Operating Room Planning and Scheduling of Elective Patients

Introducing Surgeon's Preferences into the Decision Process

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Abstract

The goal of National Health Services is to maximise the quality of treatment, increase the services efficiency, while lowering the cost of operations; and to that end, operations research has found in the domain of healthcare an opportunity to aid on the fulfilment of healthcare managers objectives, exploring multiple approaches, and proposing several mathematical and simulation models.

This dissertation focusses with the operating theatre planning and scheduling. We propose and apply a comprehensive Multi-Methodology to structure elective surgery planning activities at a Portuguese hospital, Centro Hospitalar Lisboa Norte, from stakeholder's experience; based in a relaxed version of Soft Systems Methods and Process Mapping.

Applying the first part of the Multi-Methodology, the case study begins with semi structured interviews to collect data from several specialists and make sense of their routines. Then, to map stakeholder preferences, we design Rich Picture models, CATWOE, and root definitions over hospital's scheduling activities. Consequently, we model surgeons scheduling decisions, resorting to process mapping. Finally, once conceptualising the scheduling activities at the hospital, according to key stakeholder's views, we validate our findings in contrast with operating room planning and scheduling literature.

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 its elective activity is actively conflicting with their objectives. We think that mathematical models, embedded into decision support systems, could improve surgeons elective scheduling. Furthermore, we discuss upon the mistakes of disengaging stakeholders from the decision-process.

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

1. Introduction

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 and Guido, 2011); and one of the main cost drivers in a hospital, as

well as traditionally underutilized (Magerlein and Martin, 1978), implicitly meaning that efficient OR management can both reduce costs and increase revenues for hospitals.

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 and Guido, 2011). Although authors adjust and tailor models to hospitals of study, we see that part of their contributions are often assumption-based, since in many cases, there is no mention of a formal methodology used to include key stakeholders. Therefore, this study aims to apply a solid approach for data collection, mapping, and analysis 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, hence avoiding resistance and delayed implementation.

2. Literature Review

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). Cardoen et al. (2010) developed a classification scheme based in descriptive fields. According to the authors, the OR planning and scheduling literature has several distinguishing characteristics that hinders the process of structuring studies appropriately, and therefore propose a way to structure studies, which we adopt in this work, by clustering descriptive fields: Patients characteristics; Delineation of Decision; Uncertainty; and Performance measures.

Usually patients are grouped into two classes, elective and non-elective .The first class includes patients in a non-urgent condition, for whom surgery can be scheduled in advance; whereas in the second patients group need surgery unexpectedly, and thus it is necessary to schedule in short notice (Samudra *et al.*, 2016). Furthermore, some studies further distinguish between inpatient and outpatient surgery. Inpatients refer to hospitalized patients who must stay overnight, whereas outpatients typically enter and leave the hospital on the same day (Cardoen, Demeulemeester and Belien, 2008). Furthermore, outpatient surgery often consists of more standardized procedures (e.g., routine surgeries, minimally invasive procedures). 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): Surgeries duration, resource availability, and cancellations or arrivals

of emergency care patients. 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.

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 to 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. 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 and Captivo, 2015).

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.

3. Methodology

As a starting point to build this project, we chose two OR stakeholder (surgeon and hospital manager) groups to liaise with, in which we assume they collectively detain a large portion of power onto the OR planning and scheduling

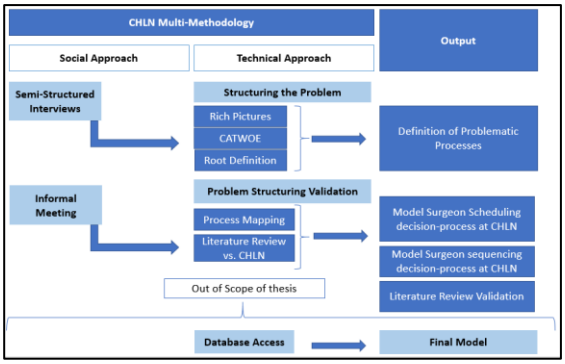

Figure 1 - Multi-Methodology

processes.

To meet the mentioned objectives, a Multi-Methodology composed by different techniques that complement themselves was built and is presented in Fig.1. It follows a social-technical approach. 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.

3.1 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, which are vital to assess if stakeholder are motivated to use scheduling models, and if their routines can translate into models.

In total, we interviewed 28 OR stakeholders: 20 surgeons, 5 surgeon interns, 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).

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. 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, we explored with surgeon specialists and interns the multiple criteria that can directly affect schedules at CHLN, and how surgeons hedge against these variables.

3.2 Structuring the Problem

Centro Hospitalar Lisboa Norte (CHLN) is the result between the merger of *Hospital de Santa Maria* (SM) and *Hospital Pulido Valente* (PV). PV has centralized CHLN outpatient surgeries activity in its Operating Theatre, containing 6 ORs. In the other hand, SM Central OR, predominantly is used to handle inpatient surgeries, within six ORs, out of the eight available. The other two ORs are exclusively used for urgent cases.

At CHLN, the Central OR's are 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. On the other hand, the department manager must distribute the OR time available to each specialist, per time horizon, after clearing by the OR manager, given the available resources – nurses (instruments, anaesthetist and circulant), anaesthetists, and auxiliary staff. Then, each surgeon specialist proceeds to select the patients to operate for is next period, assisted by the hospital information system.

After the interviews, the first Rich Picture (RP) model was build. The RP attempts to capture the CHLN system, see Fig. 2.

Furthermore, we identify and design RP's for the three decision levels commonly referred in literature: Strategic, Tactical, and Operational.

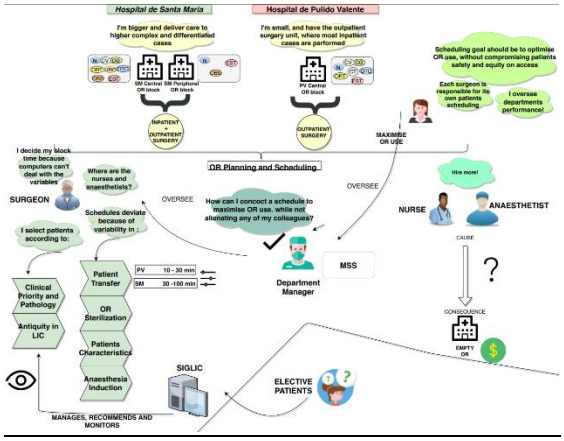

Figure 2: First Rich Picture Model of CHLN

3.3 Problem Structuring Validation

Following the structuring phase, we validate the interviews results with the OR manager in one meeting; where we detail our findings and showed the several designed RP's and tables constructed organizing data. Seeing the RP, the OR manager started immediately to comment on missing details, correcting and validating data from what we showed. This phase has enabled us to move on, overlooking on another meeting with stakeholders to validate our models. Furthermore, after discussing with the OR manager, we found appropriate to concentrate our study on the surgeon specialist's activity, i.e., the advance and allocation schedule, because: 1) The information was more reliable to address this phase, since the data was provided by the ones who own the processes and are culturally a surgeon-oriented non-systematic activity; and 2) interviews show that surgeons do not rely in decision support models and are not aware over their capabilities.

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 of defining the variability of schedules in selecting each patient. The several decisions specialists regard relevant when defining schedules for inpatient and outpatient surgery are discussed and mapped with flowcharts in the following sections.

3.3.1 Advance Schedule

At CHLN, each week surgeon specialists must define the surgeries they plan to perform in the next planning horizon, i.e. week. 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. 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 – maximize OR use. 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 specialist to maximise OR utilisation, without being considered as a scheduling discrepancy.

The specialist 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 vary. In our work, we have clustered sources of variability affecting schedules into: 1) Resource availability; 2) Patients characteristics; and 3) Non-operative times. Then, we model the decision steps surgeons from various specialties are required to follow to consider all the variables affecting the advance schedule. Fig. 3 shows the decision process as it is performed at CHLN, tacitly in the heads of each specialist.

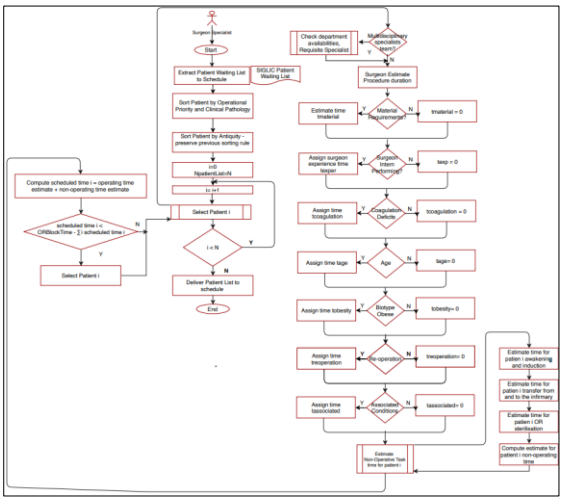

Figure 3: Surgeon Advance Schedule Decision Process

3.3.2 Allocation Schedule

In CHLN, the allocation schedule consists on the definition of surgery start time to each scheduled patient. On surgery day, the specialist must decide the order to operate his patients. According to the interviews, criteria varies.

Surgeons enumerated the criteria they regard relevant when deciding which patients to address first in a given day. The majority, for inpatient and outpatient surgery, operates on longer case first rule, because of 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.

In addition, patients with certain associated conditions have priority to be scheduled first in the day, e.g. patients with diabetes, given the glycaemic control required versus fasting before surgery. Moreover, 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; and a specialist from General Surgery stated that patients with contagious pathologies are usually scheduled for last, as a precaution, even though there is virtually no risk of contamination.

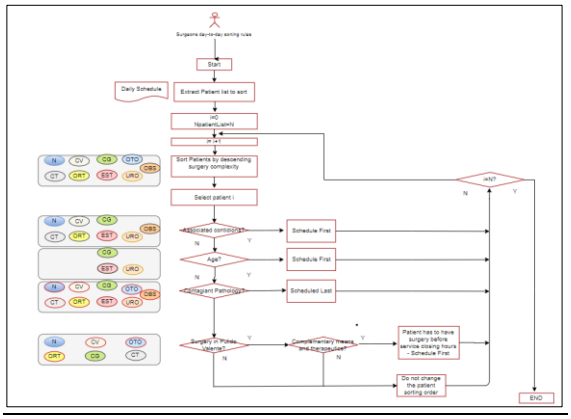

Figure 4: Surgeon Allocation Schedule Decision Process

3.4. Synthesis of Results CHLN

The results of interviewing surgeons, specialists and interns, and hospital managers has led us to to model the activity owned by each surgeon specialist, who together with the hospital information system in place (SIGLIC), selects eligible patients to deliver care on each week.

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.

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 contester of efficient scheduling according to surgeon's predictions; and surgeons make different estimates for this tasks at CHLN, see fig. 4.

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. Surgeons must select patients to schedule, by looking at resource constraints, as well as considering infirmaries throughput (patient's length of stay). Since each surgeon specialist 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, by measuring the processing times required for each surgeon per procedure - median and average time a surgeon takes to operate certain 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, which is not easily transferable. We think that it is appropriate to cluster duration parameter to insert into models by 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 redesign 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 assign estimates 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 understood 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 stakeholder's 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.

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. Surgeons desire flexibility on surgery day to sort patients according to their preferences.

However, last time changes must be penalised;

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

4. Conclusions and Future work

Throughout this work, 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 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 surgery scheduling problems.

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Service	Standardised Procedure	Surgeon Experience	Materials	Accurate Diagnose	Coagulation Deficits	Age	Obesity	Reoperation	Associated Conditions	Anaesthesia Induction	Patient Transfer	OR sterilisation
CG	X	X	X	X	X	X	X	X	X	X	X	X
OBS	X		X	N/A			X	X	X	X	X	X
ORT	X	X	X	N/A	X		X	X	X	X	X	X
EST	X	X	X	N/A	X			X	X	X	X	X
OTO	X	X	X	N/A	X			X	X	X	X	X
URO	X		X	N/A	X	X	X	X	X	X	X	X
CT	X		X	N/A				X	X	X	X	X
N	X	X	X	N/A				X	X	X	X	X
CV			X	N/A	X			X	N/A	X	X	X

Figure 5: CHLN variability criteria in the Advance Schedule N/A = [Not discussed with specialists – No comment]

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

Figure 6: Surgeons actual estimates used at CHLN for non-surgical activities [N/A = Urology Service does not operate in PV]

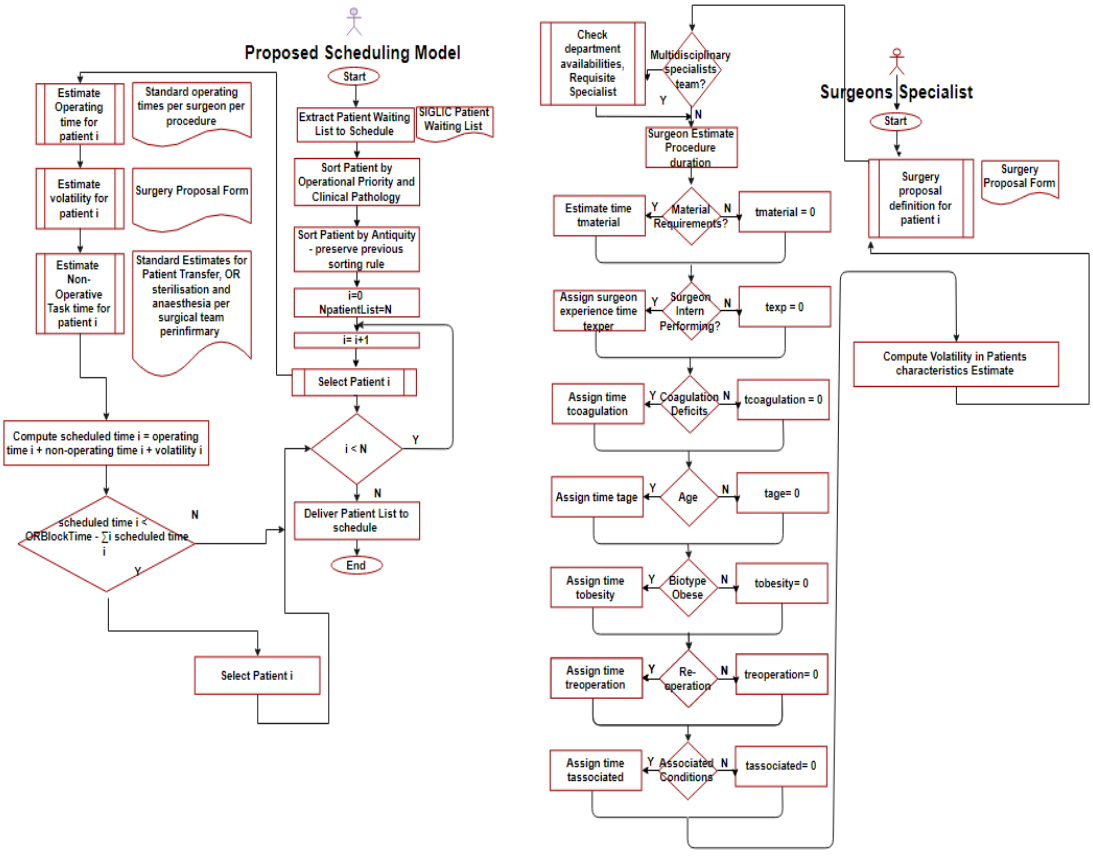

Figure 7: CHLN Advance Schedule Proposed Model