while guaranteeing that the solution is feasible for all the values of the parameters within the considered uncertainty set. Marques & Captivo (2017) tackle uncertainty concerning the surgeries duration, with a robust approach, which gives the possibility for the surgical planner to control the degree of conservatism of the solutions. Also, the authors claim that using this approach allows to consider uncertainty by solving a MILP model as the determinist version developed. Denton et al. (2007), on the other hand, developed a stochastic optimization model, alongside some practical heuristics that hedge against uncertainty in surgery durations; and showed that a simple rule based on time variance can be used to generate substantial reductions in total OR team waiting, OR idling, and overtime costs. In another study, Addis et al. (2015), both surgery durations and new patient arrivals are considered as uncertainty. Patient arrivals are considered by adopting a rolling-horizon approach with rescheduling; and surgery durations are accounted for with a robust optimisation model that allows to specify a certain level of robustness. A method that exploits neighbourhoods search techniques combined with Monte Carlo simulation is proposed in Aringhieri et al. (2015). In this paper, the authors deal with the integrated advance and allocation scheduling problem, while assuming patient surgery durations are stochastic variables with a priori given distribution functions.
3.4. Performance Measure(s) Evaluating Solutions (∆)

Different scheduling policies have different impacts on stakeholders, as well as different stakeholders have different expectations from scheduling policies. Hospital managers have scheduling objectives, such as levelling resources, maximise OR utilisation, or minimise OR related costs; whereas, patients, understandably do not have the same viewpoint, and their expectations can be summed to shortening waiting times. Given the multiplicity of stakeholders whom the scheduling policies aim to satisfy, many researchers include multiple criteria to evaluate solutions to the OR planning or scheduling problem. As such, when classifying literature, it must be stated if the research study addresses a single or multiple performance measures to evaluate model’s solutions (∆1). Furthermore, this section aims to analyse each of these criteria and include them into the classification framework (Appendix B). For the sake of clarity, the taxonomy within each descriptive field is found in Tab.3.

Since multiple stakeholders acting with conflicting interests are involved in the OR, the use of operations research plays a crucial role to realize a good balance between these conflicting needs and desires (Guerriero & Guido, 2011) for the OR scheduling process. Although many papers account several stakeholder’s interests, few explore the multicriteria characteristics of the problem or explicitly use multicriteria optimisation methodologies; information on how they deal with multiple objectives is often lacking and, in practice, most of them apply a sum (weighted or not) of the criteria to obtain just a single solution (Marques & Captivo, 2015). In their work, they tackled two conflicting objectives; alongside OR utilisation, reduction of surgery waiting lists is also addressed with a bicriteria optimisation methodology, by using an evolutionary algorithm. An advantage of this approach, unlike many other multicriteria optimization problems addressed in literature, is that the output consists on a set of potentially non-dominated solutions; not relying on decision-makers associated weights to provide one solution on each run, and instead, on each run, having the set of efficient solutions represented in the Pareto front. However, many studies rely on decision-maker weights, and thus goal programming (GP) is also found to be a desirable approach to tackle multiple objectives. By using GP methodology to analyse multiple objectives, they can assist decision-makers to see relationships among complex data and multiple variables, while establishing their objectives via single objective; however, the quality of the solutions depends on the parameters settled by the decision-makers, which might not translate set forth goals (Arenas et al., 2002). Ozkarahan (2000) has developed a GP model that simultaneously minimizes idle time and maximises satisfaction of surgeons, patients, and staff; by considering five goals into the model: 1) maximise OR utilisation; 2) assign priority use for OR block; 3) assign ORs according to surgeon’s preference; 4) surgeons preferences; 5) intensive care capabilities goal constraint, to ensure intensive care capacity (beds) for patients in need of post-surgery intensive care. Given this context, each performance measure criteria (∆2) encompassing most models in OR planning and scheduling literature are explored in the following subsections, at which point, the descriptive fields previously described (section 3.1, 3.2, 3.3) are included into the criteria at hand in Tab.4, Tab.5, and Tab.6. Furthermore, to the original classification scheme of Cardoen et al. (2010), there is an additional field introduced, where different approaches can be characterized for each study; this work distinguishes
between three approaches addressing OR planning and scheduling problems, which can be combined in same studies, given that in most cases, authors explore more than one solution approach - exact approach (e.g., Integer Programming (IP)), simulation approach (e.g., Discrete Event Simulation), and heuristic approach (e.g., SA). Furthermore, Tab.3 illustrates the taxonomy used to classify OR planning and scheduling literature.

<table>
<thead>
<tr>
<th>Patients characteristics</th>
<th>α1</th>
<th>Elective patient (E), Non-elective patient (NE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject of decision</td>
<td>β1</td>
<td>surgeon (Surg), patient (Pat), hospital (Hosp), other medical discipline (disc), other (other)</td>
</tr>
<tr>
<td>Type of decision</td>
<td>β2</td>
<td>(assignment of a) date (Date), time indication (Hour), operating room (OR), capacity (cap), other decision (other)</td>
</tr>
<tr>
<td>Degree of integration</td>
<td>β3</td>
<td>isolated (Iso), incorporated (Inc)</td>
</tr>
<tr>
<td>Uncertainty incorporation</td>
<td>Υ1</td>
<td>deterministic (det), stochastic (stoch)</td>
</tr>
<tr>
<td>Objective scope</td>
<td>Δ1</td>
<td>single (Single), multiple (Multi)</td>
</tr>
<tr>
<td>Performance measures</td>
<td>Δ2</td>
<td>overtime (Otime), undertime (Utime), level resources (Level), utilisation (Util), stakeholder’s preferences (Pref), financial (Fin), throughput (through), waiting time (wait)</td>
</tr>
</tbody>
</table>

*Table 3: Taxonomy based on descriptive fields, adapted from Cardoen et al. (2010)*

### 3.4.1. OR Utilisation

A productive surgical suite includes elements such as low cancellation rates, minimal overtime personal costs, and high utilisation. Here utilisation refers to the time an OR is used, including setup and clean up, divided by the length of time an OR is available and staffed (Dexter et al., 1999). From hospitals point of view, OR utilisation rate and overtime are important metrics, as they describe the impact on usage of limited resources (Addis et al., 2016). However, it is known that defining the optimum level of utilisation is both not easy nor clear which trade-offs are required to achieve it (Guerriero & Guido, 2011). Tyler et al. (2003) have identified some important factors affecting the optimum OR utilization; among those factors, the authors credit natural variability as the main enemy to achieve higher OR utilization. Many papers consider this performance measure and propose multiple approaches across OR planning and scheduling literature. Luo et al. (2016) developed a rolling-horizon scheduling model based on mixed MILP, if surgery scheduling is influenced by the daily variation in surgical demand, and hence the rolling-horizon approach is useful to balance and make full use of the OR. Landa et al. (2016) have developed a two-phase hybrid optimization algorithm which exploits the potentiality of neighbourhood search techniques combined with Monte Carlo simulation to simultaneously maximise OR use, while minimising the number of possible cancellations, by allowing some overtime capacity to be used. A reverse thought to aim at maximising of OR use found in literature regards the goal OR underutilisation. To solve both the minimisation of underutilised OR time and overtime cost, Fei et al. (2009) developed a column generation-based heuristic (CGBH), considering an OR open schedule to assign surgical cases to multifunctional ORs, over a weekly planning horizon.
Table 4: Classification Scheme for OR utilisation

<table>
<thead>
<tr>
<th>Patient charac.</th>
<th>Delineation of decision</th>
<th>Uncert. Incorpor.</th>
<th>Performance measures</th>
<th>Model Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α1</td>
<td>β1</td>
<td>β2</td>
<td>β3</td>
</tr>
<tr>
<td>(Wright &amp; Cooperberg, 1996)</td>
<td>E</td>
<td>Surg</td>
<td>Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Dexter et al., 1999)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Hour; Cap</td>
<td>Iso</td>
</tr>
<tr>
<td>(Ozkarahan, 2000)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>(Blake et al., 2002)</td>
<td>E</td>
<td>Surg; Hosp</td>
<td>OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Franklin Dexter &amp; Traub, 2002)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Tyler et al., 2003)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Denton et al., 2007)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Fei et al., 2009)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Marques et al., 2012)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Sperandio et al., 2014)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Marques et al., 2014a)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Marques et al., 2014b)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Castro &amp; Marques, 2015)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Landa, Aringhieri, Soriano, Tantani, &amp; Testi, 2016)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Hour</td>
</tr>
<tr>
<td>(Luo et al., 2016)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
</tbody>
</table>

First, a mathematical model (binary integer programming) is proposed, to solve the tactical OR planning problem, complying the surgeon and OR availability to assign patients over a week planning horizon. Then, a CGBH procedure is developed, where four different criteria are compared with each other to find a solution with the best performance (linear programming formulation).

Moreover, Marques et al. (2012) propose an integer programming model (ILP) to solve both the advance and allocation scheduling problem that maximises the OR use; in which the non-optimal solutions given by the optimization model were further improved by a custom-made (local search) heuristic procedure. On another paper, the same case study was solved through a different optimisation approach. The authors propose a two-level decomposition algorithm that relies on two continuous time generalised disjunctive programming for the near optimal scheduling of elective surgeries (Castro & Marques, 2015). Conversely
to optimisation methods, authors often resort to simulation studies of the OR setting. To maximise OR use, Dexter et al. (1999). The authors compared 10 scheduling algorithms through simulation to evaluate which performed best to schedule add-on elective cases (elective cases scheduled after cut-off time to maximise OR use); and conclude that the best algorithm to maximise OR utilisation is the Best Fit Descending with fuzzy constraints. Furthermore, Dexter & Traub (2002) compared two simple scheduling heuristics, earliest start time (EST) and latest start time (LST), to evaluate several scenarios on the effects of scheduling one patient with those heuristics; and concluded that, while LST performs best on balancing the workload among services OR time, EST is more economically rational for the hospital because maximises OR utilisation.

3.4.2 Level Resources

Even though many studies found in literature do not consider downstream and/or upstream facilities as process bottlenecks, thus disregarding them from models, few authors in literature explore those interdependencies. Detached facilities from the surgical suite can also influence the performance of the operating room; PACU and recovery units can become process bottlenecks, leading to patients backing up in ORs, and causing longer anticipated turnover times between surgeries, which could ultimately result in overtime or surgery cancellations (Erdogan et al., 2011). Vanberkel & Blake (2007) conducted a simulation study to aid OR managers on capacity planning decisions, by analysing the waiting list for the Division of General Surgery in a Canadian hospital. Their study showed that longer wait times are more dependent on beds than available OR time; which provided direction to focus on alternatives to free up beds and reduce the bottleneck effect. In the Netherlands, a decreasing number of available nurses has led authors to focus on reducing the number of required beds as much as possible; and hence, the authors developed a model to produce a tactical schedule (MSS) to minimize the number of required beds. Two approaches were modelled and tested; both SA and ILP. ILP performed best to achieve the objective function, reducing the number of required beds in 20% on some instances tested (van Essen et al., 2014). However, in their study, the authors do not consider the stochastic nature of the emergency patients’ arrivals, whom also have need for beds. Although these cases contribute dramatically to the huge amount of variability in bed occupancy, an important part of the variance is manageable by applying well-thought scheduling policies to the elective cases (Litvak & Long, 2000). Hence, if the bed occupancy resulting from the elective cases has adequate balance, there should be a reasonable likelihood of having resources to absorb unexpected peaks in bed requirements from non-elective cases (Beliën et al., 2009). The model proposed in their earlier paper includes stochastic number of patients per operating room block and Length of Stay (LOS) is given by a multinomial distribution that differs per surgery type for each operated patient. The model enables to build the MSS, which levels the resulting bed occupancy as much as possible; and relies on MIP and SA approaches (Beliën & Demeulemeester, 2007). Beliën et al. (2009) extended this approach and developed a DSS to visualise the OR schedule and the resulting bed occupancy. Aringhieri et al. (2015), also aimed to level the post-surgery ward bed occupancies during the days. Their model relies on binary linear programming, and as for the solution approach, the authors
exploit the inherent flexibility of variable neighbourhood search (VNS) methodology. Furthermore, Guinet & Chaabane (2003) develop a primal-dual heuristic based on an extension of the Hungarian algorithm to assign patient interventions to the operating rooms on a medium-term horizon. By using resource capacity and time windows additive constraints (release and due date), the authors claim that the decision tool could integrate bed availability, which can define a bottleneck resource when interventions are postponed.

<table>
<thead>
<tr>
<th>Patient charact.</th>
<th>Delineation of decision</th>
<th>Uncer. Incorp.</th>
<th>Performance measures</th>
<th>Model Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>α1</td>
<td>β1</td>
<td>β2</td>
<td>β3</td>
<td>ϒ1</td>
</tr>
<tr>
<td>(Guinet &amp; Chaabane, 2003)</td>
<td>E Pat; Disc Date; OR; Hour Inc Det Multi Level; Util</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Beliën et al., 2006)</td>
<td>E Surg; Other Date; OR; Other Inc Det Multi Pref; Level;</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Beliën &amp; Demeulemeester, 2007)</td>
<td>E Pat; Hosp Date; OR Inc Det Single Level X X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Vanberkel &amp; Blake, 2007)</td>
<td>E; NE Pat; Date; OR; Hour Inc Stoch Single Wait; Level X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Beliën et al., 2009)</td>
<td>E Surg; Hosp Date; OR Inc Det Multi Level; Pref X X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(van Essen et al., 2014)</td>
<td>E Hosp Date; OR Inc Det Single Level X X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Aringhieri et al., 2015)</td>
<td>E Pat Date; OR Inc Det Single Level X X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Classification scheme for levelled resources

3.4.3. Waiting

One significant performance measure that impacts the quality of scheduling systems is the ability to avoid excessive patients waiting. In this regard, one common evaluation regards the waiting time of patients or surgeons. Denton et al. (2007) have developed a stochastic optimisation model, alongside some practical heuristics, to examine how sequencing elective patients affects OR scheduling measures of waiting, idling, and tardiness. The results indicate that the customary practice of scheduling longer and more complex cases earlier in the day may have a significant negative impact to the studied performance indicators. As illustrated by Vanberkel & Blake (2007), this closely relates to throughput analysis. In their study, a discrete event simulation is built to examine how a change in throughput triggers a decrease in waiting time, as well as to determine the effects of process bottlenecks. In Addis et al. (2016), the authors propose a rolling-horizon approach to solve the patient selection and assignment problem, in which the mid-term assignment over the following n-weeks is generated by solving an ILP problem, minimizing a penalty function based on waiting time and tardiness of patients. Furthermore, a robust optimization approach is proposed considering waiting time, urgency, and patient due date, to solve the advance scheduling problem. Other approach to deal with patients waiting time is proposed in a two-level metaheuristic method, based on tabu search methodology, to jointly solve the tactical and operational scheduling
problem. The assignment of patients to block times in the planning horizon is based both on patient waiting time and urgency (prioritization algorithm), whereas the ILP goal is to minimize the total cost of all patients waiting time at the end of the planning horizon, thus increasing both patient and hospital utility (Aringhieri et al., 2015). As shown by Vanberkel & Blake (2007), patients waiting time and throughput are concepts deeply related. To deal with hospital surgery waiting list management, it is found that many researchers aim at maximising patient throughput. Indeed, if more cases are scheduled per day, it is expected that the hospital surgery waiting list is reduced. The effects of resource rationalization on surgery waiting list management have been analysed; in which the authors have developed an IP model to schedule surgical time blocks to each surgeons group, by considering compatibility, availability, block capacity, and post-surgical resources constraints. The results show that without increasing post-surgical resources, hospitals could handle more cases by scheduling specialties differently (Santibáñez et al., 2007). Spratt & Kozan (2016) attempt to manage a hospital surgery waiting list in Australia by maximising throughput for the scheduling planning horizon, while considering several constraints regarding both Australian policy, and hospital resources capacity. Their model relies upon mixed integer non-linear programming, and a variety of hybrid metaheuristics is used as solution approach. Other study attempts to minimise the patient waiting time to 6 months in a Spanish hospital, while minimising the extraordinary activities (OR overtime and patient transfers) by constructing a GP model (Arenas et al., 2002).

<table>
<thead>
<tr>
<th>Patient charact.</th>
<th>Delineation of decision</th>
<th>Uncer. Incorp.</th>
<th>Performance measures</th>
<th>Model Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>α1, β1, β2, β3, ϒ, Δ1, Δ2</td>
<td>Through Otime; Wait</td>
<td>Through Otime; Util; Wait</td>
<td>Through Otime</td>
<td>Exact Simulation Heuristic</td>
</tr>
<tr>
<td>(Arenas et al., 2002)</td>
<td>E Hosp; Pat Date; OR</td>
<td>Det</td>
<td>Multi</td>
<td>X</td>
</tr>
<tr>
<td>(Denton et al., 2007)</td>
<td>E Surg; Pat OR; Hour</td>
<td>Iso</td>
<td>Stoch</td>
<td>Through Otime; Wait</td>
</tr>
<tr>
<td>(Spratt &amp; Kozan, 2016)</td>
<td>E Pat; Surg Date; OR</td>
<td>Inc</td>
<td>Single</td>
<td>Through Otime; Wait; Through Otime</td>
</tr>
<tr>
<td>(Riise et al., 2016)</td>
<td>E Pat Date; OR Hour</td>
<td>Inc</td>
<td>Single</td>
<td>Through Util; Through Otime</td>
</tr>
<tr>
<td>(Marques &amp; Captivo, 2017)</td>
<td>E Pat Date; OR; Other</td>
<td>Iso</td>
<td>Stoch</td>
<td>Single Through; Wait</td>
</tr>
</tbody>
</table>

Table 6: Classification scheme for waiting time

3.5. Surgeons Preferences

In the neo-classic economic model, there are mainly two relevant “stakeholders” considered - the producer and consumer (Garcia-Castro & Aguilera, 2015). Stakeholder theory arises from the argument that organisations should be managed in the interest of all their constituents, besides the interest of
shareholders; in which its constituents, or stakeholders, is any group or individual who can affect or is affected by the achievement of the organisation’s objectives (Freeman, 1984). In his book, “Strategic Management: A Stakeholder Approach”, Freeman (1984) claims that, while to be an effective strategist, you need to deal carefully with the stakeholder groups that affect you, being responsive means that you must deal with those groups that you can affect. By being responsive, in comparison to past paradigms, organisations have a broader acceptance to generate value from alternative sources. Moreover, instrumental theory tells us that organisations may improve their performance when increasing the extent to which they simultaneously satisfy the interests of multiple stakeholders, whom directly affect the focal organisation’s performance, and can result either by improved reputation, increased trust from stakeholders, or improved “licence to operate” (de Gooyert et al., 2017).

Frooman (1999) has developed a typology of stakeholder influence strategies, by applying Resource Dependent Theory (RDT) to the relationship between firms and stakeholders, which he claims to provide an argument for mapping the types of influence strategies onto the types of relationships, thereby suggesting that the type of relationships is a determinant of the choice of influence strategy. In his framework, he distinguishes between four strategies stakeholders undertake to change organisation’s behaviour:

- **Indirect withholding** – When the relationship is one of low interdependence, the stakeholder works through an ally, by having the ally withholding the flow of resources to the firm
- **Indirect usage** - When the relationship is marked by firm power, the stakeholder works through an ally, by having the ally attaching conditions to continue the flow of resources to the firm
- **Direct withholding** - When the relationship is marked by stakeholder power, the stakeholder will withhold the flow of resources to influence the firm
- **Direct usage** - When the relationship is one of high interdependence, the stakeholder will continue the flow of resources to the firm, but within certain conditions.

Stakeholder power stems from the dependencies of the two parties on one another; and not engaging powerful stakeholders enough runs the risk of misinterpreting their concerns and delay implementation (Nutt, 2002). Marques & Captivo (2017) propose a MIP model aimed at converging a hospital’s administration interest on scheduling, focused on increasing throughput by promoting equity on access, against the hospital current practice, highly influenced by surgeon’s ‘lack of memory’ when selecting surgical cases to perform. Even though for the instances tested, both deterministic and robust approaches showed very good optimisation gaps within short computational time, this case study wasn’t adopted to practice; according to the authors, mainly due to the high power and influence of surgeons, as well as resistance to change from several surgical suite stakeholders within the hospital. Moreover, they have stated that the hospital administration confirmed the surgeon’s characterization as a powerful working class within the hospital, which made planning at the hospital primarily surgeon-oriented. In this case, dependency relationship between the hospital administration and surgeons clearly approximates to stakeholder power, rather than firm power. However, this cannot be further generalised into most hospitals. To some degree, however, surgeon’s acceptance to scheduling policies, as well as to the level
of responsiveness between surgeons and managers varies according to different payment systems used at hospitals, mainly due to the impact it has on physician’s production goals (Girardi et al., 2007). Since these compensation schemes affect physician behaviour, it is important to accurately model such behaviour when designing appointment systems (Gupta & Denton, 2017). For instance, in a fee-for-service system, surgeon’s income increases proportionally with the volume of surgeries performed (scheduled), which may raise concerns among surgeons to the volume of allocated OR time, thus pressuring managers to create schedules that maximise their targeted OR time (Blake et al., 2002). On the other hand, in a salary system, the economic behaviour from physicians is approximately of indifference, and thus they are more responsive to managerial control. In fact, this categorization is a simplification to predict surgeon behaviour; health services use a combination of multiple payment systems for medical compensation (Girardi et al., 2007). The argument to convey is, depending on each hospital’s managerial traditions; include surgeons when modelling elective schedules has more relevance in hospitals where surgeons have more power.

According to Ozcan (2005), surgeon satisfaction may be among the major decision criteria when scheduling, because they are the “customers” of the operating room: team leader, autonomously capable of conducting surgical procedures, hence the main character in the OR context (Penedo et al., 2015). Given the importance of the operating theatre within a hospital, it becomes relevant for OR managers to identify surgeons’ preferences, include those in the decision-making process, and reply to their expectations; given that failing to identify stakeholders’ interests has been shown to cause unanticipated resistance during the implementation of decisions (de Gooyert et al., 2017).

Gupta & Denton (2017) consider surgeons’ preferences by addressing sequencing surgeries decisions; Ozkarahan (2000), by letting each specialty define the importance of its surgeries, enables surgeons to assist in the scheduling process. Moreover, some authors model surgeon preferences, by considering each respective preferred availability (Testi & Tànfanì, 2009; Roland et al., 2010). Roland et al. (2010) state that considering the surgeon’s opinion in such a medical process should improve the satisfaction and consequently the OR efficiency, hence their research purpose consists in developing a framework that allows the medical staff to declare their agenda, and negotiate the OR schedule, according to individual preferences. To Blake et al. (2002), a perceived fair use of OR time among specialists is important to attain surgeon’s welfare. A surgeon may antagonize the scheduling process, even though it might be flexible and/or fair according to hospital’s reality; surgeons must comprehend the variables impacting the decisions made by OR managers. Allowing surgical staff to use schedules generated using operations research techniques, DSS exist in the literature (Spratt & Kozan, 2016). (Beliën et al., 2006) develops a DSS to visualize the demand for a set of multiple resources from the MSS; thus, enabling OR managers to perceive how resources vary as a function of the MSS, while easing the scheduling bargaining process with surgeons. In addition, in another study, they (Beliën et al., 2006) develop a DSS that evaluates solutions based on three objectives, one being surgeon preference-related. Thus, the authors identify that surgeons at the hospital of study prefer to operate next to colleagues of similar specialties and formulated an objective to enforce as little OR sharing among different surgeons’ groups as possible (Beliën et al., 2009).
(van Essen et al., 2012) approaches the rescheduling problem by developing a DSS to assist OR managers upon the rescheduling process, which considers the preferences of the stakeholders involved, and only evaluates the OR schedules that satisfy the imposed resource constraints. Depending on the setting, surgeons have different variables impacting their well-being, and therefore, different preferences they wish to include on schedules. Only by analysing which might those ought to be, will scheduling policies be able to express surgeon’s concerns.

3.5.1 Research Methodology Identifying Surgeons Welfare

Throughout OR planning and scheduling literature, a widespread reference is made to identify both surgeons and OR staff preferences. However, some confusion is found in the literature, because often, even if these preferences are identified, researchers do not take an explicit position in this respect, which raises a problem for the following general decisions in an operational research study: choosing the appropriate method, designing the process, as well as the right goal variables (de Gooyert et al., 2017). Therefore, the validity of methodologies from papers who reported surgeons’ preferences must be reviewed.

According to Gupta and Denton (2017), surgeons typically need to fit all procedures scheduled for a day within a block of OR time that is assigned for their use (sequencing decisions); they have preferences with respect to which types of procedures they wish to undertake on specific days and times of the week. Also, accommodating preferences into models can easily make mathematical models of the scheduling process intractable. Even so, accounting for the actor’s opinion, in such a medical process, should improve staff satisfaction, and therefore the operating room efficiency, as well as flexibility for setting-up the surgical schedules, although, it enlarges the solution space, probably leading to higher computing times than a directive formulation of the problem. Therefore, when exploiting stakeholder’s preferences, researchers are challenged to identify preferences, as well as to incorporate these into models. Such considerations can further complicate the scheduling process. Given this context, which methods do researchers undertake to identify and model surgeon’s preferences?

First, a methodology is a structured set of guidelines or activities designed to assist people in undertaking research (Mingers & Brocklesby, 1997). In addition, operations research is in nature a collaborative discipline, which presumes that to structure problems, approaching stakeholders becomes essential to learn about their issues, concerns, and overall, to gain insights through stakeholder knowledge (de Gooyert et al., 2017). It is found in literature a combination of methodologies applied by researchers to collect data on surgeons’ preferences, both direct or indirect, quantitative or qualitative. Fowler et al. (2008) have conducted an exploratory empirical case study to the perioperative microsystem work flow; they have conducted a 12 months investigation, based on observation, process flow diagrams, key informant interviews, and standardized forms procedures to collect data. Furthermore, they have used ethnographic and iterative grounded theory with constant comparison methods to define processes and interdependencies, as well as create a database of staff members who are perceived has critical to quality requirements, failures, and safety risks. Plasters et al., 2003) combined the use of observation, Critical
Incident Technique (CIT), and key informant interviews to study information flow issues on the surgical suite, which challenge coordination on a day-to-day basis at the hospital under study. Van Essen et al., (2012) study a re-scheduling problem, by developing a DSS that evaluates schedules according to stakeholders’ preferences; to assess each penalty cost for each solution that deviates from each stakeholder preference, the authors have conducted both a survey and key informant interviews at the hospital under study. In contrast, Roland & Riane (2011), through an indirect approach, gathered one year of data provided by the hospital under study, to incorporate in the usual economic objective a so-called human dimension. In their model, each surgical procedure is assigned to a specific surgeon, and a schedule is produced based on the specific agenda of availabilities, viewed as the surgeon’s specific preferences over working half-days in the following three ways:

- The surgeon mentions the half-days during which he wishes to work
- The surgeon declares the number of surgeries he wishes to perform each half-day
- The surgeon specifies on which half-day he wishes to undertake each surgical procedure

Finally, disutility measures weight each preference and penalise failure to respect them. Moreover, Testi and Tànfani (2009) also model surgeons’ availability as a measure of welfare; their methods involved a pre-processing variable before running the model, which sends the decision variable to zero, according to surgeon’s declared unavailability.

Given the number of approaches directed at surgeon’s welfare in literature; the ones that reported that focus, are further described in appendix C, in which the following context is added:

1. Which surgeon’s welfare measure has the study focused on?
2. By which means did the researcher’s collect information to structure the problem?
3. How do researchers include the welfare measure into each model?
4. Is the research in any way validated by stakeholders and implemented at the hospital of study?

3.6. Literature Review Conclusion

So far, the complexity of OR planning and scheduling problems has been described by the articles reviewed, in the previous sections of this dissertation. To cope with these problems, researchers usually decompose them into phases (i.e. strategic, tactical and operational). Given the enunciated complexity, many papers in the literature show difficulties in solving problems optimally, and thus develop efficient heuristic solution approaches. The difference in using such approaches, is that optimality is hardly proven; however, to address large instances, heuristic approaches usually (when not stuck at local optimal) find good quality solutions in a reasonable computational time compared to exact approaches, which is a major advantage when producing schedules. Consequently, to address instances of large size, future research should be devoted to develop efficient heuristic solution approaches and integrating them in decision support systems (Guerriero & Guido, 2011). Furthermore, another challenge to address may consider additional constraints for the hospitals, to represent the system more accurately. In Santibañez et al. (2007), the authors state that one way of doing it is to characterize individual surgeons; since each
surgeon performs a different mix of procedures, it is better to input surgeon specific demand in the model, rather than a generalized description for all of them.

In the literature, it is also found that each one of the descriptive fields previously introduced are explored to some extent more than others in each paper. Regarding OR integration, many researchers do not consider balancing upstream or downstream facilities with OR demand into their models, although underlining the importance of understanding in future research, if the changes derived from each proposed approach would constraint these partaker facilities. In fact, such units (e.g., PACU; ICU) affect OR performance while the OR also affects the performance of downstream units. Furthermore, even though uncertainty has become more appealing to researchers, it is still largely unexplored. For instance, uncertainty in patient demand is rarely considered, i.e., no-shows, case cancellations, and the addition of add-on cases to schedule on short notice; which can have significant impact on surgery schedules (Erdogan et al., 2011). Online approaches, which rarely are presented in OR planning and scheduling literature, can adapt and react, in situations where the original schedule is changed by unpredicted events, by reassigning patients on real-time.

In the literature, preferences used as one of performance measure criteria is often found. However, in studies that consider such preferences, sometimes it is unclear on which methods researchers rely to collect such preferences; in case studies, a common perception is that these preferences are often translated by informal conversations with manager’s or head nurses, instead of direct contact with surgeon’s or, in fact, any application of methodology to analyse processes appropriately; whereas in theoretical studies, it is often unclear if these preferences result from researcher’s setting specific assumptions.

In conclusion, how OR studies see stakeholders is often not discussed in depth, even though the implications of the varying ways of seeing stakeholders are considerable (de Gooyert et al., 2017). It is found that researchers usually focus in one of the following two dimensions when structuring OR planning and scheduling problems; either the technical or the practical interest of stakeholders. In the former, knowledge is geared towards serving human interests, in predicting and controlling the scheduling process, by proposing hard methods to support mathematical models; whereas in attempting to resolve the stakeholder’s practical environment, its interest is geared towards developing inter-subjective meaning within the OR setting by soft methods (Habermas, 1993).

This thesis concerns with the optimisation of elective schedules, considering surgeon preferences at CHLN. Regardless, we often see in literature preferences used with different meanings and inclusion of stakeholders in studies appears with distinct degrees of validation. Thus, we find few consistent conclusions over what literature considers “good schedules” from the eyes of key stakeholders at hospitals.

Considering these events, we propose then using a combination of formal methodologies in steps - approach stakeholders at CHLN, characterise their activity, and model consistently viewpoints. Hence, this thesis contributes to sustain the perception of scheduling models at CHLN, by considering key
stakeholders’ preferences, as well as contributing to the OR planning and scheduling literature, by using a systematic approach to map stakeholder knowledge, in a real case study.
4. Methodology

This thesis inserts within the field of operations management in the scope of OR planning and scheduling problems. Ultimately, our aim is to steer the conversation regarding the implementation of optimisation models for elective scheduling, considering a University Hospital in Lisbon, Centro Hospitalar Lisboa Norte (CHLN). Furthermore, our goal is to liaise with two powerful stakeholders and learn their expectations and concerns, enabling us to discuss models with real, positive impact for stakeholders, while mitigating the risk of misinterpreting their concerns and delay implementation.

In section 4.1, we make the transition from literature to the case study, and introduce the hospital, and the propose the methodology to apply during our work. Furthermore, in 4.2 we structure the approach, by reviewing literature previous works using the methodological tools proposed, justifying its use at the hospital. Finally, in section 4.3, we formalise the use of Multi-Methodology, and conclude the case study application proposal.

4.1. Centro Hospitalar Lisboa Norte (CHLN)

Centro Hospitalar Lisboa Norte (CHLN) is an educational setting, integrating two hospitals of reference, within the Portuguese NHS: ‘Hospital de Santa Maria’ (SM) and ‘Hospital Pulido Valente’ (PV).

Following the slow recovery from the financial crisis, the Portuguese government remains with an attitude of conservative optimism, demonstrating an extensive commitment for the future of improving the National Health Service, by potentiating its own resources, rather than increase capacity, restricting hospital’s funding and hiring policies. Conversely, the operating theatre has one high potential for cost containment.

<table>
<thead>
<tr>
<th>Enlisted Patients</th>
<th>Priority Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>Normal % (TMRG 270 d)</td>
</tr>
<tr>
<td>Surgery Dep.</td>
<td>80,50</td>
</tr>
<tr>
<td>Thoracic Surgery</td>
<td>146,79</td>
</tr>
<tr>
<td>Vascular Surgery</td>
<td>214,27</td>
</tr>
<tr>
<td>Stomatolatogy</td>
<td>73,51</td>
</tr>
<tr>
<td>Neurosurgery</td>
<td>86,50</td>
</tr>
<tr>
<td>Obstetrics</td>
<td>4,64</td>
</tr>
<tr>
<td>Orthopedic</td>
<td>150,67</td>
</tr>
<tr>
<td>Otolaryngology</td>
<td>106,20</td>
</tr>
<tr>
<td>Urology</td>
<td>99,00</td>
</tr>
</tbody>
</table>

*Table 7: December 2017: Average patient waiting time % of TMRG grouped by Surgical Service at CHLN*

The performance over December 2017, of the CHLN surgical services addressed in this work, for both elective inpatient and outpatient, at PV and SM are presented in Tab.7. Our entrance into CHLN context justifies itself with the necessity of increasing its operational efficiency by leveraging OR planning and scheduling optimisation, while attending to its stakeholder’s preferences.
As a starting point to build this project, we chose two OR stakeholder groups to liaise with, in which we assume they collectively detain a large portion of power onto the OR planning and scheduling processes. Addressing both surgeon’s and hospital managers preferences (social approach to validate welfare), as well as the OR scheduling system (technical approach to validate mathematical models), a combination of methodologies is needed to apply for each intervention stage, and therefore, Multi-Methodology presents itself as the logical step to undertake. Multi-Methodology is desirable, mainly because of the multi-dimensional world within interventions aligned with the different types of activities that need to be undertaken. Mingers & Brocklesby (1997) underline that for choosing methods that appropriately represent systems, both the multi-dimensional world and each project phase combine to produce a grid that is useful to map the characteristics of different methodologies and how they interconnect. Therefore, by using the categorization of Habermas (1993) (material, social, and personal world), and combining it with the different phases of a study (appreciation; analysis; assessment; and action), they proposed a framework to map the characteristics of different methodologies that can be used in each step, presented in Fig.4.

<table>
<thead>
<tr>
<th></th>
<th>Appreciation</th>
<th>Analysis</th>
<th>Assessment</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social</td>
<td>Semi-structured Interviews</td>
<td>Process Mapping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal</td>
<td>Literature Review</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>Alternative Optimisation Approaches</td>
<td>Optimisation Model</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4: CHLN Case Study Multi-Methodology**

In the beginning of a dissertation, especially for an outside agent, the primary concern is to gain as rich an appreciation of the situation “as it really is” (Mingers & Brocklesby, 1997). Therefore, it is conditioned by previous agent’s experiences, across OR planning and scheduling literature who revolved around the same issues. The purpose of the literature review is to provide sufficient proof of knowledge surrounding the OR planning and scheduling processes, the stakeholders, as to the challenges researchers face when dealing with these problems.

Then, analysis. We will focus in a real hospital, Centro Hospitalar Lisboa Norte (CHLN), to perform our data collection by the means of interviewing stakeholders. The methods to apply, must allow the proper analysis of differing perceptions among colleague specialists, the examination of the processes and interdependencies across the scope of the scheduling activity. Soft Systems Methods (SSM), as an organized learning system, allows to structure problems, by building models of concepts of purposeful activity, leading to new knowledge and insights concerning the problem situation (Checkland, 2000a). Therefore, by applying it, SSM will enable, as an ongoing learning process, to structure stakeholders pain points, and characterize the elective scheduling activity according to each of the interviewees.
Furthermore, the data collection phase leads to process mapping. This will enable us to detail and characterize the decision process for each phase, from stakeholder’s viewpoint. The proposed Multi-Methodology is described in Fig.5.

![Figure 5: Proposed Case Study Multi-Methodology](image)

Then, we validate the results of SSM with the assistance of the case study sponsor, the OR manager. Through an informal meeting, we layout the results in the form of Rich Pictures, generating an informed conversation to validate, as a group, stakeholders’ allegations during the interview phase. Furthermore, with the help of the manager, we chose a specific “problematic” process in planning the elective activity at CHLN to focus on, for the following stages of this work.

Finally, we model a surgeon-oriented task with process mapping. Information’s provided while interviewing surgeons and hospital managers allows for modelling of activities, thus exploring the various criteria implicit to their judgement, constituting then requirements for scheduling model’s formulations at CHLN.

In the final stage, we expose the case study results, and revisit this work literature review. We present furthermore, several studies complementing the results of this work at CHLN, explored by different researchers, hence validating any case study findings as well, at the eyes of literature.

4.2. Proposed Methodology

According to Mingers, adopting a paradigm is like viewing the world through an instrument such as a telescope, an X-ray machine or an electron microscope; each reveals certain aspects but is completely blind to others (Mingers & Brocklesby, 1997). Thus, appropriately structuring the operating room planning and scheduling multi-dimensional world, while considering the practical interest of its stakeholders, we expect to use a combination of methodologies that explore different understandings of the problem, and hence, practical approaches should move towards Multi-Methodology. Agreeing with Phillips & Bana e Costa (2007), models alone are insufficient: unless they are included in a social process that becomes an accepted way of doing things, institutionalised within an organisation’s culture, they will not survive when their champion leaves the organisation. Therefore, we have developed a methodology to grasp stakeholder knowledge; by blending a technical solution that captures the differing perspectives with a
social process that engages those concerned, thus improving communication, we develop a shared understanding and sense of common purpose. Our main concern entering the case study is to understand need, rather than propose change.

Problem Structuring Methods (PSM) usually apply to unstructured problems characterised by multiple actors and perspectives, with conflicting interests and high levels of uncertainty; and provide decision makers with systematic help in identifying an agreed framework for their problem. The result is either a well-defined project that can be addressed using traditional OR methods (modelling operational schedules), or a clarification of the situation that enables those responsible to agree on a course of action (Rosenhead, 1996). The main concern in using such methodologies is to assist in structuring problems, rather than solving them.

4.2.1 Semi structured Interviews

Opposing to alternative-focused thinking approach, in which people can choose out of a set of alternatives, the best option; value-focused thinking approach defends deciding first on what stakeholders want and then figuring out how to get it (Keeney, 1996). Our problem is not one where stakeholders must choose from a set of explicit alternatives, rather it involves dealing with different stakeholder’s tacit knowledge, learning from their experience and understanding the decision context, which is vital to evaluate if stakeholder motivations can translate into models. Therefore, in the first stage of the case study methodology, we will be interviewing key stakeholders from different surgical groups, at the hospital of study. Following a value-focused thinking approach to explore key stakeholder’s concerns, semi structured interviews took place.

According to Kvale (1983) an interview’s purpose is to gather descriptions of the life-world of the interviewee with respect to interpretation of the meaning of the described phenomena. Our goal, in using interviews is to see the OR scheduling processes and activities from stakeholder’s perspectives and understand how and why they come to have this perspective. There are several advantages to using interviews as the method for data collection. First, it has the potential to overcome the poor response rates of a questionnaire survey. More importantly, it is well suited to the exploration of attitudes, values, beliefs and motives; and additionally, it provides the opportunity to evaluate the validity of the respondent’s answers by observing non-verbal indicators, which is particularly useful when discussing sensitive issues.

Given the above context, our decision to follow semi structured interviews basis:

1. **Value-focused thinking approach** – Our methodology and objectives are concerned with adopting real paradigms. Therefore, we do not presume a priori which are the problematic situations faced by the hospital operating room management, rather are interested and focused in learning from the stakeholders who shape the system as it is.

2. **Research topic definition** – While we limit our assumptions regarding the OR planning and scheduling system in place, the research topic is defined to contain the OR planning and scheduling processes at CHLN, from surgeons and hospital managers point of view. Therefore, we consider that an exploratory interview could become too derivative. In choosing semi
structured interviews, we limit the conversation to a (semi; non-rigid) defined range of research-related topics, while exploiting stakeholder’s perceptions and concerns.

In the beginning, surgeons and hospital managers are not familiar with the scope of our work. Initially, we detail the project context, and the subsequent stages that our work will undergo. Overall, the main concern was to obtain as much information as possible from each interviewee and validate new pieces of data by testing allegations with other interviewees. Thus, each interview addressed in some form the following research topics: hospital organizational structure of people and processes regarding the OR scheduling routines for each surgical department; OR availability, capacity and human resource requirements; OR management procedures: strategic, tactical and operational scheduling levels; and environmental constraints, redundancies, complaints, and sources of variability. These were central to collect data and conduct the subsequent stages of the case study. Depending on the participant’s we spoken to, different depths and relevance were address throughout each meeting.

4.2.2 Soft Systems Methodology (SSM)

In Checkland (2000), Soft Systems Methodology (SSM) is reviewed, as an approach to undertake ‘messy’ problems and plan for change in existing complex systems. Derived from systems thinking, SSM has been widely used in the academic scope for its pragmatical focus and being a practical working tool to investigate and understand the behaviour of complex systems. In practice, SSM is a very flexible approach, in the sense that multiple researchers explore different contexts of the methodology. In its origin, it is a prescriptive set of seven sequential stages, used as a device for ‘making sense’ of a problem situation; however nowadays SSM appears in multiple studies with less reliance on the rigid adherence to a sequence of stages (Connell, 2001).

Since its inception, several researchers used SSM in practice. (Mingers & Taylor, 1992) collects feedback over 90 studies where researchers used SSM in some form. According to the survey results, most research had positive feedback over SSM implementation. Regardless, the authors identify three main problem areas in SSM use:

1. **Methodology per se** – time-consuming, and requires experienced practitioners
2. **Management of intervention** – establishing trust, convincing problem owners of its worth and getting them involved
3. **Problem content system** – bringing about change in the face of internal politics, and imbalanced power relationships.

Essentially, SSM is an organized learning system fed by inquiry, tested by ideas, and validated by stakeholders. In the usual format, SSM presents a seven-stage learning process: the first two stages entail entering the problem situation, finding out about it and express its nature. Root definitions are designed in stage three and modelled in stage four. The subsequent stages consist of further questioning of the problem situation and seek to define the changes, which could improve the situation through appropriate action (Checkland, 2000).

In this thesis, we use a relaxation of the seven-stage rigid processes. Since our main goal before modelling OR scheduling activities is to ‘make sense’ of the hospital processes – people, resources, facilities,
processes and constraints – we concern solely with the application of SSM tools, after the interviews, to explore different contexts and define the problem situation we want to address: Rich Picture, CATWOE and Root Definition. Therefore, we will specifically address the first three stages of the commonly known seven-stage process.

4.2.2.1 Rich Picture (RP)

Rich Picture (RP) is a cartoon-like picture of the problem situation including a wide range of information, broad-based, encompassing all those individuals (or an appropriate subset of them) who have inputs to, and interaction with, the system under study (Cassel & Symon, 2004). According to Checkland & Poulter (2010), the SSM user begins to design a RP model, by framing two dense and cogent questions:

- Do who deploy what resources in what operational processes under what planning procedures within what structures, in what environments and wider systems?
- How is resource deployment monitored and controlled?

In making a rich picture the aim is to capture, informally, the main entities, structures and viewpoints in the situation, the processes going on, the current recognized issues and any potential ones. Although, the RP is not a systemic representation of the problem domain, and nor it is a characterisation of the problem type. Thus, at this stage the user refrains from constructing an explanatory model of the problem situation, either in the form of a systems diagram or by describing it in other ways.

4.2.2.2 Root Definition and CATWOE

The use of SSM entails the necessary creativity to search for new ways of looking upon the existing problem situation. The user selects views (relevant systems) which he believes may be fruitful for uncovering aspects; and for each of these views, the analyst derives a root definition. Thus, designs a root definition for each of these views and consists in a precise verbal description over what implies the choice of the relevant system (Cassel & Symon, 2004).

Following the RP model for our problematic situation, we will explore different relevant systems to address. For each of these relevant systems, we must derive a root definition to have a sharp comparison to the ‘real world’ environment as we go along the case study.

CATWOE is a focused methodology concerned in defining the necessary elements that together constitute a human activity system from a certain perspective. Is a mnemonic that stands for the definition of a customer; actor; and transformation process; ‘why bother?’ (Weltanschauung); owner; and environmental constraints (Bergvall-Kåreborn et al., 2004).

SSM uses “systems thinking” in a cycle of action research, learning and reflection to help understand the various perceptions that exist in the minds of the different people involved in the situation (Maqsood et al., 2009).

RP, CATWOE and Root Definition will fulfil part of our case study methodology. The main goal will be to turn explicit the procedures that lack of target-oriented focus, according with the hospital scheduling routines, allowing us to evaluate if its stakeholders accurately represent the system we want to optimise. Following these definitions, we validate the interview results with the SM OR manager. Then, we begin to
breakdown scheduling activities with rely upon process mapping, to explore the criteria involved, and
the relevance according to OR scheduling literature.

<table>
<thead>
<tr>
<th>CATWOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer – the would-be beneficiaries or victims of the system.</td>
</tr>
<tr>
<td>Actor – The person or persons who would perform the transformation process</td>
</tr>
<tr>
<td>Transformation Process – Alteration of an input into an output</td>
</tr>
<tr>
<td>Weltanschauung – description of the world-view, which makes the transformation meaningful</td>
</tr>
<tr>
<td>Owner – The person who can stop the transformation</td>
</tr>
<tr>
<td>Environmental Constraints – Constraints that are taken as given</td>
</tr>
</tbody>
</table>

Table 8: Catwoe Analysis Description

4.3 Conclusion

So far, we have structured the proposal to undertake the case study at CHLN. We intend to analyse the
hospital scheduling system, using a stakeholder-oriented approach, Multi-Methodology. Before the
interviews, we do not have any prior knowledge regarding the specificities over the elective planning
processes at the hospital. The Multi-Methodology proposed was intentionally constructed to assist us in
making sense over the hospital activity and in grasping stakeholder knowledge.

In the next section, we explore the hospital’s elective scheduling activity, and report on the case study
application at CHLN.
5. CHLN EPE Case Study

Centro Hospitalar Lisboa Norte (CHLN) is the result between the merger of Hospital de Santa Maria (SM) and Hospital Pulido Valente (PV), in 2008. These two hospitals were central units in delivering care within Lisbon and parted by only few kilometres. PV, while less polyvalent in specialties and services covered, is highly diversified and specialised in the areas in which intervenes; SM, on the other hand, is much more embracing and diverse in delivery of care, covering all medical specialties. Furthermore, SM is a national and international acclaimed hospital for the process of teaching and research, fruit of sharing its space with the faculty of medicine and the institute of molecular medicine. The merger intended to improve the use of resources, by potentiating synergies from inter-institutional approximation. Nowadays, CHLN is the direct healthcare provider of 373,000 Portuguese inhabitants and in context with its requirements, has a physical inadequacy of the facilities, which constrain the hospital’s activities (“CHLN”, 2014).

The inherent casuistry associated with CHLN, in contrast with other hospitals addressed in literature, remains one of our principal arguments, in addressing this case study at CHLN, focussed with learning from stakeholder’s perceptions and routines.

In section 5.1 we introduce CHLN OR planning and scheduling context; in section 5.2 we explain the semi structured interviews at SM and PV; section 5.3 groups each scheduling decision level, where we identify and detail the elective activity from stakeholder’s viewpoints. Following the results of interviewing stakeholders, we enter the problem structuring validation in section 5.4; and once the results are validated, we synthesize the results of the case study in 5.5 and validate the results with OR planning and scheduling literature in section 5.6.

5.1. Introduction

SM has an outpatient emergency service (U). To fulfill urgent demand, two independent ORs are open, incumbent to the Central operating theatre. In addition, six OR’s are available for surgical specialties to handle elective patients (E). The elective OR’s located at SM have been used for inpatient (INP) and outpatient (OUT) surgery, although they are more commonly used for more specialized, complex and differentiated cases (INP). Furthermore, some surgical services at SM, have specialized Peripheral OR’s. The main difference between Central and Peripheral ORs is that the former is shared among multiple specialties, where the latter is allocated to one specialty, and therefore used to be more customized to handle each surgical service requirements. Although capacity decisions for each specialty regarding elective demand consider both, throughout this case study we are going to overlook the peripheral blocks activity, due to the lack of information, for each specialty addressed.

PV has the elective outpatient service. Its activity consists in delivering care to less complex and differentiated cases, where patients do not require recovery at the hospital. In total, nine surgical specialties compete for six ORs for elective outpatient surgery: General Surgery, Vascular Surgery, Cardio-thoracic Surgery, Otolaryngology, Stomatology, Orthopaedics, Neurosurgery, and Anaesthesiology.
The case study was undertaken using multimethodology. In total, we interviewed 28 OR stakeholders: 25 surgeons and 3 hospital managers, from nine different surgical services at SM and PV: Neurosurgery (N), vascular surgery (CV), Obstetrics (OBS), Thoracic Surgery (CT), Otolaryngology (OTO), Stomatology (EST), Orthopaedics (ORT), General Surgery (CG), and Urology (URO). The application of the first stage of the case study took one week at SM and PV facilities. Semi structured interviews ranged from 15 min to 60 min, depending on each interviewee depth discussing the issues. By allowing people to share knowledge openly, we must accept that people react with different interest to our cause and can show little commitment in sharing information. Furthermore, surgeons and hospital managers have extremely busy schedules, and therefore, a priori we knew that we would need to collect as much information on ‘first take’ as possible, since we could not get a chance to communicate again once the interview process ended. Given this particularity, and the interest in using SSM, we requested before conducting the interviews to the SM OR manager, if he could validate our view over stakeholder’s knowledge, mapped through SSM, thus preserving the learning cycle over stakeholder validation characteristic of SSM. This interview was done by an informal meeting and constitute then the beginning of this case study’s second stage – problem structuring validation.

<table>
<thead>
<tr>
<th>NUMBER OF SURGERIES PERFORMED PER PATIENT TYPE AT CHLN IN 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMERGENCY</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>EMERGENCY</td>
</tr>
<tr>
<td>ELECTIVE</td>
</tr>
</tbody>
</table>

Table 9: Adapted from (CHLN, 2015)
This work identifies surgeons and hospital managers as one of multiple OR key stakeholders. Additionally, as a university hospital, CHLN has both specialists and intern’s surgeons. We consider both perspectives to offer complementary knowledge assisting us to capture the OR system. While surgeon specialists have fixed schedules and report to specific settings, surgeon interns report to surgical units periodically, thus having variable schedules throughout their internship. Hospital managers, on the other hand, are the ones who negotiate the production levels with the Health Ministry and oversee surgical department’s performance.

5.2. CHLN Semi Structured Interviews

We interviewed surgeon specialists, surgeon interns, and hospital managers. Stakeholders were not aware of this study before the interviews. Since the approach did not require any previous engagement, or presentation of our work, the first step was to explain the scope of the study, and request participant collaboration onto the same.

Once people understood that we were there only to make sense of their routines and gain context over their experience of the CHLN elective scheduling, we initiated our line of questioning.

Initially, our goal was to understand how do OR planning and scheduling activities complement each other, in contrast with the decision levels often presented in literature: strategic, operational and tactical. Therefore, questions such as “which tasks are performed by each people?”, e.g. “who defines the available time you must operate on the next week?” were asked. The main goal was to identify the main processes deriving from the elective schedules, as well as define the stakeholder’s performing each of these tasks at SM and PV.

Afterwards, the conversations shifted focus onto the personal concerns over each stakeholder’s routines, e.g. their views over what criteria they consider relevant in patients scheduling.

Given this, we then questioned, in contrast with the actual schedules at CHLN, if they could point out any difference between what they would personally wish schedules were and what they are, identifying specific processes constraining activities and disrupting schedules. Furthermore, once we understood that the surgical activity is very disruptive, and that often-planned schedules at SM and PV adjust to delays,
we requested several specialists to identify the relevant decision criteria they use, when scheduling patients for the next planning horizon.

Overall, the main concern was to collect as much data as possible from the participants, assuring its quality by testing it with other stakeholders. Given this, each interview addressed the following central topics:

- Hospital organizational structure of people and processes regarding the OR scheduling routines for each surgical department;
- OR availability, capacity and human resource requirements;
- OR management procedures: strategic, tactical and operational scheduling levels;
- Environmental constraints, redundancies, complaints, and sources of variability.

In the following sections, the concepts explored throughout the interviews are presented. First, the data collection phase at CHLN is described; then it is addressed how the problem situation is characterized. Finally, the analysis validation is described, and findings are extrapolated.

5.3 CHLN OR planning and Scheduling Processes Modelling

The hospital handles both inpatient and outpatient demand. While the scheduling principles are the same, they require different resources throughout the perioperative stage, and usually have different procedure complexities. Therefore, these patients do not compete for the same surgical blocks, and two different processes manage patients waiting time. Furthermore, who (which medical specialties) competes for OR time block, in which facilities, for what type of surgery, at CHLN? There are three different OR physical elective scheduling processes in CHLN EPE. First, different specialties compete for OR block time in the SM Central OR. As pointed above, these are Neurosurgery (N), Vascular Surgery (CV), General Surgery (CG), Orthopaedics (ORT), Otolaryngology (OTO), Urology (URO) Stomatology (EST), and Obstetrics (OBS). For the most part, the Central OR at SM is used to perform inpatient surgery. However, within the Urology service, when Peripheral OR’s are fully booked, specialists can request access for OR time to perform some outpatient surgeries.

![Figure 9: Surgical Specialties access to main ORs at CHLN](image)

Furthermore, SM has Peripheral OR blocks dedicated to some specialties; namely Neurosurgery (N), Obstetrics (OBS), Urology (URO) and Stomatology (EST). This is mainly due to the requirement of certain specialties in using specialized equipment for surgeries. Additionally, the outpatient unit is located at PV, and used by the following specialties: Neurosurgery (N), Vascular Surgery (CV), General Surgery (CG),
Orthopaedics (ORT), Otolaryngology (OTO), Thoracic Surgery (CT) and Stomatology (EST). CT only performs outpatient surgery at PV.

There are several models applied by modern hospitals to manage the operating room procedures. At CHLN, the Central OR is prepared to receive on each day, per operating room, one surgical specialty at most; and each department has fixed days to use the OR’s. Since the strategic decisions over capacity, i.e. the OR time made available to surgical groups, does not change over time, the hospital manager does not intervene directly in the strategic fulfilment of the Central OR objectives at SM and PV. Regardless, the hospital manager oversees and reviews each department’s performance indicators.

The department manager must distribute the OR times available to each specialist, per time horizon. Afterwards, each surgeon specialist proceeds to select the patients to operate, given the available OR time each specialist has.

Moreover, surgery is dependent on various requirements, namely staff scheduling. Together, nurses, anaesthetists, and surgeons are responsible for managing their own Central OR activity. Despite interdependent, surgeons work schedules are designed separately from the rest of the surgical team. Since the hospital has several functional units working in parallel governances, the Central OR is booked according to the available time blocks handed to surgeons. Additionally, nurses and anaesthetists must deliver their work schedules to the OR manager, to fill the requirements which enable surgeries to occur.

The OR manager must unify the provided timetables into an MSS. For each time block over the following planning horizon, the OR manager identifies the surgical group to perform surgery, given the human resources available. Over the interviews, two surgeon specialists (CG and EST) have pointed out that since these schedules come from different designs, in some instances are not compatible and can disrupt interventions.

Together, surgeons, nurses and anaesthetists constitute the human resource requirement for patients scheduling, in which their relationship is illustrated in Fig.10. If any of these stakeholders is not available, surgeries cannot be planned. While this might constitute an obvious statement, it is relevant to identify each of these stakeholders, and if there is any evidence at the hospital of bottlenecks in this regard, given the high cost of having unused operating time. Therefore, we questioned specialists to the existence of any bottlenecks, constraining the scheduling process. In 13 interviews, 12 surgeons and one hospital manager mentioned the scarcity of surgical nurses and anaesthetists in SM, mainly credited to the hospital hiring freeze, as an effect of promoting desperately for resource rationalization, in contrast with personnel retention rates. Furthermore, six out of the 13 interviewees have mentioned that, given the scarcity of resources, often the afternoon OR blocks are unfilled, and the Central OR is left for surgical services to perform elective surgeries pending manager approval. These surgeries fall out of the scope of the hospital elective weekly program and integrates part of the “evolution” of the previously discussed PECLEC incentives, under SIGIC; surgeries are paid on a fee-for-service system to the hospital, as a stimulation to recuperate surgery waiting list performance.

Altogether, six surgeons were asked: “In your opinion, which is(are) the reason(s) behind the Central OR being unused in the afternoon block?” The results are shown in Tab.10.
Figure 10: Human interdependencies in Scheduling Elective Patients at CHLN

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Anaesthetist Shortage</th>
<th>Surgical Nurse Shortage</th>
<th>Bed Availability</th>
<th>Surgeon Shortage</th>
<th>Hospital cost containment</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>URO</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>CG1</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBS</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Surgeon feedback over SM main elective rooms unused

According to surgeon’s feedback, the OR is not booked for the afternoon because there are not enough anaesthetists working on a salary basis to cover the Central OR for a full day. Four surgeons also mentioned nurse scarcity at the hospital to be an additional reason. Two surgeons also consider that peaks in bed requirements from other facilities at the hospital can compromise the surgical activity, since the flow of beds across the hospital is mainly dependent on variability from different facilities requirements. Finally, one surgeon considered that this may be a cost-containment measure manager’s use, although, this argument was discouraged by the OR manager.

Attending to our main concern of describing in a broader sense the elective scheduling process at CHLN, after interviewing three hospital managers and twenty-five surgeons from nine different specialties, the first RP was drawn, shown in Fig.11. The RP attempts to capture the CHLN system, as per described to us during the interviews. Furthermore, it tries to include the stakeholders and processes relevant to the scope of OR planning and scheduling activity.

The RP portrays all the key players involved in the process and presents a structured view by putting into context the factors affecting the process (Maqsood et al., 2009). These interviews enabled us to
contextualize the problem situation and see the world (hospital) as it really is and specially represented by the views of its owners, rather than by what literature represents.

Figure 11: First Rich Picture of the CHLN Elective Scheduling System

Figure 12: CHLN case study participant’s hierarchy

Organizationally, CHLN surgical activity management comprehends several departments, services, and functional units. To articulate common goals, the hospital hierarchy defines that autonomous units can group into services as well as these are grouped into departments. Furthermore fig. 12 shows the hierarchical structure at CHLN directly affecting the interviewed stakeholder’s surgical groups. Additionally, the figure informs on how many participants are included in the case study and the corresponding specialities. Given this, the twenty-five surgeons interviewed belong to twelve functional units, included into nine different services, out of seven surgical departments.
5.3.1 Strategic Level

This dissertation considered the hospital manager as one key stakeholder, when preparing the case study methodology. One of the assumptions seen in literature are that hospital managers define OR achievement metrics, and therefore their interests can easily affect scheduling decisions, and ultimately, surgeon’s activity. While this is partially true, at CHLN hospital managers are a rather passive stakeholder in managing the OR planning and scheduling activities. According to three hospital managers, they do not intervene on the definition of OR management procedures at the hospital, i.e. they are not involved in the different levels of scheduling elective patients. Essentially, their view is that patient scheduling is a ‘clinical decision rather than a management one’.

The hospital manager oversees and monitors the fulfilment of SIGIC guidelines, by continuously reviewing each department performance indicators. According to the three hospital managers, ideally, the scheduling system should enable the hospital to:

- Maximize OR occupation and monetization of the operating times;
- Manage the waiting list for surgery efficiently, according to SIGIC guidelines.

The interviewees manage departments with surgery related processes: Neurosurgery, UCA (Unidade de Cirurgia de Ambulatório), and Paediatrics. Their involvement in the elective scheduling system is indirectly placed at the strategic level, with performance reviewing rather than decision-making. Since the hospital manager is the ultimate person accountable for promoting the NHS values into CHLN routines, they must liaise with department managers and surgeons periodically, to ensure that processes are running efficiently, and departments maintain their key performance metrics above standard. Regardless, their involvement does not affect directly hospital capacity decisions. At a certain point, we brought up the subject of having different timetables per professional category for OR time, to understand how schedules are compiled from a top-down perspective. According to a hospital manager, ideally, the schedules should be reconciled in a meeting where the hospital manager, the head nurse, head anaesthetist, OR coordinator, and department manager discuss altogether about the limitations and preferences each has, to construct an optimised schedule. As the interviews went on, the department manager became to us the most apparent decision-maker in OR strategic and tactical capacity decisions, given that each department has the OR available on fixed days, to assign specialists. In addition, one hospital manager has characterized the elective scheduling at CHLN to be very different from department to department; and concluded by experience that each department performance is mirrored by each respective manager’s responsiveness to the problem. If a department manager does not motivate to improve scheduling processes, or at least define a set of controls to monitor team’s activities, generally the department is less organized and lacks specific procedures and guidelines to improve metrics. Therefore, as stated by hospital managers, and validated by the OR manager, the weight of practicing effective elective schedules at CHLN fall specially on the shoulders of department managers.
Since the hospital managers at CHLN do not assign available OR time to each department, i.e. each OR has a fixed surgical group operating on each day, throughout the year, the OR manager must reconcile with the department manager, which times of the day can be used by departments, given the resources available.

5.3.2 Master Surgical Schedule

Out of the 25 surgeons, unfortunately there was no opportunity to speak with any department manager. Definitely a shortfall and a limitation to this work, the knowledge hold by department managers is very decisive in planning the hospital planning activity and limiting surgeon’s practice. However, given what was addressed in the interviews, alongside what is required from governmental guidelines (UCGIC, 2005), we review and conceptualise department manager’s activity from the viewpoint of other stakeholders, rather than by their personal experience.

Department managers have the responsibility of planning their department activity, by assigning the OR capacity available to each surgeon for a given time horizon. The tactical level concerns the development of a cyclic schedule for a given planning horizon – the MSS. In the MSS problem, the OR manager defines the allotted time blocks of each OR to several surgeons (or surgeon groups) per day, based on the fixed OR available days for the specialty. Furthermore, the department manager needs to reconcile the available resources at the hospital, given by the OR manager, with the demand volumes, given by the NHS surgery waiting list management information system (SIGLIC). Essentially, the department manager must balance workload throughout his department, while promoting the fulfilment of each service TMRG.
Therefore, as outlined above, the department manager’s decision varies according to each functional unit or service surgery waiting list (LIC); and depending on each production targets balance, OR time is allocated to a specific unit. Moreover, the manager decision is constrained by his workforce availabilities, preferences, and requests, which can vary accordingly.

5.3.3 Operational scheduling

Surgeons at CHLN are responsible for managing and designing their own schedules, although with certain supervision by each respective department manager. In fact, the scheduling model used at CHLN relies entirely upon surgeon’s estimates over surgical and non-surgical activities for any given planning horizon. The operational schedule problem is usually decomposed into a two-stage process by authors (Magerlein & Martin, 1978) in OR planning and scheduling literature: the advance schedule and the allocation schedule. In the former, elective patients waiting for surgery are selected and assigned with an OR number and a date to have surgery; the latter defines a surgery start-time for each selected patient, for each day of block time a surgeon has available. Being that surgeon’s at CHLN do not make these decisions for each patient at the same point in time, the operational process is breakdown into the advance schedule and the allocation schedule.
ROOT DEFINITION

Advance Scheduling

A system owned by each surgeon specialist or surgeon team, who together with the hospital Information System (SIGLIC) in place selects eligible patients to deliver care for next week planning horizon. The selection is constrained by the OR time available to the surgeon, defined by the department manager according to human resources availability; as well as the patient condition (clinical priority). This process has a planning horizon of one week, and each patient is assigned with a location (OR number) and a date to have surgery. In addition, it can be iterative, since patients can cancel surgery, or decease meantime. Overall, it is a process largely based on surgeon intuition and experience and lacks from explicit target-oriented procedures across surgical departments.

CATWOE ANALYSIS

Customer: Patients waiting surgery (selection)

Actors: Surgeon or surgeon team (scheduler), anaesthetist, nurse, and auxiliary staff

Transformation: Surgeon Knowledge and experience, assisted by optimisation techniques, prepare an understanding on how to schedule patients to maximise the objective of maximising the OR use.

Weltanschauung: Extremely high costs of non-usage. Also, since scheduling optimisation is not the "core business" of surgeons, we should grasp what is which for surgeon activity, and isolate what is not core to be performed by 'what is'.

Owner: Surgeon or surgeon team (scheduler)

Environmental Constraints: Hospital culture, surgeon acceptance to optimization techniques.

Table 11: CATWOE and Root Definition of the Patient Scheduling Activity

Figure 15: Rich Picture: Operational Decision Process at CHLN
5.4. Problem Structuring Validation

Following the interviews, we began structuring data, and concentrate on the surgeon specialist’s activity at CHLN, the advance and allocation schedule. Our decision basis:

- **Data Collection** - The information collected is specifically more robust across different specialties for the advance schedule phase. Furthermore, it is culturally a surgeon-oriented non-systematic activity, lacking explicit process definitions.

- **Pessimism** - Interviews show that surgeons do not rely in decision support models, and are not aware over their capabilities, disregarding DSM relevance when planning the elective scheduling. Therefore, before speaking of models, a decomposition of the patient scheduling decision-processes for each specialty is explored, hence evaluating if they can be translated to rule-based models, by comparing it to similar studies found in literature.

Despite the existent governmental guidelines orienting the patient selection decision process, CHLN does not have in place any explicit procedure guiding the specialist through the decision process, when accounting for the several variables that affect schedules.

In the following sections, we explore with specialists and interns, the several decisions they regard relevant considering, within their surgical discipline, when defining schedules for inpatient and outpatient surgery.

Given the requirement of conceptualising specialists activities, flowcharts are used to decompose the different stages into logical decisions step-by-step process.

To validate the preliminary analysis, a meeting with the OR manager at SM raised the observations over the collective views of stakeholders and showed the Rich picture (RP) models. The OR manager then, by looking into the RP, validated the perception over the CHLN scheduling system, thus generating an informed discussion to define explicit decision levels in the hospital planning and scheduling of elective patients.

Furthermore, our focus in describing surgeon’s activities with flowcharts was validated, once we went through the collected data, the CATWOE analysis and the Root Definition of the advance schedule at CHLN.

5.4.1. Advance Schedule

The CHLN resource allocation and capacity decisions are for the strategic and tactical level of elective planning. The advance schedule, however, responds to elective demand, by selecting patients waiting for surgery, according to specific procedures adopted by surgeons, constrained by ethical and medical rationales.

In CHLN, each service or functional unit has independent weekly schedules, as they also manage different waiting lists. The MSS informs the monthly capacity (OR Time) available for each surgeon on next planning horizon, given by each department manager. Depending on each unit framework, operational scheduling decisions can be:

- Singular expertise-based, if the surgeon who proposes surgery is the one to operate;
Team expertise-based, if the surgeon proposing surgery does not necessarily need to perform the procedure.

At CHLN, each week surgeon specialists must define the surgeries they plan to perform in the next planning horizon, i.e. week. The hospital must then contact patients at least eight days before surgery, with the exception for deferred urgency surgeries, and must have the anaesthetist referral before surgery. Bearing surgery a priori requirements in mind, surgeon specialists must determine the schedule, to prioritize his patient’s needs while maximizing the use of time available.

The hospital information system receives continuous feed from SIGLIC, centralizing the elective demand per surgical service and monitoring TMRG for each patient. Each week, each surgeon specialist defines the patients to schedule on next week available operating time. SIGLIC recommends a set of eligible patients (according to NHS guidelines) for each scheduling horizon. On each run, SIGLIC output is a set of eligible patients for surgeons to schedule. Within the allowed eligible set, surgeons must then determine the best schedule that maximises their objectives.

SIGLIC enforces some conditions to the patient’s selection, as referred by a general surgery specialist: if high clinical priorities are longstanding, or operational priority is approaching zero, SIGLIC insists to schedule the patient, by showing “warning signs and red alerts”. Moreover, for deferred urgencies, there is virtually no selection process, given that patients need to have surgery before the next planning horizon (TMRG: Priority level 4 – 72 hours). Additionally, on each run, SIGLIC provides an augmented (15 days) list of allowed patients to schedule (UCGIC, 2005). This increases the number of possible combinations to fill each slot, thereby enabling surgeon schedulers optimisation of OR utilisation, without being considered as a scheduling discrepancy.

The surgeon scheduler obtains the list of eligible patients to schedule for the next planning horizon. The task that follows involves designing the advance schedule. The criteria surgeons from different teams and departments consider relevant to determine their surgical schedule can vary. Given this terminology, during the interviews, the concepts and decisions steps surgeons deem relevant are considered. For each type of surgery (inpatient and outpatient); and each medical specialty, the selection process is decomposed by mapping these criteria into flowcharts. After meeting with the OR manager to validate our findings, Obstetrics was excluded from this study, given that in practice, their elective process is part of a specific circuit, where TMRG is not manageable. Therefore, the final study includes feedback from twenty-three surgeons, and three hospital managers.

5.4.1.1. Clinical Priority and Pathology, Antiquity and Operational Priority

Surgeon specialists at CHLN select enlisted patients on each planning horizon in accordance with their clinical priority, i.e., the underlying pathology, severity of the condition, illness progression rate, as well as impact on the patient’s life (UCGIC, 2010).

Following governmental guidelines, hospitals must schedule patients according to their clinical priority. Being clinical priority, a medical decision combining several variables (e.g., patient pathology), this decision falls into the attendant surgeon responsibility, at the point in time where he proposes surgery to the patient and the patient is registered in the waiting list. Depending on the patient condition, the
surgeon assigns one of four classes of priority, which has a defined maximum allowed response time (TMRG). According to the 23 surgeons interviewed, the operational schedule is always constructed attending to the patient’s clinical priority and pathology first, i.e., specialists select patients from the waiting list for surgery primarily according to the severity of their condition.

Furthermore, the antiquity criterion establishes that for two patients with the same clinical priority level, the scheduling system will select the patient on a first-come-first-served (FCFS) basis.

The combination of clinical priority and antiquity allows SIGLIC to calculate for each patient the operational priority value, which is the maximum number of days the hospital can wait to operate the patient, updated daily, and tending towards zero, until the patient is selected or continues waiting for surgery (negative value). The operational priority concept is the single value respecting clinical priority and patient antiquity at the same time. Therefore, by minimizing this value for patients within TMRG, surgeons ensure that patients in critical condition are scheduled, as well as patients with low priority, waiting accordingly.

SIGLIC presents to the surgeon list of proposed cases, where patients are sorted according to their operational priority. Since lower operation priority cases need to be addressed as soon as possible, the scheduler tries to fit in as much surgeries as he can to the assigned capacity. All surgeons mentioned these guidelines during the interviews. Therefore, we consider all specialties having this process embedded to their routine, explicitly – select patients based on lower operational priority first.

The output of the surgeon scheduler previous action is a list of eligible patients, in which the first patient is the most urgent one (highest operational priority) and the first to be scheduled. Considering the available OR time the surgeon has, he then selects patients one by one, following the sequence (top-down), until he runs out of time to schedule any other case, given the operating and non-operating time associated to each patient if scheduling.

The criterion for patients’ scheduling is to minimise operational priority. While this is true, the multiple variables in action transform often surgeon’s schedules, and their estimates for procedure times, consequently disrupting schedules: either by excessive optimism - underestimation (leading to surgery cancellation and overtime), or by excessive pessimism – overestimation (leading to OR under-utilised).

These variables, according to the interviews, is where the hospital does not share any explicit guidelines,
enabling specialists to estimate these variables effectively, and improve their schedules, as these are estimated tacitly by each specialist individually, based on his/her knowledge and experience. In addition, two surgeons mentioned that operational scheduling is very different from surgeon-to-surgeon.

Some surgeons construct overly-confident schedules, while others can develop overly-pessimist schedules (surgeons do not receive on fee-for-service), given that there are no incentives in place to increase efficiency or to design accurate schedules. Furthermore, if surgeries delay throughout the day, usually the last surgery is cancelled, which creates an inconvenient; the patient, who is prepared to have surgery and the surgeon, besides not optimising his OR utilisation rates, must fit the patient into his next schedule. In addition, a surgeon (CG) mentioned that in average, 10% of his schedules have its last surgery cancelled due to delays throughout the day.

The interviewees mentioned that the variability on surgery-day, brought by the patient (patient characteristics), is one factor affecting surgeon’s efficiency, therefore interfering with the standard execution time.

Given this context, it is important to define from where variability can show up throughout the perioperative stage, to avoid schedules from being disrupted by our representation of the actual OR system.

First, we need to define the parameters by which the selection process iteration may follow. The scheduler selects one patient at a time, for which he estimates the procedure time. Therefore, the iteration is updated by an increment of 1, because once a patient is evaluated to be or not selected, the scheduler proceeds to the next one. Furthermore, the stopping criterion is when the scheduler runs out of patients to fit in the available time or arrives the end of the list.
<table>
<thead>
<tr>
<th>Set</th>
<th>(Patient) (i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>(Number of Patients in SIGLIC) (N_{\text{Patients}})</td>
</tr>
</tbody>
</table>

*Table 12: Set and Parameter used in models*

### 5.4.1.2 Resource Requirements

According to the surgeons interviewed, standardization of procedure times is very difficult; and given patients characteristics, each case may be even singular. Occasionally, an additional specialist can be required to assist a surgery. Varying with patient’s pathologies, and associated conditions, surgeons can ask for an additional specialist to assist surgeries. While this is uncommon to most specialists addressed, some specialists recognise that this happens with medium frequency, and therefore, must be considered to organise their schedules. Therefore, while planning his activity for the following week, the decision process needs to check for the following condition: “Check other specialist availabilities, in case it requires multi-disciplinary teams”.

![Decision process of requesting for an additional specialist at CHLN](image)

*Figure 18: Decision process of requesting for an additional specialist at CHLN*

Fig. 18 represents the decision process, and the specialties for which this decision node is relevant, according to the collected data. Furthermore, Orthopaedics and Otolaryngology did not provide any information on the following condition for inpatient surgery, therefore presented with a red borderline in the figure. The surgeon specialist must evaluate the need to request another specialist when addressing a certain patient \(i\); and check any colleague surgeon availabilities before scheduling patient \(i\). For this criterion, the collected data reflects:

- **Inpatient Surgery** - Neurosurgery and Stomatology require multidisciplinary teams with medium frequency to address determined pathologies;
- **Outpatient Surgery** - The criterion is not relevant to the specialists interviewed.

Surgical equipment can increase the complexity of surgeries due to variability in its handling. Once the advance schedule is complete, the administrative scheduler informs a nurse in charge of logistics, for the
In CHLN, surgical equipment shortage occurs rarely. According to the surgeons interviewed, surgeries do not get cancelled because of missing equipment or material. However, surgeons mentioned that the equipment can introduce variability to the standard procedure time. Therefore, for each eligible patient proposed procedure, the specialist enquires if the materials to use introduce variability in its handling. If yes, then he can give an estimate time, which we will call decision Tmaterial, to give our account of this variable. If not, then the surgeon does not consider the variable Tmaterial to his operative estimate for patient i.

Throughout the interviews with each surgeon specialist, all mentioned that the material equipment is one element that introduces variability to a procedure, both for inpatient and outpatient surgery.

5.4.1.3 Standardised Surgical Procedure

According to Ozcan (2005), although some routine health care tasks can be automated, there remains a wide range of tasks that require a high level of judgement, e.g. a surgeon and an anaesthetist must make specific decisions before operating, to plan the surgery for the condition of the patient. The heterogeneity of patients’ conditions, already noted, often mandates considerable specialization in the delivery of care.

In designing the advance schedule, the surgeon scheduler must predict how much time he will take to operate, and acknowledge, for each patient, where can additional variability rise from. Initially, the surgeon abstains from estimating the multiple “time coefficients” for each patient, and estimates the standardised procedure time for each patient, according to his experience performing the proposed procedure.

The following part of the interview was to exploit the multiple criteria surgeons consider relevant during the operative time. Questions such as “Which are in your opinion the factor(s) that can(or not) have a negative impact in your standard scheduled time?” were asked, and specialists were to enumerate the multiple criteria they regard relevant to their specialty, for each type of surgery. The gathered data allows us to map the different criteria explored throughout the patient selection decision process, for both inpatient and outpatient surgery.

Surgeons mentioned that usually procedures for inpatient surgery are generally more complex and less standardized, in which the surgeon experience and differentiation performing the procedure has a large impact on the procedure time. The ability to map estimates for individual performances over several
procedures allows improving estimates, in comparison with using the average estimates per procedure, among several specialists. The specialist does not always estimate the time required to perform the surgeries; being that CHLN is also a university hospital, the OR is in addition a setting where students observe and learn by performing. An intern assists the responsible surgeon specialist, i.e. attends and in many instances performs under the specialist supervision. Naturally, an operation done by a student does not take the same time as done by an experienced surgeon. Therefore, the surgeon considers some additional time to his scheduling, to teach and let medical students perform. With the texp factor, the scheduler can also specify if it will be the intern to perform surgery.

![Figure 20: Surgeon decision node estimating texp coefficient](image)

To deconstruct consistently surgeon’s judgment when designing the advance schedule, we need to understand how surgeons assign predictions for procedure times, per patient, considering the multiple variables contesting the schedules. Therefore, the scheduler first thought in his assessment of variability to a standard procedure, starts by estimating the procedure times for each patient surgery, in minutes, according to his experience performing the proposed procedures.

This process is especially relevant because of the different procedure times for similar pathologies, given that similar pathologies can have different treatment options. Additionally, two (CG) surgeons mentioned that procedure times vary according to the choice of access to the patient, by the selected treatment option e.g., laparotomy versus laparoscopy. Initially, the surgeon estimates the duration for the proposed procedure.

The surgeon scheduler estimates the surgery duration for each patient. This corresponds to the “best-case scenario”, for a surgery of similar nature where there are no extenuating variables. Thus, “on average, usually the following procedure takes this many minutes to operate”. However, according to a CG specialist, schedules often disrupt. For inpatient surgery, specialists from General Surgery (CG), Neurosurgery (N), Otolaryngologist (OTO), Stomatology (EST) and Orthopaedics (ORT), mentioned that the procedure times are much dependent on which specialist performs the surgery, and the patient having surgery.
5.4.1.4 Patients Characteristics

According to Riise et al. (2016), surgeries duration is difficult to predict because, for some surgeries, the magnitude of the procedure only becomes apparent once the surgery is already in progress, and additionally the durations often depend on complex factors, e.g. the characteristics of the patient, the surgeon, and the surgical team.

Surgeons at CHLN mentioned that patients introduce much of the variables affecting schedules into the OR. Moreover, stated that in having an extensive patient history, and a clear diagnostic, many of these variables are circumvented and mitigated. The natural variability triggered by patient’s characteristics is one of the main reasons why schedules fall short.

The criteria surgeons at CHLN consider relevant to affect precise scheduling, and were medical judgment is essential to adjust estimations are:

- Patient age;
- Coagulation deficits;
- Obesity;
- Re-operation;
- Associated conditions.

Patient characteristics are especially important to consider for inpatient surgery. Outpatient surgery consists in procedures usually less complex and with more standardized operating time.

The specialist so far has already prioritized the patient list to schedule and defined for each a best-case scenario procedure estimative, alongside two correction factors for handling surgical equipment and assigning time depending on which surgeon specialist is performing the procedure. Additionally, the scheduler defines the need of assistance from a different specialist for each patient.

Inpatient surgery refers to elective cases performed at SM and patients need to stay in the hospital an overnight at least; while outpatient surgery usually occurs in PV. CG, EST, OTO, ORT, URO, and CV require patient monitoring for coagulation deficits. If the diagnose is known prior to surgery, then the surgeon can over-estimate the standard time it would take normally, for handling these patients, according to his experience in dealing with the condition. Otherwise, schedules may disrupt, possibly due to natural variability inherent to the patient’s conditions. The correction factor tcoagulation is estimated in minutes.

Surgeons from CG and URO also mentioned age has an additional variable to schedule patients. The interviewees denoted that, while age itself does not have a direct impact on surgeries performance, usually age has a positive correlation with anatomic fragility, and therefore can take more time for the surgeon to address the pathology at hand for a more aged patient. Following this, specialists from CG and URO consider age as an additional complexity, and for inpatient surgery, can estimate tage, which consists in the time surgery can deviate from the best-case scenario, because of the patient anatomic fragility.

Surgeons also consider Biotype obese as relevant to increase procedure time variability, because of the anatomic complexity. For CG, ORT, OBS, and URO, the patient biotype (obesity) affects the duration of surgeries, and therefore the surgeon scheduler needs to estimate obesity has an independent factor that contributes to add complexity to procedures, tobesity, in minutes.
Operating a previously addressed condition can difficult its execution, thereby increasing the procedure times. According to the interviewed surgeons, the first operation changes the anatomic complexity of a patient at hand, and when re-operating, first the surgeon must get familiar with the patient anatomy. After contemplating and interpreting the patient, the surgeon is then able to start the procedure. In this scenario, the surgeon need to estimate a coefficient, \( T_{\text{operation}} \), in which he prepares himself for the time he takes to interpret the patient anatomic situation. While this is crucial to estimate accurately the operating times, the hospital information systems must have the patient records up to date, enabling surgeons to predict accurately this value, and improve their schedules.

Co-morbidities refer to the identification of associated conditions appending to the base pathology diagnostic. The surgery proposal informs of any relevant co-morbidity, and at the time of selecting patients to schedule, the surgeon evaluates their relevance, and decides if the surgery maintains the same level of complexity, or not. If he determines that any associated condition has influence to the standard
time, the surgeon scheduler will estimate the time, consistent with the deviation surgeon has to undertake from the usual procedure time, because of the condition.

The criteria mentioned above, consist in decision steps surgeons from different specialties hold as tacit knowledge, when selecting patients to operate. Furthermore, each criterion is also dependent on the scheduler, and each estimate provided by experience, in tacit form, rather than by monitoring surgeon’s activities in the past.

Essentially, OR capacity bounds the decision maker options to select patients. Therefore, he must prioritize and reconcile the limited resources at hand (OR time), to maximize the use of his OR time by optimizing his predictions on procedure times. Before tacit, the above figure tries to turn explicit the criteria surgeon schedulers find relevant to make their predictions when scheduling. Furthermore, the scheduler must predict the pre and post operating times, which contain activities included in the surgeon OR time-block schedule, such as patient transfer, anaesthesia induction, and OR sterilization.

5.4.1.5 Non-Operative times

Advance schedule assigns eligible patients to specific surgery days and operating rooms, for a weekly horizon. A surgery day contains the activity in the operating room throughout the available operating hours in a day. Additionally, the schedule needs to predict for each day, the activities required to happen in between surgeries, which constraint the operative activity, namely the patient transfer, anaesthesia induction and OR sterilization. Although the scheduler usually aggregates the times in between surgeries, we will decompose into three separate decision processes, for surgeons to estimate these activity times.

In SM, the patient transfer activity is the one where surgeons consider most time is lost. Furthermore, many surgeons mention that in PV, the same task takes much less time than in SM. The reason, according to one hospital manager, is the infirmary in PV is much closer to the Central OR than the wards in SM. Regardless, several surgeons have stated that this is not consistent, given that in SM the time it takes to transfer patients also suffers much variation (ttransfer).

Anaesthesia induction is a criterion that is not often associated with advance scheduling decisions. Conversely, when asked about facts that cause variability in the operating room, surgeons mention that patients respond differently to similar anaesthetic procedures, which can impact on time in either patient induction or awakening. Furthermore, we consider the anaesthetic times, given that CHLN does not have induction rooms, which means that the patient must awake before transfer from the OR to the recovery rooms. The scheduler can give an estimate average per procedure and per “patient type” (tinduction) into his schedule. Furthermore, after patient awakening, a bed must be available to transport the patient out of the OR. Otherwise, staff cannot proceed to sterilize the OR.

Finally, the OR sterilization must be done according to different requirements, which can vary. The surgeon scheduler knowing the different requirements can make different estimates per patient (tsterilisation). However, one surgeon mentioned that even if some procedures require more time to sterilize the OR, usually this task delays because of availability of the material used to clean the OR. If staff does not have the required containers available, time is lost to pick up the materials.
Surgeons pointed out that their daily schedules (operational schedules) do not realize often as predicted, mainly because of non-operating time tasks. Therefore, we asked six specialists from five surgical teams regarding their own estimates for how much time they consider in between surgeries to their schedules, both for PV and SM elective scheduling.

<table>
<thead>
<tr>
<th>Functional Unit</th>
<th>Average Time Pulido Valente (min)</th>
<th>Average Time Santa Maria (min)</th>
<th>Number of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neurosurgery</td>
<td>10</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>General surgery</td>
<td>30</td>
<td>60-100</td>
<td>2</td>
</tr>
<tr>
<td>Stomatology</td>
<td>25-45</td>
<td>30-45</td>
<td>2</td>
</tr>
<tr>
<td>Urology</td>
<td>N/A</td>
<td>45</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 13: Surgeons actual estimates used at CHLN for non-surgical activities [N/A = Urology Service does not operate in PV]

The responses from surgeons reveal that surgeons estimates to time spend in-between operations is far from consensual among colleagues and shows that surgeons struggle to define explicitly their predictions, both in each functional unit and outside each service elective scheduling.

The surgeon scheduler must select the maximum number of eligible patients to operate, while prioritizing the surgeries in most urgent need according to their operational priority. Therefore, within his head, the specialist reviews each eligible patient one-by-one and evaluates the combination of criteria associated with each case, estimating then the perioperative time per patient, to the best of his knowledge. At the end, he decides upon the combination of patients that allow him to fulfil his objectives.

The department manager delivers to each surgeon the OR time available to the surgeon on each week. With the available OR time per specialist, decisions are made to optimize the use of the OR (without support of aid decision models). The following decisions regard the allocation schedule, where the surgeon specialist defines for each patient a surgery start-time, e.g. the order in which the specialist operates each patient to maximize his objectives – maximising the use of his block time.
While surgeon specialists need to estimate these times to construct their schedules, it is not easy, and it is associated with non-controllable variability, resulting from several entities performing inter-dependent tasks. Figure 23 attempts to describe the step-by-step decision-process surgeons face when designing advance schedules at CHLN.

5.4.2. Allocation Schedule
In CHLN, the allocation schedule consists on the definition of surgery start time to each scheduled patient. Each OR is daily exclusively assigned to up to one medical specialty. Approaching the surgery day, the surgeon specialist must decide by which order to operate his patients. According to the interviews, some regard different criteria to fulfil daily objectives.
Surgeons enumerated the criteria they regard relevant when deciding which patients to address first in a given day. For the majority, both for inpatient and outpatient surgery, surgeons usually operate on longer case first rule. The reasons are due to the higher variability in longer surgeries which tend to be more complex, and therefore by operating them earlier on the day, they can manage to control the remaining time more efficiently. In addition, specialists say that the most complex surgery of the day should be the first one, because it is when surgeons are at their best, either physically and mentally.
Although rule-based for sequencing patients, specialists mention that they also regard some relevant criteria, which may be exceptions to the longest case first rule. The first criterion is that patients with certain associated conditions also have priority to be scheduled first in the day, e.g. patients with diabetes, given the glycaemic control required versus fasting before surgery. Therefore, extenuating circumstances brought by patient’s conditions can affect how specialists order patients on surgery day and need to be considered.

Additionally, surgeons from General Surgery, Stomatology and Urology mention that patient age can be relevant, and select patients by age in ascending order, varying also according to each surgery complexity. Furthermore, a specialist from General Surgery has also stated that patients with contagious pathologies are usually scheduled for last, as a precaution, even though there is virtually no risk of contamination.

![Figure 24: Surgeon Allocation Schedule Decision Process](image)

Finally, surgeries at PV are constrained by the functioning hours of the medical support facilities of complementary means of diagnostics. According to surgeons from CT, N, and CG, if a surgery requires the assistance of anatomic pathology, the surgeon must operate throughout the morning OR block, since the facility closes by 16h00 on business days. Therefore, the surgeon holds this criterion to sort the set of selected patients as well, in addition to the ones previously mentioned.

### 5.5. Synthesis of Results CHLN

Initially, the goal was to develop an understanding of how we could purposefully model the elective scheduling activity at CHLN, by incorporating key stakeholders concerns into the problem formulation; hence, twenty-five surgeons and three hospital managers were interviewed. Our understanding over people common practices and routines at the hospital was enriched by stakeholder’s views; and their experiences and tacit knowledge was conceptualised through the application of a relaxed version of Soft
Systems Methods. Rich Pictures, CATWOE analysis and Root Definitions were helpful methodologies in this regard. Hence, characterising stakeholder tacit knowledge led us to focus on operational stage of elective planning, the advance and allocation schedule problem.

The reasons for this choice are twofold. First, the operational schedule at CHLN is designed by each surgeon specialist, and therefore lacks explicit procedures across the organization, since their design is clear only in the heads of the surgeons who perform each task. Second, surgeon specialists mention having low confidence in the use of decision support models; their belief is that medical judgement cannot be replicated by rule-based models, given the existent variables affecting the elective schedule at CHLN. Therefore, before modelling, we think it is appropriate to validate their concerns by characterising the problem, their activity, and what is expected according to literature, for hospitals with similar features.

Afterwards, we compare how surgeons at CHLN perform, against what OR planning and scheduling literature declares. Our hope is that the comparison will bridge a discussion between surgeons and hospital managers, easing the acceptance of using scheduling optimization techniques to fulfil stakeholder’s goals. Without facilitating such discussion, we fear models to be of little use at CHLN, since models alone are insufficient: unless they are included in a social process that becomes an accepted way of doing things, institutionalised within an organisation’s culture, they will not survive when their champion leaves the organisation (Phillips & Bana e Costa, 2007).

Our view of the elective scheduling problem at CHLN, based on the descriptive field classification system follows.

![Figure 25: CHLN characterisation according to descriptive fields](image)

In CHLN, the OR’s of PV and SM are managed independently and have different elective schedules. Moreover, the schedules consist in two different problem formulations, constrained by the types of surgery performed. CHLN delivers care to urgent and elective demand. However, there is no need to consider non-elective cases into the elective schedule since each patient type has dedicated ORs. Furthermore, there are different routes for elective patients: inpatient and outpatient surgery. The outpatient elective routing is handled at PV, while the inpatient agenda is booked for SM main elective rooms.

The task to model consists in a process owned by each surgeon specialist, who together with the hospital information system in place (SIGLIC), selects eligible patients to deliver care for the next week planning horizon. The objective defined by CHLN within SIGLIC consists in minimising patient operational priority. The patient selection is constrained by the OR time assigned to the surgeon, defined by the department.
manager and the OR manager, depending on the available staff; as well as the patient condition (clinical priority). The advance schedule at CHLN have a planning horizon of one week. The output is a set of selected patients to schedule for the next planning horizon, thus each patient is assigned with an OR number and a date to have surgery. In addition, the advance schedule decision process can be iterative, since patients can cancel surgery, or decease meantime. Overall, it is a process largely based on surgeon intuition and experience and lacks from explicit target-oriented procedures across surgical departments. Furthermore, how surgeons sort patients throughout the day implies preparation, and action from several human resources. Lack of explicit procedures and standard means of communication potentiates the increase of processing times.

At CHLN, the department manager has fixed days to schedule his teams to specific ORs. Thus, he assigns each surgeon OR block time, according to each functional unit’s performance and waiting list status, as well as restricted by the pressure to maintain a balanced workload among colleagues. The main objective to surgeons when designing operational schedules is to maximise OR use, given their available time to operate. Although the hospital being short of anaesthetists and nurses, the time available to surgeons is assigned by department managers, and guaranteed by the OR manager, who manages strategically the Central OR, given the available staff at disposal. Therefore, we can ignore from the operational problem scarce when modelling of human resources availabilities, given that this is sorted at the tactical level by the OR manager. With the available OR time each surgeon has, the decision concerns with selecting patients, and assign each with a date, an OR number to have surgery and a surgery start time.

The activities inside the OR affect other activities within the hospital, namely patient recovery units (e.g., wards). An elective scheduling model should state if related facilities are incorporated. At SM, the patient transfer activity is the main contestor of efficient scheduling according to surgeon’s predictions; and surgeons make different estimates for this tasks at CHLN. Furthermore, occasionally, if beds are not available when required, operational work freeze ends up disrupting surgeon’s schedules at CHLN. According to Samudra et al. (2016), when OR planning and scheduling decisions do not incorporate supporting facilities, in which case the OR is studied as an isolated system, improving the OR schedule may worsen the efficiency of those related facilities. Thus, it is important to incorporate related facilities into the scheduling model, to guarantee that schedules do not disrupt wards’ activities.

Surgeons must select patients to schedule, by looking at resource constraints, as well as considering infirmaries throughput (patient’s length of stay). For each available time slot, surgeons select patients, if the available capacity adjusts to his estimates over each procedure. Since in practice, each surgeon designs his own schedule, many of the variables associated to the surgery processing times directly relates with the surgeon who performs the surgery. Reinforcing this, the appropriate way to model the advance schedule is by characterizing individual surgeons. Since each surgeon performs not only a specific mix of procedures, with each taking different standard times, it is better to input surgeon specific demand in the model, rather than a generalized description for all of them; by measuring the processing times required to each surgeon per procedure (median and average time a surgeon takes to operate determined
procedure). Otherwise, taking an average operating time over a group of surgeons per procedure could easily turn schedules unusable, since these times vary widely from surgeon to surgeon at CHLN.

In practice, at CHLN, surgeons hedge against uncertainty by combining their experience with their medical judgement. However, using their experience translates into tacit knowledge, which is not easily transferable. Furthermore, surgeons that predictions have lower accuracy rates given the complexity of random variables around the elective scheduling process. Given this, it is important to consider several deterministic processes estimates, provided by relevant sources, augmenting surgeon’s estimates reliability. In section 5.3.1.3, we identify the most important variables throughout the perioperative time estimates to surgeons from different specialties. Additionally, we believe that realistic models to improve the performance of schedules at CHLN must incorporate the variables identified by multiple surgeons. Therefore, useful time predictions at CHLN are clustered into three main group estimates, i.e. different sources of modelling data: (1) standard operating times per procedure per surgeon; (2) volatility in patient’s characteristics estimate; (3) standard estimate for patient transfer, OR sterilisation, and anaesthesia induction per surgical team per ward.

While we are confident we can effectively average the standard operating time per surgeon per procedure, other variables such as impact from patients with coagulation deficit, are intangible (2), and cannot be precisely quantified by surgeons. If surgeons identify a priori intangible criteria, which they feel add complexity to surgeries; implicitly, they overestimate the standard operating times. A scheduling model that accurately represent surgeon’s judgments must recognise these criteria as surgeons do and use when necessary (over/under) parameters that “estimate” standard processing times, per surgery. Thus, this variability must be accounted building efficient schedules at CHLN.

Let us consider the surgery proposal form as one model input; we can expect useful information, provided by each patient’s physician, identifying relevant information to hedge against unforeseen events during the surgery, associated to the patient characteristics, and where they can place their estimates, as well as consider synergies between intangible variables.

At CHLN day-to-day practice, surgeons do not include estimations into the surgery proposal form, e.g., patient likely complications; rather, the proposal consists in a generalized qualitative description of the patient condition. Thus, we propose a collaboration between attending physicians and the CHLN operational scheduling model, in which the former places their inputs dynamically, allowing the latter to adjust their ruling, and optimise schedules at CHLN realistically. Identity of each patient upon surgery proposal is done upon the definition of four parameters: Clinical Priority, expected length of stay, expected operating and non-operating times.

Our attempt to integrate intangible factors, i.e., natural variability described by Litvak and Long (2000), is one of the distinct characteristics we think CHLN scheduling system modelling can be of successful implementation, since its input data is not being feed through any of our assumptions, rather by each stakeholder knowledge over their core activities.
Finally, surgeon specialists must compute into their schedules estimates for non-operating activities (3). Our perception when discussing specialist’s routines regarding these tasks was that most surgeons did not understand fully their contribution to increasing variability in the time patient transfer activities take on CHLN. The hospital has limited human resources to conduct the activities, and since most stakeholders does not exclusively report to one operating room, activities can delay if surgeon specialists do not communicate openly with OR stakeholders or fail to predict accurately their operating schedule.

<table>
<thead>
<tr>
<th>OR Setting</th>
<th>Patients characteristics α</th>
<th>Decision delineation β</th>
<th>Uncertainty Y1</th>
<th>Performance Measures Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>B1</td>
<td>B2</td>
<td>B3</td>
</tr>
<tr>
<td>SM</td>
<td>E – Inp, Out</td>
<td>Pat</td>
<td>Date, OR, Hour</td>
<td>Incorp</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV</td>
<td>E – Out</td>
<td>Pat</td>
<td>Date, OR, Hour</td>
<td>Iso</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15: CHLN characterisation according to descriptive fields

Therefore, CHLN can benefit from creating explicit communication procedures among stakeholders, by taking advantage of model’s transparency, thereby stabilizing the duration of non-operating tasks at CHLN, which according to surgeon specialists disrupt often weekly schedules. The data surgeons should use to estimate the non-operating tasks must consider isolated mean times per ward and per specialty. At CHLN, both surgeons and hospital managers exploit different scheduling combinations to maximise OR utilisation. Ultimately, surgeon’s objectives are constrained by governmental guidelines, which prevent decisions to base purely on maximising OR use. Therefore, our problem consists in a bi-objective of maximising the OR occupation, while minimising of selected patient’s operational priority value.
The CHLN operational scheduling system must thus accommodate the following requirements:
Surgeon’s goal of maximizing OR use, by applying well thought out considerations into their available OR time;

The number of eligible patients to schedule is greater than the available capacity, provided by SIGLIC;

Surgeon’s trying to maximize the number of patients selected with the lowest values of operational priority;

For each procedure and each surgeon, the hospital has the standard surgery duration, fed by historical data averaging;

For each patient and surgeon, the hospital has the estimated surgery adjustment times, fed by surgeon’s surgery proposal;

For each team and each patient infirmary, the hospital has the standard non-operative task times, feed by historical data averaging;

The available OR time constraints the patient assignment task;

CHLN does not allow overtime. If surgeries delay throughout the day, the last surgery does not occur. Moreover, surgeons need to fit cancelled patients in following schedules, leading to snowball effect;

Surgeons desire flexibility on surgery day to sort patients according to their preferences. However, last time changes must be penalised, and not communicating effectively among stakeholders, and with considerable warning, leads to disruptions and therefore must be discouraged;

Staff cannot transfer patients to recovery rooms unless a bed is available.

These remarks are overall specificities of CHLN operational scheduling. Our understanding is that the processes surgeons undergo, i.e., designing the weekly operational schedule, can be improved by modelling the activity, oriented towards optimizing the hospital goals. However, surgeons at CHLN are very powerful stakeholders; if they do not see the benefits over the application of scheduling models at the hospital, their refusal in using the hospital scheduling system barriers implementation. Therefore, this work orientation has shifted, attempting to align surgeon’s acceptance to eventual models, by understanding how previous similar experiences in literature were successful. These slight changes in focus calibration throughout this work integrates well with the proposed Multi-Methodology. Thus, in the next section, a set of literature is selected, and each characteristics are advised and is highlighted how they relate to CHLN advance and allocation schedule processes.

5.6. OR Planning and Scheduling Literature Vs CHLN

Every year, CHLN handles about 23,000 elective surgeries, through several surgical groups and subspecialties. This section aims to clarify how, and by which means did other researchers in literature overcome the systematic concerns over advance schedule and allocation schedule in their studies. Initially, the set of papers concerned with problematic situation was selected from the literature review.
According to our review, the studies in tab. 16 address similar contexts of the problem, resorting to optimization techniques, evaluating several performance measures, constrained by multiple resources. Ozkarahan (2000) develop a model that potentiates OR use. The hospital of study practices block-scheduling for specialties to operate. Similarly, surgical specialties are allocated a full day during which they are supposed to use a specific OR, and accordingly, each surgeon has a certain day to schedule his patients. At Dokuz Eylül University Hospital, as in CHLN, surgeons send their planned lists of cases for their next block day. Even if surgeons know they will not be using all their allocated time, they do not have to inform anyone, which eliminates any chance of making unused OR time available to other specialties. Similarly, since surgeons do not have to provide any estimates before surgery, at CHLN the cut-off time ends up being the block itself, limiting the OR occupation rates. Conversely, usual block scheduling systems practice cut-offs, increasing the OR occupation rates by improving communication. Additionally, at CHLN, surgeons do not share any estimates nor are required to determine the order of cases before surgery-day. Hospital staff in place, transfer patients to the OR and take them back to each respective infirmary, after surgery. Since no prediction is made regarding the expected duration of operations, the staff do not know when the next surgery will begin. Either the patients are brought in early and left alone waiting or they are brought in late which results in OR idle time. It is crucial to share this information internally and with other departments, since OR resources are shared among different specialties and people. Using goal programming for the advance and allocation schedule, Ozkarahan (2000) propose a mathematical model that satisfies the conflicting objectives in the OR environment. The model’s solution is compared with the hospital’s actual schedule using the hospital’s heuristic, and the hypothesis test on the equality of sample means show that the hospital’s heuristic schedules generated up two hours of more distortion from the desired eight hours of room utilization per day compared to the models with 95% confidence. This proves the superiority of the model over the hospital scheduling procedure (heuristic). The main drawback of the goal programming approach is that is dependent on decision maker’s weight assignment. However, it is a rather flexible approach when it comes to reconcile multiple conflicting objectives. Therefore, Ozkarahan (2000) deals with hospital systemic issues, and shows that surgeon’s preference in scheduling patients can remain, while improving from the orientation towards modelling of structured goals. Despite the hospitals scheduling model’s similarity, the approach remains not applicable to our view of CHLN scheduling activity. The author considers that accurate surgery estimates are available to the scheduler, per procedure, which does not translate into designing efficient schedules. Furthermore, at CHLN there is high variability in surgeries durations, and it is a university hospital, where often surgeon interns perform surgeries. In addition, there is a widely known discrepancy between surgeon specialist’s performance per procedure. Sperandio et al. (2014), similarly to CHLN current practice, witness surgeons using different methods to devise their schedules, such as personal agendas, spreadsheets and online calendars; reducing the level of centralization and integration within the hospital to insignificant levels.
<table>
<thead>
<tr>
<th>Patient charact.</th>
<th>Delineation of decision</th>
<th>Uncer. Corp.</th>
<th>Performance measures</th>
<th>Model Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>α1</td>
<td>β1</td>
<td>β2</td>
<td>β3</td>
<td>Y1</td>
</tr>
<tr>
<td>(Ozkarahan, 2000)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>(Denton et al. 2007)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Lamiri et al., 2008)</td>
<td>E; NE</td>
<td>Pat</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Testi &amp; Tànafani, 2009)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Roland et al., 2010)</td>
<td>E</td>
<td>Surg; Disc</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Roland &amp; Riane, 2011)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Marques et al., 2012)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Sperandio et al., 2014)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Marques et al., 2014b)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Marques et al., 2014a)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Addis et al., 2014)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Marques &amp; Captivo, 2015)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Castro &amp; Marques, 2015)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Aringhieri et al., 2015)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Aringhieri et al., 2015)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>(Duma &amp; Aringhieri, 2015)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>(Riise et al., 2016)</td>
<td>E</td>
<td>Pat</td>
<td>Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>(Spratt &amp; Kozan, 2016)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>(Landa et al., 2016)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Luo et al., 2016)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Addis et al., 2016)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
</tbody>
</table>

Table 16: OR planning and scheduling literature covering the advance schedule and allocation

In their formulation, they have included stochastic operating times, by integrating a data-mining model, which gives the user an estimative of the surgery duration, with tested results improving surgeon’s actual estimates. There is a widespread reference in literature discouraging the thesis that surgeons perform accurate estimates. Sperandio et al. (2014) credit surgeon’s poor performance over procedure estimates,
to time granularity they use, reinforcing that this presents a severe constraint to fine tune schedules. According to surgeon specialists at CHLN, schedules disrupt often because of unforeseen events while operating. However, according to the SM OR manager, if we use historical averages per individual surgeon’s performance, estimates could be useful to predict standard procedure time. This would significantly reduce both the granularity in surgeon’s individual estimates, while avoid taking the average times at CHLN per procedure. Furthermore, given the stakeholder’s feedback, we believe schedules can further improve, if we rely in surgeon’s estimates to the variability brought by patient’s characteristics into the OR. This volatility is for the most part characterized by the multiple intangible variables acting during the procedures, brought by patient’s characteristics, which can disrupt schedules. At CHLN, many surgeons hedge against unforeseen events at the OR by deconstructing the patient diagnosis. While intangible, their experience in dealing with these variables is relevant, improving the surgeon operational schedule by relying on their estimate for surgical procedure volatility. In the literature, researchers deal with these factors considering uncertainty into their models, as described in section 3. However, at CHLN, stochastic values are not considered, rather the deterministic estimates from who we think performs best, based on our findings: perform statistical analysis to estimate standard procedure duration per surgeon; and rely on surgeon’s variability estimate for procedure per patient.

When researchers consider deterministic procedure estimates, usually they include some pre-defined time for OR clean-up and setup. While this rationale is theoretically sound, in practice, there is no guarantee that the next patient will be ready for surgery once these tasks are finish. In fact, one of the most disrupting activities affecting CHLN schedules concerns the non-operative times, i.e., the task where auxiliary staff transfers patients from infirmaries to the OR, while surgical nurses setup the material requirements to address the following surgery. CHLN, being a sizeable hospital and operationally complex, have multiple wards working with different schedules, teams, in different proximities to the Central OR. We asked five different specialists, how much time they usually compute in their schedules for non-operative activities. Given that their estimates were non-consensual, with min-max 30-100 minutes, we propose that instead of considering deterministic standard time for non-operative tasks, we compute the average time per non-operative task, per infirmary patients are transferred from. This way, we not only consider the scarcity of resources at each facility, but we also consider the distances between physical locations. (Marques et al. (2012), for instance, considers 30 minutes between each surgery for OR clean-up and patient transfer activities.

The advance schedule at CHLN must be handed to the scheduler assistant at least eight days in advance, so patients can be noticed and agree upon the proposed date. Surgery start-time, however, is sort on surgery day. Usually specialists prefer to address more complex and longer procedures first. Besides being more attentive and sharp by morning, they believe this improves their time management throughout the day, since they can hedge against delays. Denton et al. (2007) analysed three simple sequencing heuristics that can hedge against uncertainty of surgeries duration:

- **Heuristic (H1):** Sequence surgeries within each surgeon’s block of cases in increasing order of mean of durations.
● Heuristic (H2): Sequence surgeries within each surgeon’s block in increasing order of variance of durations.
● Heuristic (H3): Sequence surgeries within each surgeon’s block in increasing order of coefficient variation of durations.

These simple sequencing rules were tested with actual hospital data (e.g., surgeries durations historical data and objective function weights based on input from OR scheduling decision makers). According to their results, longer case first rule (CHLN routine) performs poorly from a staffing perspective, and that the shortest case first (H1) performs relatively well with respect to other decision rules. In fact, the heuristic performing best was H2, which is reasonable, since positioning high variance surgeries late in the schedule minimizes the potential impact on waiting time for surgeries later in the schedule. Regardless, certain exceptions override this heuristics, applicable to specific surgical groups, as explained in section 5.4.2. e.g., schedule patients with diabetes first. We are keen to mention that efficient schedules to balance workload across OR partaker facilities preferably use shorter case first rule, and such is widely recommended throughout OR planning and scheduling literature (Dexter & Marcon, 2006). However, at CHLN the common practice transversal to all surgical groups is to consider longer case first rule. Surgeons guide sequencing decisions throughout each surgery day and may not even be aware of the consequences arising from their decisions and affecting OR performance measures. Thus, acknowledging the consequences of their decisions, can begin to accept more easily any proposed change on the sequencing rules surgeons routinely apply at CHLN.

Finally, at CHLN the main concern surgeons have when scheduling is preserving NHS equity and access, according to the patient’s clinical priority.

<table>
<thead>
<tr>
<th>CHLN</th>
<th>(Ozkaraham, 2000)</th>
<th>(Denton et al., 2007)</th>
<th>(Roland et al., 2010)</th>
<th>(Marques et al., 2012)</th>
<th>(Sperandio et al., 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR management strategy</td>
<td>Fixed OR/day per specialty</td>
<td>Fixed OR/day per specialty</td>
<td>N/A</td>
<td>Surgeons define their availability to model OR block preferences</td>
<td>Fixed OR/day per specialty</td>
</tr>
<tr>
<td>Planning horizon</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
<td>1 week</td>
</tr>
<tr>
<td>Patient characteristics</td>
<td>Elective Inpatient, Outpatient</td>
<td>Elective</td>
<td>Elective</td>
<td>Elective Inpatient, Outpatient</td>
<td>Elective</td>
</tr>
<tr>
<td>standard operating times per procedure per surgeon (1)</td>
<td>Historical Averaging per surgeon per procedure</td>
<td>Historical Averaging per procedure</td>
<td>Sampling based on surgery type, rather than individual surgeon</td>
<td>Historical Averaging per procedure</td>
<td>Data mining model encompassing two algorithms to predict surgery durations: Baggins and M5 Rules</td>
</tr>
<tr>
<td><strong>Volatility from patient’s characteristic</strong></td>
<td>Surgeon estimate on surgery proposal</td>
<td>Not addressed</td>
<td>Stochastic procedure durations</td>
<td>Not addressed</td>
<td>Stochastic procedure durations</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------------------------------------</td>
<td>---------------</td>
<td>-------------------------------</td>
<td>---------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td><strong>Non-operating time planning</strong> (3).</td>
<td>Historical averaging per specialty per infirmary</td>
<td>Not addressed</td>
<td>Not addressed</td>
<td>30 min</td>
<td>Not addressed</td>
</tr>
<tr>
<td><strong>Surgical specialties addressed</strong></td>
<td>CG, CV, CT, EST, OBS, ORT, N, URO, OTO, Plastic Surgery, ORT, CV, URO, Paediatrics</td>
<td>Trauma Service</td>
<td>Not disclosed</td>
<td>OTO, CG, CT, URO, CV</td>
<td>CG, CV</td>
</tr>
<tr>
<td><strong>Overtime flexibility</strong></td>
<td>No. If there isn’t enough time, the last surgery is cancel</td>
<td>Impose a goal penalty for Overtime</td>
<td>Penalties on tardiness</td>
<td>Penalties on tardiness</td>
<td>Not allowed. Overtime barred</td>
</tr>
<tr>
<td><strong>Performance Measures</strong></td>
<td>OR use</td>
<td>OR use, OR preference access</td>
<td>OR use</td>
<td>OR use</td>
<td>OR use, Max throughput, min waiting time</td>
</tr>
</tbody>
</table>

Table continues in the following page

<table>
<thead>
<tr>
<th>CHLN</th>
<th>(Ozkarahan, 2000)</th>
<th>(Denton et al., 2007)</th>
<th>(Roland et al., 2010)</th>
<th>(Marques et al., 2012)</th>
<th>(Sperandio et al., 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Assignment Criteria</td>
<td>Minimise patient operational priority</td>
<td>Surgeon preferences based on clinical priority</td>
<td>Surgeon preferences based on clinical priority</td>
<td>Minimise patient operational priority</td>
<td>Surgeon preferences based on clinical priority</td>
</tr>
<tr>
<td>Patient Sequencing Criteria</td>
<td>Varies according to the specialist. Usually is LST</td>
<td>Varies according to the specialist. No guidelines in place</td>
<td>Longer, more complex cases first</td>
<td>Not addressed</td>
<td>Not addressed</td>
</tr>
<tr>
<td><strong>Optimisation Technique</strong></td>
<td>-</td>
<td>Goal Programming</td>
<td>Stochastic optimisation model + improvement heuristics</td>
<td>Resource Constrained Project Schedule Model executed by a</td>
<td>ILP + Improvement heuristic</td>
</tr>
</tbody>
</table>
Marques & Captivo (2017) propose a systematic approach to help the surgical planner in the scheduling of elective surgeries, to optimise the use of the available surgical resources and improve equity and access to operated and waiting patients. This concern arose, since surgeons at the hospital of study, while well intentioned, lacking from definitions when scheduling patients, tend to schedule patients they remember best. Marques & Captivo (2017) refer this effect as a resultant from surgeons ‘lack of memory’, and the analysis of data showed that patients waiting fewer days were first scheduled, as in a last-in-first-out (LIFO) strategy. Conversely, surgeons at CHLN said to prioritize patient scheduling by patient clinical condition and antiquity, thereby preserving SIGIC guidelines and rules of equity on access. Regardless, since it is a surgeon-oriented and non-systematic task where there is not in place any effective validation tool to guide the decision process besides SIGIC, surgeon ‘lack of memory’ effect might well be a feasible concern. The design of a systematic approach to tackle the patient assignment problem at CHLN could lead to jointly maximising stakeholder’s objectives.

In table 17, we characterise CHLN against few selected papers covering similar topics in look-alike instances. Our view of the system does not concern itself with the theoretical interest of advising upon different optimisation alternatives, rather is interested with the practical interest of designing realistic views over the constraints and objectives stakeholder’s have with operational scheduling at CHLN.
6 Conclusions and Future Work

The demand for healthcare services has been increasing over the years. The technological advances for medical equipment’s in past decades have increased the safety of procedures, as well as the acceptance from populations to receive medical treatment, which partly justifies this increasing demand. Also, due to the ageing population and increase longevity in most industrialised countries, delivering care to societies means great challenges for governments. The goal is maximising the quality of health care provision, increase services’ efficiency while lowering the cost of operations. To that end, operations research has found in the domain of healthcare an opportunity to aid on the fulfilment of healthcare managers objectives, by exploring multiple approaches, and proposing several mathematical and simulation models.

Throughout this thesis, we show that often researchers fail to implement custom models in hospitals of study, because of stakeholder resistance - either by missing to interpret stakeholder’s requirements or failure to educate surgeons regarding the benefits of scheduling optimisation models. Thus, this dissertation explores how key stakeholders see and experience the elective scheduling, for a specific setting, to improve chances of successful implementation, by proposing a Multi-Methodology.

First, through semi structured interviews, the principles governing the operating theatre at PV an SM are identified, and the routines of different specialists when planning elective schedules are analysed. Their insights allow us to characterize the OR planning and scheduling at CHLN as a set of surgeon-oriented tasks; and given the scarce of nurses and anaesthetists at CHLN, surgeons must optimise schedules to improve their use of OR time, while fulfilling the hospital guidelines. Our analysis using SSM enables to identify and characterize processes performed by surgeon specialists at CHLN, exceptionally decentralised from management, and lacking from directive formulations toward set forth goals.

The second stage of this work map surgeon’s decision processes, when selecting patients to operate. Our attempt to conceptualise the activity for nine surgical groups, using flowcharts, show that while each patient and surgical specialties are singular in its characteristics, it is possible to model a comprehensive sequence of logical decisions, aggregating collectively the concerns of the group of 23 surgeons interviewed.

In this work, decisions-making are clustered by type of elective surgery performed - inpatient and outpatient. The results show that surgeons regard few variability for outpatient surgery attributed to patient’s characteristics, in comparison with inpatient surgery. In contrast, our analysis shows that surgeons regard that throughput is mostly affected daily because of non-operating activities at the hospital, namely patient transfer to the OR from wards.

We conclude that both surgeons and hospital managers look towards maximising the same performance measures of OR utilisation, although find that the actual model by which the hospital manages the elective surgical activity is actively conflicting with their objectives.

Our main concern with this work is to explore inclusive methodologies, to engage and analyse processes, thus helping stakeholders to understand the applicability of modelling schedules at the CHLN.

Nevertheless, future work should be dedicated to investigating specifically efficient and reliable methods of gathering the proposed model inputs, to estimate the relevant decision variables for scheduling
patients at CHLN; and in addition, modelling of the CHLN elective schedules, following this thesis structure.

In conducting the case study, we find that the application of the SSM may have been relaxed somewhat in excess, given the overlook to the stakeholder validation phase. Instead, we have collectively validated our results through the judgement of the OR manager, although, ideally the interview results should have been validated by the interviewed stakeholders iteratively, and then consensually validated in group by a methodology like decision conference. Furthermore, we also think that the data collection phase would improve if the interviewers were experienced in doing interviews, and the lack of maturity in guiding the process may have dictated part of the collected data. Regardless, we think that the application of this Multi-Methodology is a solid approach for problem structuring.

Finally, in this dissertation, we propose the set of guidelines to model the scheduling activity at CHLN. This Multi-Methodology can be applied to similar problems, in different hospitals, where researchers would want to make sense, before tackling elective surgeries scheduling problems.
7. References


Blake, J. T., Donald, J., & Ball, S. (2002). Mount Sinai hospital uses integer programming to allocate operating room time. *Interfaces, 32*(2), 63–73. https://doi.org/10.1287/inte.32.2.63.57


Cardoen, B., Demeulemeester, E., & Belien, J. (2010). Operating Room Planning and Scheduling


## Appendix A – Key Reviewed Studies

<table>
<thead>
<tr>
<th>Maximise OR use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(Luo et al., 2016)</strong> – The authors develop a rolling-horizon scheduling model based on mixed integer programming, to compare with the hospital existent scheduling system (non-rolling-horizon), considering that the results of surgery scheduling are influenced by the daily variation in surgical demand. Thus, the results show that the rolling horizon is useful to balance and make full use of the OR, while increasing the number of surgeries. Since the demand pool for surgeries considered was 5 days (the used system scheduled the day of surgery based on surgeon’s daily request list), there is a larger set for optimal solutions and increase of the OR utilization. The main limitations of this study regard both the impact of resources availability in scheduling, by not considering mixed services incorporated to the OR, as well as uncertainty on surgical durations, which were modelled as deterministic.</td>
</tr>
<tr>
<td><strong>(Landa et al., 2016)</strong> – The authors propose a two-phase hybrid optimization algorithm (combines neighbourhood search techniques with Monte Carlo simulation) to schedule elective surgeries (assign and sequencing) considering surgical durations as random variables. The hybrid algorithm approach starts from any deterministic solution, which assigns patients to available ORs, and then adapts the pre-schedule to consider stochastic surgery durations that maximizes OR use. The second phase of the algorithm seeks to minimize the number of possible cancellations by assigning the available overtime through a sequence of greedy procedures, while maintaining the reliability of the first phase schedule. The authors consider a given amount of overtime available to mitigate the unavoidable consequences of surgery time variability. This approach has the advantage of exploiting the trade-off between achieving an acceptable level of OR utilization rate while limiting the negative effects of surgery cancellations and postponements. The main drawback from this approach, according to the authors, is the difficulty of introducing and interfacing standalone resolution methods into the hospital information systems.</td>
</tr>
<tr>
<td><strong>(Marques &amp; Captivo, 2015)</strong> – Alongside OR utilization, reduction of surgery waiting lists is also addressed with this bicriteria optimization methodology, by using an evolutionary algorithm. The authors claim that this is an efficient approach, with small computational time for the instances tested. An advantage of this approach, unlike many other multicriteria optimization problems addressed in the literature, is that the output consists on a set of non-dominated solutions; by not relying on decision-makers associated weights to provide one solution on each run, and instead, on each run, having a set of efficient solutions representing the Pareto front, this makes the model suitable to embed in hospitals information systems as a decision support instrument for managers. The main drawback of their approach regards the uncertainty of surgery durations, thus diminishing the robustness of the solutions.</td>
</tr>
</tbody>
</table>
This paper proposes a two-level decomposition algorithm that relies on two continuous time generalized disjunctive programming for the near optimal scheduling of elective surgeries. Both levels feature continuous time integer programming formulations that allow considering accurate surgical times. In the first level, a subset of surgical cases is selected from the waiting list (neglecting surgeon’s availability constraints); and then in the second level, patients are assigned to an OR and a start time, considering all the previous neglected constraints, and checking for the feasibility of the overall schedule. The same problem had already been addressed in (Marques et al., 2014b) and (Marques et al., 2012). Even though in this study the authors used different optimization approaches, they credit most of the success of their model in comparison to the use continuous-time integer programming formulations, that led to 5.1% and 4.6% improvements in the OR occupation rate.

In this paper, the authors approach both advance scheduling and allocation scheduling to solve an elective surgery scheduling problem applied to real case instances. The model integrates two versions of a single objective genetic heuristic; while maximizing the number of surgeries scheduled, the model also maximises the utilization rate of the surgical suite. The approach has presented better results with less computational effort than previous approaches - ILP (Marques et al., 2014b) and bicriteria heuristic (Marques et al., 2012). The main drawback of this study is the use of discrete-time integer programming formulation (uniform intervals of 15 minutes), thus the processing times forced to roundup, becoming even more inaccurate. Other limitation of the model is to not consider resource capacity and availability constraints, either from upstream or downstream facilities to the OR. On this issue, the authors claim there is no bottleneck from those facilities, thus they do not limit activities and these limitations don’t need to be incorporated into the model.

Within the same problem conditions as the paper above, in this study a bicriteria heuristic model was constructed in two steps. First, to search for efficient solutions, the authors minimize a weighted Chebyshev distance to a reference point. Secondly, a constructive and an improvement heuristic procedure is designed. The main advantage of this approach is that a good feasible solution is provided on each run with short computational time. Even so, the model has the main limitation of, on each run, only one solution is provided, biased to the decision-maker perceived importance of each criterion (associated weights). On the previous work done by the authors, using a genetic algorithm, this drawback is avoided;

Using a regression like-model that encompasses a bagging and M5 rule algorithm to account for stochastic surgery durations, and an adapted multiple knapsack problem to advance schedule elective surgeries, the authors have developed an intelligent (data mining) decision support system to plan for resource rationalization within the OR and to improve OR efficiency, within the context of surgery waiting list management in the Portuguese NHS;

The authors propose an integer programming model to maximize the OR use, considering deterministic surgical times. The non-optimal solutions given by the optimization model were further improved through a custom-made heuristic. The paper jointly considers advance
scheduling and allocation scheduling, and thus assigns elective surgeries to an operating room, a day and a specific start time, on a weekly planning horizon.

(Fei et al., 2009) – To solve both the minimization of underutilized OR time and overtime cost, the authors develop a column generated based heuristic (CGBH) procedure, considering an OR open schedule to assign surgical cases to multifunctional ORs, over a weekly planning horizon. First, a mathematical model (binary integer programming) is proposed to solve the tactical OR planning problem, complying the surgeon and OR availability to assign patients over a weekly planning horizon. Then, a CGBH procedure is developed, where four different criteria are compared with each other to find a solution with the best performance. The results presented by the authors are positively encouraging; when the lower bound of the best solution obtained from the CGBH procedure is compared with linear programming, to evaluate the distance between the approximate solution obtained and the optimum one, it was found that the solution is nearly optimal, thus validating the proposed algorithm to find efficient solutions.

(Tyler et al., 2003) – The authors propose a simulation model to identify the crucial factors that must be considered in determining the optimum OR utilization. The simulation is based on one procedure being performed repeatedly in one OR, with deterministic short mean case duration. The authors credit natural variability of the surgery durations to the settled OR utilization goals. By increasing variability in surgery durations, the utilization that can be achieved within these targets decreases. Even though results suggest the impact of such factors, this approach does not give an adequate measure of how efficiently resources are used.

(Franklin Dexter & Traub, 2002) – Compared two simple patient scheduling heuristics, earliest start time (EST) and latest start time (LST), to evaluate several scenarios on the effects of scheduling one patient with those heuristics. They concluded that EST is rationally economic at such facilities, since it maximizes OR use. LST, however performed best on balancing the workload among services OR time.

(Ozkarahan, 2000) – With a goal programming approach, the author developed a model that minimizes idle time, while increasing satisfaction of surgeons, patients, and staff. The author considers five goals (maximal OR use; scheduling block restrictions – priority use to the owner of the OR time block; OR preferences – schedule the operations of a unit according to surgeons’ preferences; surgeons preferences – each specialty defines the importance of its surgeries, and the difference between the sum of weights of scheduled surgeries and the sum of weights of listed surgeries should be minimized; and intensive care capabilities – this goal constraint, to ensure intensive care capacity (beds) for patients in need of post-surgery intensive care. The main advantage of this model is its inherent flexibility, achieving goals such as surgeon and staff satisfaction. The main drawbacks in the use of goal programming models are the involvement of decision-makers into the decision process (parameter setting). This may question the validity of the approach, since managers may not have the sensibility to define appropriate weights translating the real operational goals.

(Franklin Dexter et al., 1999) – The authors compared 10 scheduling algorithms through simulation to evaluate which performed best to schedule add-on elective cases (elective cases scheduled after cut-
off time to maximize OR use). They have concluded that Best Fit Descending with fuzzy constraints is the algorithm that maximises OR utilisation. The authors remark the use of this algorithm for surgical suites that usually do not concern on scheduling add-on elective cases; to implement it, either manually or embed the algorithm in the hospital scheduling information system.

**Stakeholder preferences**

(Lim et al., 2016) – In this study, the authors propose a model to efficiently schedule surgical nurses' caseload, by minimizing the idle time, staff shortages, room changes, number of assignments, and broken assignments. Furthermore, a second optimization problem was solved to maximise the total number of nurses who can be given a break during lunch time. The multi-objective optimisation problem is solved with a column generation algorithm and a two-phase swapping heuristic. The unique feature of this study, according to the authors, is to jointly consider a surgery and lunch break schedule for the nursing staff. Limitations on the schedules quality arise from deterministic time considerations.

(van Essen et al., 2012) - When undesirable changes happen to the original schedule, the OR manager must decide how to adapt. The authors in this study propose an ILP model, whose objective is to minimise the deviation from the preferences of the considered stakeholders. As a decision support system embedded in hospital scheduling information systems, this approach helps managers determining the best adjusted schedule for one OR with respect to the given constraints and gives insights in how the workload of stakeholders is influenced by adjusting the OR schedule throughout the day. The results obtained by a simulation model show that with this decision support system less surgeries get cancelled and use of resources throughout the hospital wards are better managed. Nonetheless, the authors claim that if priorities of the stakeholders change (patients; nurses; OR assistants; managers; technicians; surgeon's), the decision rules of the system may not be applicable and result in a larger number of cancellations of surgeries.

(Roland & Riane, 2011) – The authors develop a mixed integer programming model to cope with the OR planning and scheduling problem. The authors include the human factor in drawing up surgical schedules, specially by introducing some cooperation in this decision process (game theory); they associate a disutility function with each surgeon as a cardinal measure of dissatisfaction, related to violations of the surgeons' preferences. In this model, each surgeon specifies an agenda of availabilities, preferences over working half-days in three separate ways. Also, the authors consider staff physical and moral welfare by minimising working costs (overtime and open OR costs), as well as surgeons’ disutility. The main limitations of this study are the validity raised by not considering uncertainties; and the computational effort required to run the model for real-life instances. By taking surgeons preferences into account it enlarges the solution space, thus leading to higher computational times. Nonetheless, the model has more flexibility when scheduling, and OR satisfaction leads to increase efficiency and reduces the absenteeism risk.

(Roland et al., 2010) – While modelling human resources preferences, by stressing their availability in the design of schedules, the objective function focus on cost containment when using the OR. The authors consider preferences as flexibility to fit human resources agenda with OR schedule. Using a
genetic algorithm (given the unusable practice of exact approaches to the complexity of the problem) to provide various schedules that minimize cost of using the OR and overtime pay, the surgeons and their team may choose the schedule that maximizes their preferences. The main advantage of this approach is its flexibility (problem with relaxed OR accessibility), and by using a genetic algorithm, in each iteration, the algorithm provides a population of solutions in a reasonable time. Although the algorithm provides good solutions, the authors work in a deterministic context, thus raising the issue of validity of their approach. Also, the authors state two antagonistic objectives in the same objective function (cost minimization and welfare loss); and it would be appropriate to investigate the multi-objective optimization to separate the conflicting goals.

(Testi & Tànfani, 2009) – The authors propose a prioritization algorithm to minimize patient welfare loss when planning and scheduling OR time. The algorithm has been used to evaluate the impact of increasing capacity costs on some performance indexes such as welfare loss. To include surgeons’ preferences, availabilities are considered in the model. The authors exclude some pre-defined days by using a variable pre-processing before running the model that sets to zero the decision variables corresponding to the days of the week that surgeons are occupied in other activities.

(Plasters et al., 2003) – With a methodology based on direct observations of OR management of information flow, and the use of critical incident technique (CIT), the authors propose a taxonomy of coordination challenges OR stakeholders face when changes happen to the daily schedule, grouped according to the major components of the perioperative process. The authors claim that in the hospital under study, the information systems currently provide only a fraction of the necessary information to adequately manage the changing schedule of the OR.

(Fowler et al., 2008) – The authors sought to study in detail the perioperative workflow; they have focused specifically on the flow of information and materials, the team member roles, tasks, relationships and interdependencies, process variations, failures and staff members work arounds. They used ethnographic and iterative grounded theory with constant comparison methods to define processes and their interdependencies; and created a database of staff members who are perceived has critical to quality requirements, failures, and safety risks; and elicited information from Semi-Structured interviews. These methods were applied to identify barriers on OR efficiency. Since this case study was exploratory, the results have very limited generalizability to other settings. Even so, the results show the effectiveness of using these methods to study perioperative microsystems.

(McCord, 2003) – In a scenario were surgical procedures are physician-specific, in which surgeon preferences are considered for each surgical procedure, keeping up with surgeon’s preference card can be a clogged process. In this study, the authors develop a program (personal digital assistant) that enables to streamline updating surgeon’s preference card, by storing, tracking and organizing the critical information for which circulating nurses are responsible.

(Blake et al., 2002) - The authors use an integer programming model to create a master surgery schedule perceived as fair among surgery specialists. The objective is accomplished by minimizing the under allocated time to specialist surgeons, according to each target. The authors claim that the
scheduling process was greatly improved. Political manoeuvring was reduced; the hospital accounted savings in administrative cost; and the system produces a quick and effective master surgery schedule. 

(Blake et al., 2002) – The authors develop an integer programming model to develop a consistent schedule that minimizes the shortfall between each surgical group target hours and the actual assignment of OR time. The model is built upon OR capacity and availability constraints, were a penalty charge for undersupplied OR time assigned to specialists. By relaxing this condition, a heuristic procedure searches for efficient solutions within a reasonable computational time. The authors suggest an appropriate approach for hospitals with limited OR budgets that must modify their master surgical schedules in response to changes in available funding, staff availability, or patient demand.

Waiting list management

(Marques & Captivo, 2017) – To attain to both hospital administration and surgeon’s personal interests when scheduling, the authors developed a mixed integer programming model that selects patients from a large waiting list to have surgery in the planning horizon, and assigns a date, an OR, and a block time for the selected patients (advance scheduling). The authors developed three versions of this assignment problem: one that considers the hospital administration’s goals; one to consider surgeons’ current practices; following by a version that combines both intents, reflecting a negotiation process between managers and surgeons. A robust approach is also proposed to tackle the uncertain surgeries duration that allows to control the level of conservatism in the solutions, without the need to assume a given distribution for these random parameters. In the hospital at hand, while the administration objective is to schedule in a way that promoted equity on access and use of the OR, it was verified that surgeons are a powerful political force in the hospital, and due to ‘lack of memory’, they usually schedule recent patients based on memory, unintentionally disregarding longer waiting time patients. When comparing the results of the three versions developed with the hospital current practice, the one for surgeons is the closest to the current scheduling in the hospital. For the instances tested, both deterministic and robust approaches solved show very good optimisation gaps within short computational time. Overall, the main drawback of this study regards the inclusion of the OR with upstream and/or downstream facilities, which limits the scope of the study by not considering resource consumption patterns.

(Riise et al., 2016) – The authors developed an optimisation model for a generalised operational surgery scheduling problem, to efficiently schedule elective patients at an operational level. Besides maximizing the number of surgeries scheduled, overtime and a scheduling rule (‘children early objective’) are also embedded in the objective function, via linear combination of objective components with given weights. The model relies on time-windows constraints and resource related constraints. To search for efficient solutions, the authors developed a general-purpose metaheuristic. The main drawback of this model concerns uncertainty on activities durations. According to the authors, the hospitals have a pragmatic approach on this issue; they treat activity durations as deterministic, although may add some slack to hedge for unforeseen delays.
(Spratt & Kozan, 2016) – This case study relates to both a master surgical case problem and a surgical case assignment problem in Australia. The authors attempt to manage and reduce the hospital waiting list by maximizing the number of surgeries scheduled during the planning horizon, while considering several constraints regarding both Australian policy and hospital resources capacity. The formulation of the problem is done by mixed integer non-linear programming and solved using a variety of hybrid metaheuristics, since any of the commercial solvers tested were able to cope with the size of the instances and the complexity of the problem. This approach could find good feasible solutions in reasonable computational time. The authors also consider stochastic surgery durations to produce more robust schedules and reduce unexpected overtime. Limitations to the proposed model include the incorporation of length of stay, emergency arrivals, and capacity of downstream wards.

(Addis et al., 2016) – A rolling horizon approach for the patient selection and assignment problem is proposed. At each iteration, short term patient assignment is decided. However, in a look-ahead perspective, a longer planning horizon is considered when looking for the patient selection. The mid-term assignment over the next n-weeks is generated by solving an ILP problem, minimizing a penalty function based on waiting time and tardiness of patients. The model also considers surgery duration and new patient arrivals to the waiting list as uncertainty sources. Overall, the proposed approach provides both an a priori schedule and reschedule, thus it not only limits the number of cancellations, but also allows to deal with cancelled patients. However, resource availabilities from upstream and downstream facilities are not considered, which may affect patients’ throughput if a bottleneck appears outside the OR unit.

(Duma & Aringhieri, 2015) – A hybrid simulation-optimization model is proposed to solve the real-time management operating room problem. A discrete event simulation is developed to analyse the discrete and stochastic workflow. The model jointly considers the advance and allocation scheduling of patients. It assigns patients to a date and an OR with a greedy construction of an initial solution and then a local search is used to improve that solution. Sequencing is performed based on waiting time, priority level and probability of cancellation or overtime. An online approach is considered to supervise and execute that schedule, in case of delays, to take more rational decisions regarding the surgery cancellation or the overtime assignment.

(Aringhieri et al., 2015) – The authors propose a two-level metaheuristic to solve jointly the tactical (master surgical schedule) and operational (advance schedule) problem. The assignment of patients to OR block times is based both on patient waiting time and urgency (prioritization algorithm). The objective of the proposed ILP model is to minimize the total cost of all patients waiting time at the end of the planning horizon, thus increasing both patient and hospital utility. The two-stage metaheuristic solution approach is based on tabu search methodology. It uses a greedy constructive heuristic to build an initial solution from which a basic search procedure is launched. The basic search explores different neighbourhoods to search for improved solutions until some stopping criterion is satisfied. Results show good quality solutions in reasonable computational time. The main drawbacks, however, concern
the flexibility when reacting to uncertainties, as well as not including the OR with the recovery room, limiting the visibility of resource consumption patterns.

(Addis et al., 2014) – The authors propose a robust optimization approach considering waiting time, urgency and patient due date, as well as stochasticity of surgery durations to solve the advance scheduling problem. The problem aims at minimizing a measure of the waiting time of patients. To accomplish that, the authors introduce a penalty function associated to waiting time, urgency and tardiness of patients. The main advantage from this approach is translated by the flexibility in tuning parameters value, which allows choosing the level of risk accepted for the solutions robustness.

(Lamiri et al., 2008) – A stochastic model for operating room planning with competing (emergency and elective) patients is developed. To schedule the elective cases, a linear programming model is proposed; then Monte Carlo simulation is used to generate sufficient samples of emergency capacity requirement for each period to perform emergency surgeries. A solution method combining the Monte Carlo simulation and mixed integer programming is proposed to minimise patient related costs and overtime costs of operating rooms. This approach is suitable for hospitals using a block scheduling system, which reserve OR time blocks to surgical specialties. The authors state various issues to be further addressed for real-life application of their approach. First, to represent simultaneously hospital costs, surgeons’ preferences and several other characteristics, the authors point out the need to set costs related to elective patients. Given the extension of the model and complexity of the problem, for large-scale problems the optimization method may need improvements. The validity of this approach may be questionable since surgical times are considered deterministic.

(Santibáñez et al., 2007) – The authors study the effects of resource rationalization on surgery wait list management. They developed an integer programming model to schedule surgical blocks for each surgical group into ORs, considering compatibility, availability, block capacity, and post-surgical resources constraints. The results gave promising insights, showing that without increasing post-surgical resources, hospitals could handle more cases by scheduling specialties differently.

(Arenas et al., 2002) – With a goal programming model, the authors attempt to minimize hospital patient waiting time to 6 months, while minimizing the extraordinary activities (OR overtime and patient transfers). The authors claim that by using goal programming to analyse both objectives, they can assist decision makers to see relationships among complex data and multiple variables, while establishing their objectives via a single objective; however, the quality of the solutions depend on the parameters settled by decision-makers, which might not translate the set forth goals.

Levelled resources in the surgical suite

(Aringhieri et al., 2015) – The authors propose a binary linear programming model to deal with the surgical case scheduling problem. In this study, elective patients are assigned to a date and an OR; and the planning decisions must satisfy resource constraints, such as number of ward stay beds (ORs and post-surgery) for each specialty and day (system bottleneck). The authors exploit a variable neighbourhood search procedure as a solution approach, claiming that the inherent flexibility of this
methodology is suitable to provide a general solution framework, easily adapted to the different operative context and settings.

(van Essen et al., 2014) – Case study in a Netherlands public hospital. The authors develop a model that produces a tactical schedule (master surgery schedule) to minimize the number of required beds. Two approaches were modelled and tested; both simulated annealing and integer linear programming (ILP). ILP performed best to achieve the objective function, reducing the number of required beds in 20% on some instances tested. The main limitation of this study is not considering the stochastic nature of the emergency patients’ arrivals, competing for beds. Also, the authors don’t take the available capacity at the ward when minimizing the number of required beds. This would be an interesting approach, since the number of required beds do not need to be minimized further than the available bed capacity at the wards.

(Beliën et al., 2009) – In this case study, the authors develop a decision support system to assist decision-makers constructing a surgery master schedule, considering levelled resulting bed occupancy. The authors rely on mixed integer programming techniques for the optimization model. Given the complex nature of the problem, to search for good solutions a simulated annealing metaheuristic was tailored. The main advantage is to give OR managers important insights into the opportunities or limits with respect to the master OR schedule. However, the system is built upon deterministic data, thus not considers uncertainty on activities.

(Beliën & Demeulemeester, 2007) – The authors focus on minimizing the total expected bed shortage in a public hospital; and compare a metaheuristic approach with an ILP model. The objective is to build a cyclic master surgery schedule for which resulting bed occupancy is levelled as much as possible. The results show that the metaheuristic approach provides the best output.

(Vanberkel & Blake, 2007) – A discrete event simulation model is proposed to: maximize throughput with fixed resources; determine the effects of process bottlenecks; and develop a plan to achieve the waiting time standards set forth by professional healthcare societies. The results show that long waiting times are more dependent on beds than available OR time. Furthermore, the study also highlights that OR time is better utilized if allotment is made based on surgeon demand, instead of historically means of equality among surgeons.

(Beliën et al., 2006) – The authors develop a visualisation system to facilitate the detection of resource conflicts. The model has been extensively used in the hospital at study; and was considered promising as a decision support consultant when shaping the master surgery schedule. Furthermore, the authors claim advantage of the system to assist during the master schedule bargaining process (between managers and surgeon’s), and to persuade hospital managers to invest extra resource capacity.

(Guinet & Chaabane, 2003) – In this study, a primal-dual heuristic based on an extension of the Hungarian algorithm is proposed to assign patient interventions to the operating rooms on a medium-term horizon. By using resource capacity and time windows constraints (release and due date), the authors claim that the decision tool could integrate bed availability, which can define a bottleneck resource when interventions are postponed.
## Variability in hospitals

**Litvak & Long, 2000** – A variability-based methodology is proposed to determine the threshold at which cost reduction negatively impacts quality in healthcare. In this study, the authors consider variability as the universal key to constrain hospitals from providing the best care at the lowest cost. This research indicates an additional source of admission and occupancy variability, previously unconsidered - the OR. The authors conclude that a sizeable portion of that variability is introduced into the system by the advance elective surgical scheduling process. Moreover, this artificial variability can and must be removed by producing an effective advance schedule (one that minimizes cancellation rates and overtime, attends to surgeons’ preferences, etc.).

## Uncertainty

**Wright & Kooperberg, 1996** – In this study, the authors compare the surgeons time estimates for elective cases with those of commercial scheduling software and ascertain whether improvements can be made by regression modelling. They conclude that surgeons provide more accurate estimates than the scheduling software; and credit this fact to the lack of specificity of Current Procedural Terminology (CPT) coding in the prediction software in-house coding scheme.

**Denton et al., 2007** – The authors develop a stochastic optimization model to compute OR schedules that hedge against uncertainty in surgery durations. The objective is to minimize the weighted sum of expectation of waiting, idling, and tardiness. Due to the complex combinatorial nature of the problem (NP-hard), the authors constructed three different practical heuristics to search for efficient solutions. The results indicate that the common practice of scheduling longer and more complex cases earlier in the day schedule may have a significant negative impact on OR performance measures;

**Addis et al., 2015** – The authors use a cardinality-constrained model application to healthcare management. The use of robust optimisation is suitable to handle OR uncertainty (surgical time duration, length of stay, arrival rates) because it allows to consider a trade-off between the level of robustness and the cost of the solution. Moreover, the cardinality constrained approach does not rely on a detailed description of the uncertainty.
### Appendix B – OR Planning and Scheduling Literature Classification Scheme

<table>
<thead>
<tr>
<th>Patient charact</th>
<th>Delineation of decision</th>
<th>Uncer. Incorpor.</th>
<th>Performance measures</th>
<th>Model Formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>α1</td>
<td>β1</td>
<td>β2</td>
<td>β3</td>
</tr>
<tr>
<td>(Wright &amp; Kooperberg, 1996)</td>
<td>E</td>
<td>Surg</td>
<td>Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Dexter, et al, 1999)</td>
<td>E</td>
<td>Surg</td>
<td>Hour; Cap</td>
<td>Iso</td>
</tr>
<tr>
<td>(Ozkarahman, 2000)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>(Litvak &amp; Long, 2000)</td>
<td>E</td>
<td>Hosp</td>
<td>Other</td>
<td>Inc</td>
</tr>
<tr>
<td>(Blake et al., 2002)</td>
<td>E</td>
<td>Surg</td>
<td>Hosp</td>
<td>OR</td>
</tr>
<tr>
<td>(Blake et al., 2002)</td>
<td>E</td>
<td>Surg</td>
<td>OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Dexter &amp; Traub, 2002)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Arenas et al., 2002)</td>
<td>E</td>
<td>Hosp; Pat</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Plasters et al., 2003)</td>
<td>E</td>
<td>Disc; Surg</td>
<td>Hour; OR; Other</td>
<td>Iso</td>
</tr>
<tr>
<td>(McCord, 2003)</td>
<td>E</td>
<td>Disc; Surg</td>
<td>Other</td>
<td>Iso</td>
</tr>
<tr>
<td>(Guinet &amp; Chaabane, 2003)</td>
<td>E</td>
<td>Pat; Disc</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>(Tyler et al., 2003)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Beliën et al., 2006)</td>
<td>E</td>
<td>Surg; Other</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>(Denton et al. 2007)</td>
<td>E</td>
<td>Surg; Pat</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Santibañez et al. 2007)</td>
<td>E</td>
<td>Surg</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>(Beliën &amp; Demeulemeester, 2007)</td>
<td>E</td>
<td>Pat; Hosp</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>(Vanberkel &amp; Blake, 2007)</td>
<td>E; NE</td>
<td>Pat; Hosp</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>(Fowler et al., 2008)</td>
<td>E</td>
<td>Disc; Surg</td>
<td>Other</td>
<td>Iso</td>
</tr>
<tr>
<td>(Lamiri et al., 2008)</td>
<td>E; NE</td>
<td>Pat</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>(Fei et al., 2009)</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>(Testi &amp; Tànfani, 2009)</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Study</td>
<td>Type</td>
<td>Date; OR</td>
<td>Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>------</td>
<td>----------</td>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>Beliën et al., 2009</td>
<td>E</td>
<td>Surg; Hosp</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>Roland et al., 2010</td>
<td>E</td>
<td>Surg; Disc</td>
<td>Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Roland &amp; Riane, 2011</td>
<td>E</td>
<td>Surg; Pat</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>van Essen et al., 2012</td>
<td>E</td>
<td>Surg; Disc</td>
<td>Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Marques et al., 2012</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Sperandio et al., 2014</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>van Essen et al., 2014</td>
<td>E</td>
<td>Hosp</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>Marques et al., 2014b</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Marques et al., 2014a</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Addis et al., 2014</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>Marques &amp; Captivo, 2015</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Castro &amp; Marques, 2015</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Aringhieri et al., 2015</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>Aringhieri et al., 2015</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Inc</td>
</tr>
<tr>
<td>Duma &amp; Aringhieri, 2015</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>Riise et al., 2016</td>
<td>E</td>
<td>Pat</td>
<td>Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>Lim et al., 2016</td>
<td>E</td>
<td>Disc</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Spratt &amp; Kozan, 2016</td>
<td>E</td>
<td>Pat; Surg</td>
<td>Date; OR; Hour</td>
<td>Inc</td>
</tr>
<tr>
<td>Landa et al., 2016</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>Luo et al., 2016</td>
<td>E</td>
<td>Pat; Surg</td>
<td>OR; Hour</td>
<td>Iso</td>
</tr>
<tr>
<td>Addis et al., 2016</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Iso</td>
</tr>
<tr>
<td>Marques &amp; Captivo, 2017</td>
<td>E</td>
<td>Pat</td>
<td>Date; OR</td>
<td>Other</td>
</tr>
</tbody>
</table>
### Appendix C – Research Methodology Considering Surgeon’s Welfare

<table>
<thead>
<tr>
<th>Study</th>
<th>Welfare Measure</th>
<th>Data Collection Method(s)</th>
<th>Preference Formulation</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Marques &amp; Captivo, 2017)</td>
<td>Balance administration (equity on access) and surgeons’ interests (sequencing decisions)</td>
<td>Historical records (50,659 surgeries performed by 180 surgeons)</td>
<td>Two assignment models in mixed integer linear programming, one for each half-day, according to each preference</td>
<td>The study was not implemented at the hospital, due to resistance to change from the perioperative staff, and influence power of surgeons</td>
</tr>
<tr>
<td>(Van Essen et al., 2012)</td>
<td>Minimize overtime; and assignment of surgeon OR time only to the surgical procedure (excluding anaesthesia and OR disinfection)</td>
<td>Survey performed at the Isala Clinics; and key informant interviews</td>
<td>Integer linear programming model. Data collected enabled the authors to assess penalty costs for dissatisfaction, whereas the objective is to minimize the deviation from surgeon’s welfare</td>
<td>Implemented in practice, the authors have determined that the given preferences to the re-scheduling problem leads to: 1) shift a surgery; 2) scheduling a break between surgeries</td>
</tr>
<tr>
<td>(Roland &amp; Riane, 2011)</td>
<td>Maximize surgeon’s assignment to work over each preferred half-day</td>
<td>Hospital records (one year). However, the dataset does not mention disutility as the authors do</td>
<td>Four mixed integer formulations. They differ on if and how surgeons’ preferences are considered. Preferences are weighted by a disutility function that penalises failure to respect them. Finally, they bring cooperation into the planning</td>
<td>The four models were validated through a real-life application which proved to be robust, as the way preferences were modelled had few impact on the computational times or best lower bounds</td>
</tr>
<tr>
<td>(Roland et al., 2010)</td>
<td>Each surgeon can declare his preferred agenda to perform surgery</td>
<td>Data recorded from a Belgian Hospital</td>
<td>Mixed integer programming for small instances, and genetic algorithm</td>
<td>By adding the welfare objective, the exact approach becomes unusable</td>
</tr>
<tr>
<td>Source</td>
<td>Goal</td>
<td>Data</td>
<td>Method</td>
<td>Case Study</td>
</tr>
<tr>
<td>--------</td>
<td>------</td>
<td>------</td>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>(Belien et al., 2009)</td>
<td>Minimize OR sharing between different surgeons’ groups</td>
<td>Input data derived from the hospital’s central database. However, it’s not clear if the surgeon’s welfare measure was obtained either from contact with surgeons or OR managers</td>
<td>The goal is accomplished by adding to the model a penalty term in the objective function that penalises OR-sharing between different surgeon’s groups</td>
<td>Case study in a medium-sized Belgium hospital. As a DSS, enables managers to answer relevant questions (e.g. to what extent can surgeons be assigned OR’s with same specialty colleagues?)</td>
</tr>
<tr>
<td>(Testi &amp; Tànfani, 2009)</td>
<td>Surgeons defined daily availabilities</td>
<td>Hospital records (400 patients in the waiting list). Each case characteristics is obtained by the surgeon’s clinical judgments registered on the electronic waiting list</td>
<td>Prioritization algorithm. By using a variable pre-processing before running the model, they assure schedules ruled by surgeons defined availabilities</td>
<td>The model was applied to a real case study, and successfully solved for all test problems with a time limit of 600 seconds and an average tolerance of less than 0.01%.</td>
</tr>
<tr>
<td>(Belien et al., 2006)</td>
<td>Facilitate the negotiation for OR planning decisions with surgeons</td>
<td>Historical records from the university hospital Gasthuisberh</td>
<td>Underlying model based on project scheduling. With a custom graphical user interface, the DSS enables stakeholders seeing the schedule consumption patterns</td>
<td>The model is viewed as a good alternative to effectively produce master surgery schedules, while improving resource rationalization</td>
</tr>
<tr>
<td>(Plasters et al., 2003)</td>
<td>Impacts on coordination between</td>
<td>Observation (2 observer collected about 24h dataset)</td>
<td>With the data collected, the team develop a</td>
<td>The methodology applied enabled the authors to 1)</td>
</tr>
</tbody>
</table>

otherwise. Models surgeons availabilities in half-days, where each personal availability is defined by a binary matrix in practice, thus the use of genetic algorithm is justified.
<table>
<thead>
<tr>
<th>Stakeholders at the surgical suite</th>
<th>CIT; and key informant interviews</th>
<th>Preliminary information flow map, from which they developed a taxonomy of coordination challenges (grouped accordingly to the major components of the perioperative process)</th>
<th>Analyse the components disrupting the coordination; 2) the root causes of the disruptions; 3) and the methods of coping with the limitations (e.g. 1) personal preferences; 2) inability to act professionally; 3) sensitive management).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blake et al., 2002</td>
<td>Produce an equitable master surgical schedule among specialties, as well as simple (repetitive)</td>
<td>Mount Sinai Records; and informal meetings (iterative process)</td>
<td>By using integer programming, the authors devise a method for equitably dividing OR time. Furthermore, to ensure both surgeons’ and managers’ satisfaction a custom heuristic is developed to guarantee solutions with simple schedules. The model was implemented at the hospital of study. Moreover, the hospital managers have stated that the political manoeuvring has reduced, since surgeons no longer question the fairness of the calculations or the method used to allocate time.</td>
</tr>
<tr>
<td>Blake et al., 2002</td>
<td>Equitable distribution of OR time among the five surgery groups</td>
<td>Historical records from the Mount Sinai hospital</td>
<td>Integer programming model, that minimizes the deviation between OR time allocated and targeted for each surgical group. The model was implemented at the hospital and eleven schedules have been developed with this methodology (mean schedule accuracy of 99.7%).</td>
</tr>
<tr>
<td>Ozkarahan, 2000</td>
<td>Each specialty defines the</td>
<td>Historical records from hospital</td>
<td>Goal programming model. The model solution compared with the</td>
</tr>
<tr>
<td>Importance of its surgeries</td>
<td>Preference objective is achieved by minimizing the difference between the sum of weights of scheduled surgeries and listed surgeries</td>
<td>Hospital previous schedule, the hypothesis test on the equality of sample means revealed that the hospital’s heuristic generated up two more hours of distortion, thus proving its inferiority</td>
<td></td>
</tr>
</tbody>
</table>