MASTER

Reliable and acceptable planning of elective patients for general surgery on the day of diagnosis

Goedhart, C.E.

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Reliable and Acceptable Planning of Elective Patients for General Surgery on the Day of Diagnosis

by
C.E. Goedhart

BSc Carlijn Goedhart
Student identity number: 0637176

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Supervisors:
dr.ir. N.P. Dellaert, TU/e, OPAC
dr.ir. I.T.P. Vanderfeesten, TU/e, IS
J.G. Huldman, Radboudumc

TUE. School of Industrial Engineering
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Abstract

In this report an approach is developed for patient surgery date allocation (PSDA) right after patients are diagnosed, based on a case study performed at the general surgery department of the Radboud university medical center. The aim was to design a planning method for PSDA on the day of diagnosis, while limiting the number of operation cancellations (reliability); operating patients within their urgency period (acceptability) and limiting operating room (OR) overtime. In the first phase, a descriptive research was performed to identify the changes that will be needed in the planning process and method. In the second phase, useful planning concepts from literature were used to develop six steps for PSDA, in which an innovative way of flexible block scheduling was applied. In the third phase, a simulation model was developed in order to analyze how different modifications of the planning method affect the planning performance. These modifications included (1) five variations of admission and cancellation rules, (2) four block scheduling strategies, (3) two variations of patient sequencing within the same registration day, (4) a Master Surgery Schedule modification, (5) OR flexibility of patients filling empty OR time slots, and (6) a reduced waiting list. The approach led to substantial performance improvements compared to the actual, validated scenario. Most significant improvements were an increased reliable and acceptable PSDA (from 53% to 80%) and an increase of overall acceptability (from 64% to 92%), mainly caused by waiting list reduction.

Preface and Acknowledgements

This report is a result of my graduation project that has been conducted at the general surgery department of Radboud university medical center Nijmegen in completion of the master Operations Management and Logistics at Eindhoven University of Technology. I am very thankful Radboudumc gave me this opportunity.
The project was initiated in the summer of 2012 by Robert Opsteeg, head of the Radboudumc general surgery department at that time. Since this 'patient logistics related assignment' took my great interest, I already applied for the project during my international semester at Boğaziçi University in Istanbul, autumn 2012. During the first meeting at the Radboudumc in February 2013 the exact assignment became more apparent: giving patients a surgery date right after the decision is made that operating is necessary, instead of giving a date only one week prior to the actual surgery. From the start of the project, I was enthusiastic about the topic, since it is highly related to my ambition to improve healthcare processes, especially for patients.

I would like to thank all people that made this project possible. However, I want to mention some people in particular. Firstly, I would like to thank my first supervisor Nico Dellaert. You gave me valuable planning insights and always made time to discuss one of my questions. Secondly, I would like to thank my second supervisor Irene Vanderfeesten. You gave me new insights in the field of simulation and gave me detailed feedback in the end phase of my graduation project.

Furthermore I would like to thank James Huldman from the Radboudumc for getting familiar with all activities taking place at the planning office, and in general at the general surgery department. You provided me with all planning information or referred me to right people to acquire this data. I would like to thank Bart van Acker from the department Procesverbetering & Innovatie for his detailed explanation of hospital data and his feedback on my simulation model during the project. I would like to thank surgeons Vincent Leferink and Han Bonenkamp for the conversations we had about the practical relevance and consequences of my project. Last, but not least I would like to thank the planners at the planning office; Diana, Esther, Frits and Maria. You gave me all valuable operation planning information which I never would have obtained from hospital data solely.

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Carlijn Goedhart

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Summary

Background

Comprehensive developments in healthcare indicate the need for efficiency. Specifically, planning of operations is essential since operating rooms (OR's) are important resources within hospitals. An upcoming service concept is giving patients a surgery date right after they are diagnosed, instead of one week prior to the operation. A case study is performed at the planning office of the general surgery (GS) department of Radboudumc Nijmegen, in order to analyze this service concept in practice. Four sub departments are distinguished: abdominal & oncology surgery (aos), trauma surgery (trs), vascular & transplantation surgery (vts) and child surgery (chs). For each of them, time blocks are reserved on a six weeks cyclic OR scheme or Master Surgery Schedule (MSS). In the current situation, planners communicate the surgery date to the patient after the final OR program of next week is approved during the workplace management (WPM) meeting.

Research Question and Objective

The main problem at the GS department is patient dissatisfaction about the time period of the surgery date announcement, caused by last-minute changes in the OR program, unclear and conflicting information about the (expected) surgery date, and exceeding the patient urgency period. The following research question is defined: *In which way should the planning be designed to give the elective patient for general surgery a reliable and acceptable surgery date on the day of diagnosis?* The main objective is to enable the GS department to give patients a surgery date on the day of diagnosis. Further, the aim is to limit the number of operation cancellations (reliability), to operate patients within their urgency period (acceptability) and to limit the number of OR overtime hours. As a result, the overall aim is to develop a planning method which meets these requirements. The research is focused on the tactical and operational level of planning. The planning of elective and day surgery (DS) patients, availability of GS surgeons, the MSS and last-minute cancellations due to OR overtime fall within the scope. The planning of urgent and semi-elective patients, preoperative screening (POS), OR teams, instrumental resources, beds and cancellations due to absenteeism fall beyond the scope.

Method

A preliminary research is performed to answer the following sub questions: *In which way should the planning process - and planning method be designed?* Regarding the planning process, it turned out that the following two changes are needed: Firstly, it is needed to introduce an earliest operating period (EOP) in which necessary tests for surgery can be executed. Accordingly, the planning window is defined as the time between the EOP and the patient urgency period. Secondly, during the WPM it is needed to restrict surgery modifications to the allocated surgery date. Further, several scenarios of surgery date announcement were considered: surgery date allocation at the outpatient department by the surgeon, by the planner, or on the phone by the planner one day *after* the day of diagnosis.
Regarding the planning method, it turned out that the following changes are needed: the removal of the 'patient surgery date allocation waiting list', the introduction of a variable planning horizon and the prohibition of changes in the established surgeon availability, especially once a surgeon is planned. Literature study showed that research goals should be more focused on patient service. None of the studied articles on tactical or operational level aim to give patients a surgery date on the day of diagnosis. However, the literature provided useful planning concepts, which are used to

develop six steps for surgery date allocation: (0) finding out OR and surgeon availability, (1) defining operation groups, (2) checking whether capacity meets demand, (3) reserving time blocks, (4) admitting patients, (5) dealing with surgery cancellations and (6) dealing with discrepancy demand and supply. The last step is important for the innovative way of flexible block scheduling. This includes the identification of low urgency patients who are defined as 'fill patients' to fill empty time slots on the OR program. In case no reserved OR time is left on the OR program, an OR block which is reserved for another operation group is opened to search for less feasible surgery options. Historical quantitative data from the hospital systems Oksimed and Okapi were obtained to follow the steps. Up to step 4, this resulted in operation groups defined on the basis of their use of resources (1) and a MSS supplemented with reservations for operation groups and/or surgeons (3). From the capacity check it turned out that the overall demand fits capacity. However, the aos sub department has a shortage of capacity (2). The remaining steps are implemented in the planning method of a simulation model.

A generic simulation model is developed in Excel 2010. The input exists of the operations with corresponding planning information, the MSS with its block reservations and the two weeks cyclical surgeon availability scheme, including a scheme for all surgeon-operation group combinations. The output exists of performance measures regarding acceptable and reliable patient surgery date allocation (PSDA), overall reliability, overall acceptability and OR performance, which includes OR occupancy and OR overtime. Historical records of patients who needed to be operated after January 1st, 2013, were loaded into the model. The performance is calculated over the period from February 1st, 2013 until September 1st, 2013.
Six modifications of the planning method are defined, which resulted in additional sub questions: *How do(es) (1) the admission and cancellation rules, (2) the four block scheduling strategies, (3) patient sequencing for one registration day, (4) a MSS modification, (5) 'fill patient' OR flexibility and (6) a patient waiting list reduction affect the planning performance?*

Simulation Results

Modifications 1 to 5 are simulated within both the historical patient waiting list and the reduced waiting list (the variations of modification 6). The first modification concerns the admission and cancellation rules. The current admission rule allows planning operations for eight hours. The current cancellation rule specifies that operations are cancelled last-minute when the expected end time of operations exceeds the end time of the OR. Five variations allow some overtime in both rules, by increasing the OR availability with (half) an hour. This resulted in an increased performance on reliability and acceptability, at the expense of some increased weekly OR overtime, for both variations of the waiting list. The highest reliability (96%) is obtained by combining the 'lowest' admission rule and the 'highest' cancellation rule. The biggest relative improvement is obtained by increasing the OR availability during the cancellation rule to 8.5 hours.
The second modification concerns the variation of four block scheduling strategies, in which time blocks are reserved for operation groups and/or surgeons on the MSS. No significant performance effects are found. Therefore, the allocation of feasible surgery options to the operated patients is analyzed. The strategy of reserving blocks according to either operation groups or surgeons showed the same surgery option percentages as the strategy of combining the block reservations.
The third modification concerns patient sequencing. Patients with similar registration dates are sequenced on urgency period, surgery duration and surgeon requirement. Variations in the patient

sequencing modification include the sequencing on longest processing time (LPT) first and shortest processing time (SPT) first regarding the surgery duration sorting. Performance changes are mainly observed within operation groups. The only overall significant performance effect is found in the reduced waiting list: the LPT variant showed an improvement on acceptability.

The fourth modification concerns the MSS modification, which reallocates 32 and 28 hours respectively from trs and chs to the aos sub department. This resulted in an improved performance for aos regarding reliable and acceptable PSDA, reliability, acceptability and (unacceptable) waiting time. The opposite effects are shown for chs, and to a marginal extent for trs. Further, the aos OR occupancy decreased, while the chs and trs OR occupancy increased.

The fifth modification concerns the 'fill patients' OR flexibility, which allows operating 'fill patients' on the OR hours of other sub departments. Generally, this resulted in a higher OR occupancy for aos, vts and chs, whereas the OR occupancy for trs was lowered. For both waiting lists, the unreliability for trs increased when combining the 'fill patients' OR flexibility with the modified MSS.

The sixth modification concerns the patient waiting list reduction, which left out all patients who fell outside their planning window on January 1st, 2013. It showed a high increase in performance regarding reliable and acceptable PSDA (from 52%-60% to 72%-83%) and acceptability (from 62%-70% to 83%-95%). Further, it showed a substantial decrease of the overall (unacceptable) average patient waiting time. The OR occupancy and OR overtime decreased to a small extent.

Conclusions and Implications

From preliminary research, it turned out that an EOP should be introduced. Shifting patients in the OR program during the WPM should be restricted to the surgery date only. It is recommended to start with announcing the surgery date by planners one day *after* the diagnosis. For announcing the surgery date *on* the day of diagnosis, organization changes in the planning process should be considered in more detail. Additionally, last-minute changes in surgeon availability cannot be allowed anymore, especially once a surgeon is planned.

The simulation results showed that the implementation of giving the patient a reliable and acceptable surgery date on the day of diagnosis is only successful by removing the unacceptable waiting list. This is only possible if extra capacity would be temporary created to operate all patients of whom their planning window is expired. Additionally, it is suggested to increase the OR availability during the cancellation rule to 8.5 hours, since the simulation results showed a decreased number of both cancelled operations (reliability) and operations which were performed outside the planning window (acceptability). Further, it is suggested to reserve blocks for both operation groups and surgeons, in a more consistent way than in the current situation. Although the benefits of this strategy are not proven in the simulation, it could make planning easier and more transparent. Additionally, when announcing the surgery date one day *after* the diagnosis, it is useful to order patients on highest urgency and longest surgery duration within the urgency category. Furthermore, it is highly recommended to modify the MSS to balance the demand and supply of each sub department. Although no optimal MSS is obtained, several time blocks from trs and chs should definitely be reallocated to the aos sub department. Finally, the 'fill patients' OR flexibility did not show improvements in combination with the modified MSS.

To end with, a next step could be to develop a planning instrument, in which (most of) these recommendations are implemented. An employee should be appointed to be responsible for the transformation of the simulation model into a planning system for the GS department.

List of Abbreviations

aos	abdominal & oncology surgery
chs	child surgery
CI	Confidence Interval
CV	Coefficient of Variation
DS	Day Surgery
EOP	Earliest Operating Period
EPR	Electronic Patient Record
GS	General Surgery
ICU	Intensive Care Unit
IGZ	*Inspectie voor de Gezondheidszorg* (Health Care Inspectorate)
LPT	Longest Processing Time
MCU	Medium Care Unit
MSS	Master Surgery Schedule
NVvH	*Nederlandse Vereniging voor Heelkunde* (Dutch Association for General Surgery)
OM	Operations Management
OR	Operating Room
POS	Preoperative Screening
PSDA	Patient Surgery Date Allocation
PVI	*Procesverbetering & Innovatie* (Process Improvement & Innovation)
SPT	Shortest Processing Time
SSU	Short Stay Unit
trs	trauma surgery
VBA	Visual Basic for Applications
vts	vascular & transplantation surgery
WPM	*Werkplek Management* (Workplace Management)

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1 Introduction

Healthcare providers have to respond to comprehensive developments in healthcare. The first one depicts demographic change. With the increase in ageing population, demand for healthcare is increasing. Simultaneously, workforce to catch this progress is decreasing, which results in a gap between healthcare supply and demand. Secondly, consumerism results in a pressure to change the patient service delivery. Therefore, patient friendliness is an arising term in healthcare institutions. Thirdly, medical technological development increases the costs of healthcare. Moreover, governments and other healthcare financing agencies require healthcare providers to focus on quality improvement, efficiency and cost reduction (Jeang & Chiang, 2010; Vissers & Beech, 2005; Zelenock & Zambricki, 2001).

Consequently, due to the pressure of improvement caused by the developments in healthcare described above, the drive for efficiency is searched into one of the most important resources within hospitals: the Operating Rooms (OR's). Surgical services involve labor intensive work from surgeons and surgical teams and require expensive equipment and materials. As a result, an OR department typically represents 40% to 75% of most hospital's net operating income (Zelenock & Zambricki, 2001). In addition, the surgical volume is increasing over time. In Dutch hospitals, the average annual growth in surgical volume ranged 0.6% to 5.3% since 2000. As a result, the total average growth in ten years was equal to 31%. This growth is especially caused by the 57% increase of day surgeries (CBS, 2012).

Accordingly, planning and scheduling of patients into OR's is a popular topic in research. Zelenock & Zambricki (2001) mentions the aspect of scheduling as one of the major drivers of patient satisfaction. Further, it is challenging for researchers to get a grip on the variability that is inherent in surgical procedures (Testi, Tanfani, & Torre, 2007). Due to the current healthcare developments, patient service is becoming more important in research as well, such as minimizing patient waiting time rather than only maximizing OR utilization. In practice, Dutch healthcare insurers use more service criteria for awarding healthcare providers with quality labels. An upcoming criterion is giving a surgery date to the patient right after the diagnosis (Menzis, 2013). However, this concept is still hardly implemented as scheduling technique in literature (Vissers, Adan, & Dellaert, 2007) .

The subject of this master thesis is the planning of operations as soon as the diagnosis is communicated with the patient. A case study has been done at the general surgery department of Radboudumc Nijmegen. A description of this research environment is given in the following chapter. In chapter 3, the problem description with its problem analysis, research question, objective and scope is described. In the fourth chapter a literature overview with useful planning concepts is given. In the fifth chapter, the methodology to answer the research question is described. The included preliminary research and the concepts from the literature chapter form the basis for the six steps for surgery date allocation and consecutive data collection and analysis. In the sixth chapter, the simulation model is described, including the model development, configuration, verification, and validation. The seventh chapter includes the several scenarios of the planning method which will be simulated. The results of this simulation are presented in chapter eight. Chapter nine provides the conclusions and recommendations, which will provide an answer to the research question. Finally, the limitations and further research are discussed in chapter ten of this master thesis.

2 Research Environment

This research is performed at the planning office of the general surgery (GS) department of Radboudumc. In the following three sections of this chapter, a description is given of the hospital, the GS department and the activities taking place at the planning office to plan operations.

2.1 Radboudumc

Radboudumc (formerly known as UMC St Radboud) located in Nijmegen is a University Medical Centre which delivers primary care, broad specialty care and tertiary care. Next to (high-specialized) patient care, research and education are important areas for the hospital (Radboudumc, 2013a). On December 31st, 2012, 9,897 employees were working at the hospital. In 2012, there were 953 beds with 61% bed occupancy; 157,450 first visits at the outpatient departments; 31,363 hospitalizations with an average length of stay of 6 days; 53,087 day surgeries; 21,672 visits at the emergency department and 21,481 elective operations (Radboudumc, 2013b).

Radboudumc faces the general developments as mentioned in the introduction. Therefore (since October 2013), the mission of the hospital is to remain at the forefront of the development of innovative, sustainable and payable healthcare. The hospital wants to comply with this mission by delivering good and patient focused care, preventing diseases, and sharing and increasing knowledge. The mission is summarized into the sentence: "To have a significant impact on healthcare" (Radboudumc, 2013c). With respect to patient focused care, Radboudumc signed as first hospital in the Netherlands the Salzburg Statement on Shared Decision Making, in January 2013. The aim of this statement is to call attention to the patient in medical decision making (Radboudumc, 2013d; Salzburg Global Seminar, 2012). As a result, the hospital has to realize this promise to the patient by designing their care processes in a patient friendly way.

2.2 General Surgery Department

At the GS department, patients are treated with surgical affections within four different sub departments; abdominal & oncology surgery (aos), child surgery (chs), trauma surgery (trs) and vascular & transplantation surgery (vts) (Radboudumc, 2013e). Next to the distinction between sub departments, a distinction is made between patient flows; urgent, elective, semi-elective and day surgery patients. The classification in patients will be described in the first sub section. Generally, the different patient flows at the GS department follow the process as presented in Figure 1, which is described in the second sub section. In the third sub section, the OR resource allocation is explained.

2.2.1 Patient Classification

Each sub department has four different patient flows with respect to urgency and hospitalization duration: urgent, elective patients, semi-elective and day surgery (DS) patients. Each patient flow passes through the process in a different way, which is described in the second sub section. Firstly, urgent patients have the highest urgency and have to be treated immediately up until 6 hours after arrival. Urgent patients are operated in emergency OR's, by physicians who are especially planned for urgent patients. Secondly, elective patients are less urgent than the prior patient flow. A distinction is made between four different urgency labels which indicate a patient has to be treated within 2 weeks, within 6 weeks, within 12 weeks or after 12 weeks. Thirdly, semi-elective patients are less urgent than the urgent patients, but more urgent than the elective patients. These patients have to be operated within 24 hours up until one week after arrival. This patient flow is introduced in July 2013, to leave less empty slots in the elective OR program. Since that moment, separate OR hours for semi-elective patients are reserved at the expense of the OR hours for the elective patient flow. All patient flows are operated in the central OR's, except for the last patient flow: the DS patients. This patient flow can be operated in the DS OR, which is a less extended OR compared to the central OR. The DS patients have the same urgency labels as the elective patients. Nearly deterministic surgery durations can be taken into account since these operations are more standard to perform.

Table 1 presents the number of patients operated at the GS department in 2012, sorted by sub department and patient flow. The number of elective and DS patients is obtained from the combined datasheet of the hospital information systems Okapi and Oksimed, which are further described in chapter 5. The sub department for urgent and semi-elective patients is not known from that source. Therefore, the numbers for these patient flows are obtained from other sources. Since the numbers from the table are coming from several information systems, one should be careful with comparing these numbers. In total, about 5,000 GS patients were operated in 2012.

	Urgent	Semi-elective	Elective	Day Surgery	**Total**
aos	322[1]	417[1]	946	696	**2381**
trs	189[2]	119[2]	362	233	**903**
vts	264[1]	413[1]	165	83	**925**
chs	268[1]	344[1]	247	54	**913**
Total	**1043**	**1293**	**1720**	**1066**	**5122**

Table 1: Number of operated GS patients in 2012, sorted by patient flow and sub department

2.2.2 Patient Process

Elective, DS and a part of semi-elective patients run through the process via the outpatient department, preoperative screening (POS) and the preoperative nursing unit to the OR. Urgent patients and the other part of semi-elective patients enter the OR via the emergency department. After surgery, patients are going to the postoperative nursing unit from which they finally leave the hospital. The dotted arrows in Figure 1 show the less common process, such as a revision operation.

[1] The number of urgent and semi-elective patients is obtained from the hospital information system Business Objects. The semi-elective patient flow only contains the number of patients with the urgency label 'within 24 hours'. The label 'within one week' is not registered in this system, so probably the number of semi-elective patients is a bit higher. The numbers for child surgery are missing, so these are obtained from Okapi.

[2] The number of urgent and semi-elective patients for child surgery is obtained from Okapi. The urgent patients are the ones with an acute label, operated within one day. The semi-elective patients are the ones with a semi-elective label or an acute label, operated from one day after arrival.

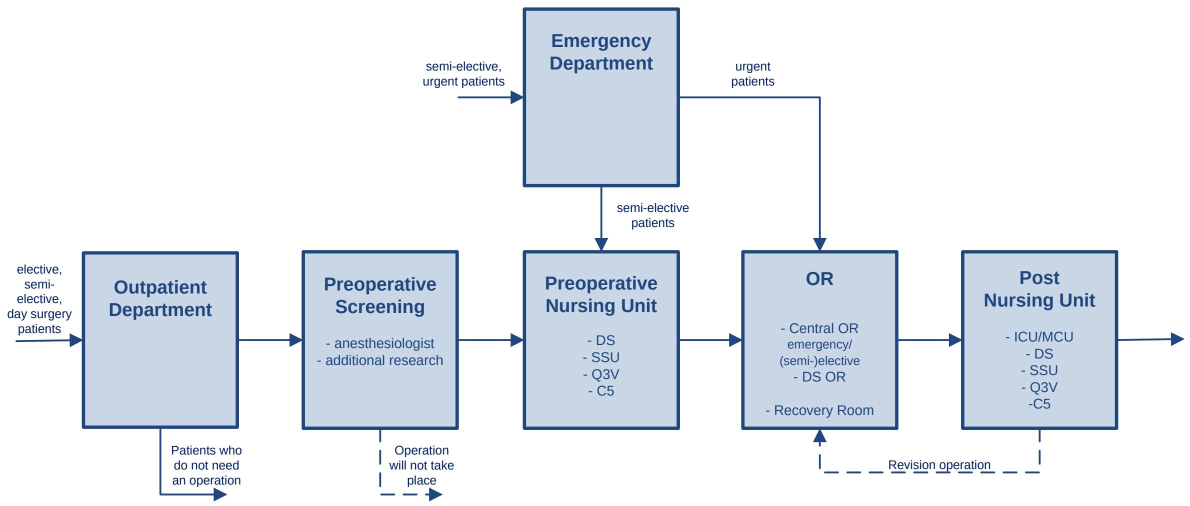

Figure 1: General process of a GS patient

At the GS outpatient department a physician examines the elective patient, discusses the treatment plan and decides whether a surgical operation has to take place. When an operation is needed, the patient is placed on a list, on which patients are waiting for surgery date allocation. Further, two appointments are made at the outpatient department; for the POS consulting-hours of the anesthesiologist and for a hospitalization interview with a nurse. Yearly, the number of first visits at the GS outpatient department is about 12,500 (Radboudumc, 2013e).

During the POS, patient information is collected which is relevant for the operation, such as physical condition, medicine usage, blood pressure, etc. An anesthesiologist decides whether additional research is needed (such as allergy or cardiac tests) before the operation can take place. During the consulting-hour the anesthesiologist tells the patient whether the patient will receive local or general anesthesia during the operation. The operation can be performed after the anesthesiologist gives approval for the operation (Radboudumc, 2013f).

After approval, the operation is planned at the planning office. Usually a week before the operation, a planner contacts the patient to announce the surgery date. Normally a (few) day(s) before the operation, the patient is contacted by a nurse for information about the hospitalization. GS patients are hospitalized at several nursing units. Children are hospitalized at nursing unit Q3V which has 12 beds reserved for GS. Adults are hospitalized at the Short Stay Unit (SSU) which has 9 beds reserved for GS. When the expected hospitalization is longer than five days, patients are treated at GS nursing unit C5 which has 49 beds; of which 45 beds are reserved for elective patients and 4 beds for urgent patients. When hospitalization and treatment takes one day, the patient is treated at the day surgery (DS) OR.

After hospitalization, the operation takes place. There are 20 OR's at the hospital in which complex surgery can be performed. These OR's are managed at the OR department. One emergency OR is used for urgent patients of GS and other hospital departments (24 hours a day, 7 days a week). The resource allocation for the other patient flows is further described in the next sub section. After the operation, the patient is brought to the recovery room, which is part of the OR department.

When the patient has recovered, the patient is brought from the OR department back to the nursing unit (SSU, Q3V or C5). Some postoperative patients are taken care of in the intensive care unit (ICU) or medium care unit (MCU) (Radboudumc, 2013e). There are yearly about 3,000 GS hospitalizations (Radboudumc, 2013e). After discharge, the patient finally leaves the hospital.

2.2.3 Resource Allocation

The GS department uses five central and two DS OR's. Generally, a DS patient can be performed on a central OR, but the other way around is not possible due to the complexity of surgery. The OR resource allocation for each sub department and patient flow is decided by the management of the GS department. Weekly, about 153 OR hours are bought (for €800-1000 per OR hour) for elective, semi-elective and DS patients; 109 OR hours are available for elective patients, 12 OR hours for semi-elective patients (since July 2013 reallocated from the elective program) and 32 OR hours for DS patients. The OR hours for semi-elective and DS patients are for all sub departments. However in practice, the most semi-elective OR hours are used by trs and the DS hours are mostly used by aos. The 109 elective weekly OR hours are further specified by sub department; on average about $57^1/_3$ for aos, $21^1/_3$ for vts, $13^1/_3$ for trs and 17 for chs. Based on this resource allocation, a six weeks cyclic OR scheme or master surgery schedule (MSS) is used for each sub department and its patient flow.
In Table 2, week 1 of the MSS is given. Each block is equal to eight hours (08:00-16:00). As can be seen, a full day is allocated to one sub department. The even weeks of the MSS have an extra chs block on Tuesdays. Furthermore, the weeks of the MSS differ from each other with respect to the reallocated hours for semi-elective patients. In week 1, eight hours from aos are reallocated. In this way, 8-16 hours from a sub department are weekly reallocated. Usually, operations of a sub department are executed on the same OR. As can be seen, OR16 and OR34 are intended for chs, and vts and trs patients are always planned in OR4 and OR3, respectively. Theoretically, it is not necessary to plan in a constant OR, since the OR's are designed in a way that these are interchangeable. The empty blocks on the MSS are filled in by operations performed by other hospital departments.

WEEK 1	OR3	OR4	OR5	OR8	OR16	OR34	OR36
Mon	trs	vts	aos				trs (ds)
Tue		vts	aos	aos			aos (ds)
Wed		aos	aos	aos	chs		aos (ds)
Thu		vts	aos	aos		chs (ds)	
Fri	trs				chs (5h)		
Sat							
Sun							

Table 2: Week 1 of the MSS, used at the GS department in the period January – August 2013

2.3 Planning Office

The planning office is established in 2010 at the GS department. Four planners and the chief of the planning office take care of the planning of operations for all sub departments and patient flows except for urgent patients. Since March 2013, DS patients are planned by the planning office as well. Each planner is responsible for a part of the operation planning: aos, chs and trs & vts. Further, a fourth planner is doing the supporting and administrative tasks around the planning. OR's are planned for 8 hours. Sometimes, OR time is left open to be sure that the last operation will not end after closing time. Namely, late finishing of operations is very expensive. Weekly, some OR's are allowed to end late for a maximum of 5% of the weekly operated hours. The resource information and communication of the surgery date are described in the following sub sections.

2.3.1 Resource Information

Since October 2013, Epic has been implemented at Radboudumc. The healthcare software replaced several information and planning systems which were used at the planning office. The information flows described below stay comparable to the old situation. At the outpatient department, information about the patient and corresponding operation is recorded by the physician in Epic. Significant planning information holds patient urgency, expected duration of the operation, need for a certain surgeon or additional surgeons, need for ICU/MCU, need for systems, materials and medication during the operation, etc. Further, the availability of the OR's is presented in Epic.
Next to the information in Epic, planners have to take into account the availability of physicians which is denoted in Outlook Calendar. The surgeon availability should be known 6 weeks in advance. However, this is not always the case in practice due to last-minute availability changes. In case of absenteeism, highly specialized surgeons are difficult to get replaced. On average, a surgeon has to execute operations at least 8 hours per week, for 40 production weeks a year. Further, a surgeon is occupied with clinical shifts, lectures, courses, medical congresses, days-off, etc. Planners strive to plan one surgeon in one OR for a full day. This is preferable concerning change-over times. Additionally, planners have to take into account the availability of beds on the SSU, ICU, MCU and nursing unit. An Excel sheet containing the bed spread is used to have an idea of the bed occupancy on a nursing unit during a week.

For some treatments, time is reserved on the OR scheme; so called dummies. There are several reasons for creating a dummy: Firstly, when the number of operations is high and the availability of the surgeon is constant. For example, hernia operations are planned on Mondays on the DS OR. Secondly, when the patient urgency is high, a dummy is created. For example, mamma operations are planned on Tuesdays and Wednesdays on DS OR's. Thirdly, a dummy is created when an extended surgeon team is needed. This is useful for complex operations, such as HIPEC operations, so that time in everyone's agenda is reserved far in advance. A fourth reason for creating dummies is to achieve minimum volume standards. Hospitals have to perform a certain number of treatments each year to be contracted by an insurer (RIVM, 2012). For example, 20 HIPEC operations need to be performed each year (NVvH, 2012).

2.3.2 Communication of the Surgery Date

Some operations are planned until six weeks in advance. Then a preliminary surgery date is kept in mind without communicating this date to the patient. On Tuesdays, a workplace management (WPM) meeting takes place together with an anesthesiologist, a surgeon and a planner to discuss the operation program of the following week. Some patients are shifted on the program, sometimes the expected surgery duration is adapted, the need for an ICU bed can be changed or notes can be added to the final operation program. Next to the discussion of the final operation program, performance indicators of the previous week are shortly analyzed during the WPM. An overview is provided for the preceding week and past year with respect to the OR occupancy, OR overtime, late start and early ending of operations denoted in percentages. After the WPM, the planner adapts the final changes and calls the patients to communicate the final surgery date.

3 Problem Description

The problem description consists of the central research question and the research objective. Before these topics are described in section 2 and 3, the problem analysis at the GS department is given in the first section of this chapter. The scope of this research is given in the fourth section.

3.1 Problem Analysis

The GS department deals with several problems with respect to planning of patients for operations. The link between these problems and its causes are found by creating an Ishikawa (or fishbone) diagram, presented in Appendix I. The main problem for both patient and GS department is the patient dissatisfaction about the time period of the surgery date announcement. This problem is caused by three underlying problems: firstly, last-minute changes in the OR program; secondly, the patient receives unclear information about the period of the surgery date; thirdly, the urgency period in which the patient has to be treated is not achieved. These three problems are further described in detail.

Short-term dissatisfaction exists when patients get a call about changes or cancellations of their surgery date, caused by a last-minute change in the OR program due to operation overtime. This occurs when the realized operating duration is longer than expected. OR program changes can also occur due to the arrival of more urgent patients who need to be operated first.

Patients receive unreliable information about the expected surgery date, given earlier in the process. Many patients call the planning office each working day between 09:00 and 10:00, questioning whether a surgery date is already known. Apparently, according to patients, physicians promised to execute the operation within a certain period. One of the reasons is that some surgeons do not have a clear insight about the throughput of patients. Regularly, planners ask patients to wait until the phone call from the planning office with the surgery date.

Additionally, surgeons (and patients to a lesser extent) are worried since patients cannot be planned within the urgency period. This is a problem for the department as well, keeping in mind the deals with the health insurer. The urgency period is not achieved since the match in planning is difficult which leads to a high workload of planners. The difficulty in planning is caused by different factors. Firstly, the patient waiting list does not shrink which makes it more difficult to plan every patient within the indicated urgency time (and less urgent operations stay on the waiting list for a long time). Secondly, planners face additional demands from other parties. For example, surgeons need to execute more operations for their research, nurses want to have their information on a certain moment and patients wish for getting their announcement for an operation at least one week in advance. Furthermore, surgeons feel pressure to execute at least the number of operations which is stated as volume standard. Thirdly, there is no clear insight into the availability of surgeons which is denoted in several agendas. Fourthly, incorrect and incomplete patients are registered in the system. Fifthly, the planning of patients cannot be made further in advance due to the absence of approval of the anesthesiologist. Finally, some operations have high requirements with respect to materials, medications, multi-disciplinary specialists and surgeon requirements.

3.2 Research Question

As can be read in the last section, the operation planning of patients takes several problems along, divided in three "fish-bones" with respect to the Ishikawa diagram. The GS department started several projects to solve parts of the problem. In July 2013 the department opened a special OR for only semi-elective patients and since October 2013 the department is working with historical surgery durations per surgeon generated by Epic, with the intention that problems with respect to last-minute changes on the OR program will be reduced (which is one of the fish-bones).

Additionally, the management of the GS department wants to give elective patients a surgery date on the day of diagnosis. In this way, the department tries to take away the miscommunication about the announcement of the surgery date; another "fish-bone" of the Ishikawa diagram. Giving a surgery date on the day of diagnosis would improve the expectancy management at the GS department, since the day of the operation is known in an early stage for patient, planner, surgeon, anesthesiologist, nurse, etc. Therefore, the department wants to know how the planning should be designed to achieve this. Consequently, this research focuses on the research question presented below.

Problems with respect to the planning of a patient within the urgency period due to a difficult match in planning (the third fish-bone) can be foreseen a long time in advance. Therefore, capacity measures can be taken into account, matching supply and demand. Still, sub problems of this "fish-bone" should be taken into account while designing a planning for giving a surgery date on the day of diagnosis, to get a reliable and acceptable planning. The terms 'reliable' and 'acceptable' are described in the next section.

Research Question

In which way should the planning be designed to give the elective patient for general surgery a reliable and acceptable surgery date on the day of diagnosis?

3.3 Research Objective

The patient has the right to know about the total waiting period. Therefore, the main objective of this research at the GS department is designing the planning in a way the elective patient can be given a surgery date as soon as the decision is made for an operation. More precisely, the desired outcome is to give a patient an appointment for the operation when the patient visits the physician at the outpatient department on the day of diagnosis.

At the same time, the aim is to give patients *reliable* surgery dates. The term 'reliable' refers to an operation which is actually performed on the allocated surgery date. This means that the number of operation cancellations has to be limited.

Furthermore, the aim is to give the patient an *acceptable* surgery date, which points out the patient waiting time has to be smaller than the indicated medical sound maximum waiting time. This maximum waiting time is indicated with the urgency period, which is determined by indicators of quality, depending on the disease itself and the physical condition of the patient as determined by the physician at the outpatient department.

Next to patient focused purposes, there exist financial stimulations within the research. A supplementary goal is to limit the average weekly number of OR overtime hours till a maximum of 5%. Further, maintaining a high OR occupancy (80%-90%) is preferred.

The main research objective of giving the patient a surgery date on the day of diagnosis, within the indicated urgency period (acceptable) and with a small probability of being cancelled (reliable), fits within the overall goal of Radboudumc, since patient service is of increasing importance. At the same time, the departments of the hospital have to be cost-efficient by limiting the hours of OR overtime. Consequently, the overall objective of this research is to develop a planning method which meets these requirements.

Research Objective

- Giving a surgery date on the day of diagnosis
- Limiting the number of operation cancellations (reliability)
- Operating the patient within the urgency period (acceptability)
- Limiting the number of overtime hours on the OR
- Developing a planning method which meets these requirements

3.4 Scope

In this section, the scope of this research is defined according the conceptual framework developed by Vissers and Beech (2005), to position health OM theories and to make clear on which level of detail is operated. After that, with respect to the content of the problem, the system boundaries are given in the second sub section.

3.4.1 Conceptual Framework

The conceptual framework presented in Figure 2, consists of five different levels, each dealing with another planning horizon. Firstly, strategic planning decisions create the long-term vision of the hospital and the types of services that it should provide. The second level of patient volume planning and control includes the first check whether a hospital possesses the correct services to treat patients (including types of units, resources, operations). The level resources planning and control is the middle level which checks whether resources can be shared by more than one patient group, whether a resource is scarce and might be a bottleneck in the process. The patient group planning and control level deals with patient groups which exist of patients with similar care needs, requiring specific types of procedures. The lower level of patient planning and control deals with the scheduling of individual patients (Vissers and Beech, 2005).

The upper two levels of the conceptual framework are determined by the management of the hospital and GS department and fall beyond the scope of this research. The middle level of the framework partly belongs to the scope of this research. For example, the allocation of the amount of resources to each sub department is determined by the management. However, it is interesting to analyze the performance when re-allocating the resources in a different way. The two lower levels of the conceptual framework fall within the scope of this research. The different operation groups of the sub departments are defined and the research focuses on the actual planning of patients. Additionally, several distinctions on the lower level are made in literature, as described in Goedhart (2013). Although the concepts sequencing, appointment scheduling and online scheduling influence the final planning performance, these fall beyond the scope of this research.

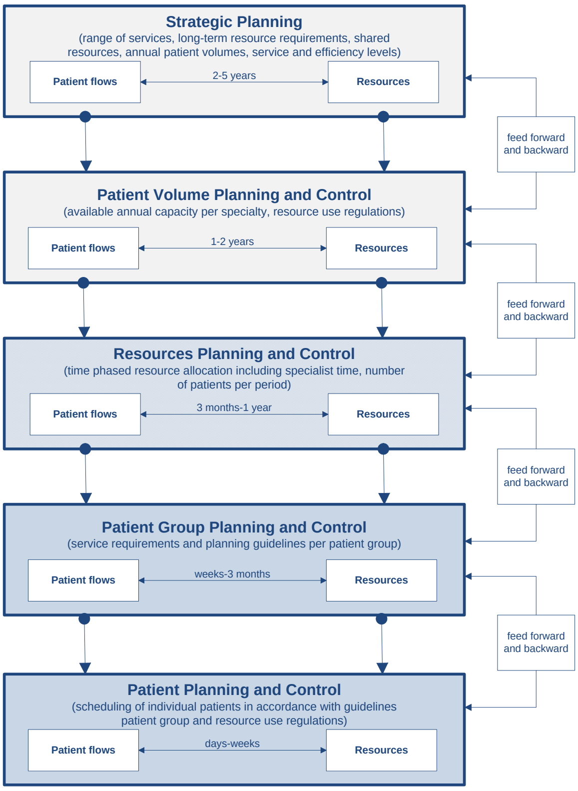

Figure 2: Conceptual framework (Vissers and Beech, 2005)

3.4.2 System Boundaries

Firstly with respect to patients, only elective and DS patients are taken into account since these patients have to receive a surgery date in advance. Since the urgent and semi-elective do not influence the planning of elective and DS patients, the urgent and semi-elective patient flows fall beyond the scope of this research. Accordingly, the OR availability which is allocated to these patient flows and each sub department is taken into account. This is the MSS described before.

Secondly, regarding the process prior to the planning of a patient surgery date, the earliest operating period (EOP) is defined in this research. The anesthesiology department has to perform the POS within this period. As a result, the planning of the POS and corresponding availability of anesthesiologists fall beyond the scope.

Other system boundaries are defined with respect to the needed (personnel) resources in the OR during the operation. The assumption is made that there are no problems with planning the OR teams and anesthesiologists for GS operations at the OR department and anesthesiology department. This assumption is reasonable since this is mostly the case in practice as well. Therefore, the planning of a needed OR team and anesthesiologist during the operation fall beyond the scope of

this research. Obviously, the availability of needed GS surgeons is taken within the scope, since this information is crucial in deciding whether an operation can be planned on a particular date.
Subsequently, the availability for needed materials, machines and other instrumental resources during the operation are not taken into account. A distinction is made between OR restrained and patient restrained OR materials. Patient restrained OR materials are custom-made, such as a stand for vts. However, the number of operations which need patient restrained OR materials is not significant and thereby, this information cannot be found easily in the information systems. For all the other resources the assumption is made these are always available in the OR. This seems reasonable, since each OR is provided with the most common used resources.

Further system boundaries are found in the GS patient process, after the operation. The absence of a bed on the SSU, ICU, MCU or nursing unit has far-reaching consequences on the continuity of the operations in the OR. However, the availability of beds and corresponding availability of nurses are not taken into account within this research. This makes the planning in this research somewhat easier than in reality. On the other hand, bed availability is not that rigid in practice. In case of shortage, the planners arrange so-called 'guest beds' which are initially reserved for other hospital departments.

Finally, system boundaries are defined with respect to cancellations of operations. It happens that operations are finally not taking place due to absenteeism of surgeons or patients. As a result, the operations have to be cancelled. It also occurs a patient cancels the operation voluntarily (e.g. due to last minute announcement of the surgery date). Further, overtime of operations is a cause of cancellation. In Radboudumc, only the planned and executed operations are controlled. The difference between these two is the number of cancellations, which means no distinction is made between the causes of these cancellations. Absenteeism of people falls beyond the scope of this research, but the number of cancellations due to OR overtime is taken into account.

Within Scope

- Planning elective and DS patients
- Earliest operating period
- Availability GS surgeons
- Availability of OR's (MSS)
- Cancellations due to OR overtime

Beyond Scope

- Planning urgent, semi-elective patients
- Planning POS
- Planning anesthesiologists
- Planning OR teams
- Availability of instrumental resources
- Planning of (ICU/MCU) beds and nurses
- Cancellations due to absenteeism

4 Literature Overview

Prior to this master thesis, a literature study was done to create a theoretical framework, present useful findings for the thesis, embed the thesis research and find gaps in the current literature. With respect to the theoretical framework, two gaps were identified. Firstly, it turned out an overkill of different, conflicting and overlapping scheduling concepts are discussed in the current literature. Probably the novelty of this topic is a reason for this chaos in concepts. Although several literature reviews tried to position their concepts, there does not exist some dominant paradigm or use of leading concepts and definitions. As a result of this gap, Goedhart (2013) recommended placing the used scheduling concepts in a framework and highlighting the relationships between the different concepts. On the basis of the literature study, a start was made to categorize the scheduling concepts among two dimensions; a time horizon and a scheduling problem domain dimension. This could serve as a knowledge management framework, which represents and couples scheduling insights (Goedhart, 2013).

Furthermore, regarding the content of the scheduling concepts, there can be concluded research goals should be more focused on patient service since the need for patient service in practice. Minimization of patient waiting times and number of cancellations, rather than maximizing resource utilization, are upcoming performance indicators (Cardoen, Demeulemeester, & Beliën, 2010), but patient service goes beyond these goals (Frankel, Coast, Baker, & Collins, 1991; Vissers, Adan, & Dellaert, 2007). On strategic level, giving patients their surgery date on the day of diagnosis (Booked Admission) seemed promising since it showed similar performance in comparison with the maximum resource use service concept (Vissers, Adan, & Dellaert, 2007). The study of Vissers et al. (2007) is the only research on this service concept, while this master thesis is focused at another time horizon dimension. Therefore, a second gap in literature was defined with respect to a scheduling technique on the tactical and operational level of planning, which gives the patient a surgery date on the date of diagnosis. In this way, elective patients knowing their surgery date in advance instead of waiting on a list to be selected for an OR slot (Goedhart, 2013). In practice, giving a surgery date to the patient right after the diagnosis, is a recently released service criterion by a Dutch healthcare insurer (Menzis, 2013). Therefore, this thesis research is a contribution to the current literature studies.

The following consecutive steps are described in the sections of this chapter: definition of operation groups, session planning, resource allocation and surgical case assignment. After that, related topics have to be taken into account, which includes a manner to deal with variation of surgery durations and a method to cope with patients and OR capacity in case of discrepancy between demand and supply.

4.1 Definition of Operation Groups

Măruşter et al. (2002) used clustering techniques to group medical multi-disciplinary patients in logistically homogeneous groups. Vermeulen et al. (2009) executed a less complex analysis on the definition of operation groups. They used the most important patient attributes for their definition of patient groups which were medical constraints and urgency. Dellaert and Jeunet (2010) considered patient groups which were distinguished based on the use of OR and ICU resources. Therefore, the groups varied from each other on the expected surgery duration, average length of stay at the ICU and average number of patients to be operated within the planning horizon. It seemed that a complex analysis on the definition of operation groups is not necessarily needed. However, it is important to take into account the categorization is made on the basis of homogeneity in resource use rather than on medical similarity (Vissers, Adan, & Dellaert, 2007; Măruşter, Weijters, de Vries, van den Bosch, & Daelemans, 2002).

4.2 Session Planning

Testi et al. (2007) defined *session planning*, in which the available OR time is distributed among individual surgeons or surgical groups. This can be based according several criteria, such as historical utilization, waiting list and financial criteria. They considered session planning as a bin packing-like problem. The target patient throughput, target utilization of resources and restrictions on admission profiles should be known before balancing supply and demand during the next step (Adan & Vissers, 2002; Vissers & Beech, 2005).

4.3 Resource Allocation: Open and Block Scheduling

Resource allocation deals with how to reserve capacity for operation groups. There are two main scheduling strategies which can be distinguished; open and block scheduling. In an open scheduling system, surgical patients are scheduled on a first-come-first-serve basis. Generally, this strategy has lower utilization and more cancellations than a block scheduling strategy. A block scheduling strategy assigns individual surgeons or elective surgical groups to a set of OR time blocks in a time period, in which patients can be scheduled. The allocation is presented in a cyclic timetable called Master Surgical Schedule (MSS) (Pham & Klinkert, 2008; Van Oostrum, Van Houdenhoven, Hurink, Hans, Wullink, & Kazemier, 2008). Van Oostrum et al. (2008) demonstrated that their MSS approach leveled the workload of the surgical specialties, ICU's and wards, optimized OR utilization without increasing overtime and cancellations. To provide more flexibility, modified block scheduling can be used leaving some blocks open or reallocating unused time blocks at some time (Fei, Meskens, & Chu, 2010). Another combination of these strategies is designed by Fei et al. (2010), where time blocks were reserved for surgeons and were able to be assigned to patients until the Thursday before the coming week. Each Friday, a management committee finally decided the weekly operation schedule with an open scheduling strategy.

4.4 Surgical Case Assignment

After the creation of blocks in the prior step, the surgical cases need to be assigned to the allocated resources. Several admission heuristics can be used to fill in patients on the OR scheme. Best Fit Descending with Fuzzy Constraint (BFDFC) and First Fit Decreasing (FFD) seemed promising for decreasing the number of operation days and increasing the utilization (Fei, Meskens, & Chu, 2010; Vijayakumar, Parikh, Scott, Barnes, & Gallimore, 2013). The sequencing component in both heuristics (descending/decreasing) ensures the surgical patients are considered in such an order that the longest operation with the highest urgency is assigned to an OR at first. Vijayakumar et al. (2013) showed an increased performance by using a longer pooling window. However, when giving a surgery date on the day of diagnosis this is not relevant, since no waiting list is created.
In the First Fit algorithm, the patient is assigned to the first OR which is "open". An OR is open when it has space for more patients, else it is closed. A new OR is opened when the patient does not fit in

the other open OR's (Vijayakumar, Parikh, Scott, Barnes, & Gallimore, 2013). In the Best Fit algorithm, the patient is assigned to the OR which has the lowest amount of available open time (Fei, Meskens, & Chu, 2010).

4.5 Reserving Amount of Time

Besides *how* to reserve time slots in future, it is also important to know *how many* time slots to reserve. Both during resource allocation and surgical case assignment, planners have to deal with the expected surgery duration. Two ways of dealing with the variation of surgery durations are discussed; using particular surgery durations or using slack planning.

Several ways to estimate surgery durations can be used (Jebali, Hadj Alouane, & Ladet, 2006). Firstly, surgeons or OR department managers can provide durations by experience. Secondly, information systems can be used to generate average surgery durations. Jeang and Chiang (2010) used the average surgery duration per surgeon and operation type to be more accurate. Finally, probability distributions can be used to estimate surgery durations. The characteristics of an operation seemed to be satisfied by the log-normal distribution (Zhou & Dexter, 1998). However, the sum of operations could not be approximated by this distribution (Hans, Wullink, Van Houdenhoven, & Kazemier, 2008). Another way of dealing with this variation is to include slack planning, which involves the reservation of capacity for more patients than the average. Dellaert and Jeunet (2010) and Adan et al. (2011) based their amount of slack on a certain maximum percentage of operations exceeding an acceptable waiting time. Hans et al. (2008) based their amount of planned slack on a certain percentage of operations finishing on time, taking into account the expected variance of the surgery durations. Concerning slack planning, it seemed a trade-off should be made between patient satisfaction (waiting times or cancellations/overtime) and hospital efficiency. The total planned slack can be minimized using the so-called portfolio effect from financial literature. Operations with similar variability should be clustered on the same OR (Van Oostrum, Van Houdenhoven, Hurink, Hans, Wullink, & Kazemier, 2008; Van Houdenhoven, Van Oostrum, Hans, Wullink, & Kazemier, 2007).

4.6 Discrepancy Demand and Supply

During the surgical case assignment, more or less patients could arrive than was estimated. Therefore, the discrepancy between demand and supply should be taken into account. In case of unfilled slots, Vermeulen et al. (2009) developed a dynamic adjustment approach and Dellaert and Jeunet (2010) and Adan et al. (2011) applied flexibility rules which made it possible to reallocate capacity between operation groups. Vissers et al. (2007) recommended having a number of patients on call when other patients have been cancelled, to fill unused OR capacity. This is similar to the idea of Pham & Klinkert (2008), who defined add-elective cases as elective patients who fill up remaining OR time. In case of too filled slots or cancellations, Zonderland et al. (2010) increased the patient urgency label. In their paper, canceled elective patients became semi-urgent patients.

5 Methodology

The research method which is used during this research is the regulative cycle developed by Van Strien (1986). The regulative cycle with its five stages is presented in Figure 3. The first stage consists of the problem description. The second stage consists of the problem analysis and finding the causes for the problem. The third step consists of designing a plan to improve the situation. The fourth stage is to implement the idea in practice and measure the performance. In the fifth stage, it is evaluated whether the problem is resolved by the implemented plan (De Lange, Schuman, & Montessori, 2010; Van Aken, 1994). Van Aken (1994) highlighted that in most cases, these stages are not sequentially walked through. Therefore, double arrows between the stages are added.
In this research, the first and second stages were already described in chapter 3. However, to be able making suggestions for redesign, the stage of analysis is extended in this chapter. The fourth en fifth stages of the cycle are not taking place in practice within this research. Instead, a simulation model is built to evaluate the performance of the redesigned planning.

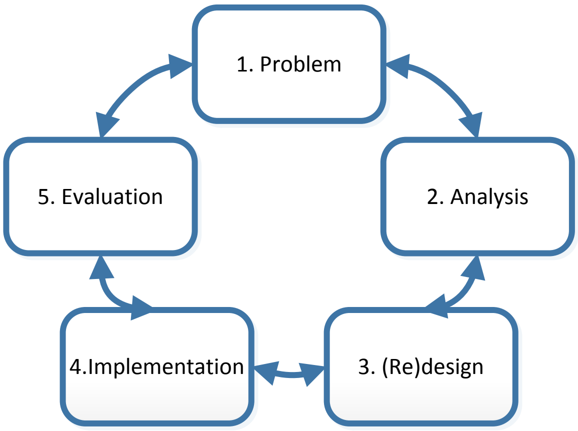

Figure 3: Regulative cycle (Van Strien, 1986)

The research question is divided into several sub questions which were obtained by making a question tree as presented in Appendix II. The most important sub questions are presented in the overview below. As can be seen, the term 'planning' is divided into two planning subjects, namely planning process and planning method. The planning process concerns the chain with all parties which are involved by the planning of an operation. With the term planning method, the way of working regarding the planning executed by the planners is intended. The focus in this research is on the planning method. Particularly, the research focuses on the simulation of several planning method variations which is described in the next chapters.

The questions regarding the planning process and the first question of the planning method are answered in the first section of this chapter. The second question of the planning method is found in literature, described in the previous chapter. The third question is answered by predicting several planning scenarios regarding demand and capacity. Together with the usable literature concepts, these are included in six consecutive steps to allocate a surgery date, which is described in the second section of this chapter. The last question is also included in the steps of the procedure. Answers on this question will be given in the fourth section, during the data collection and analysis.

Sub Questions for Preliminary Research

1. How should the planning process be designed?
   a. How is the current planning process? What should be changed in the process to give the date of surgery on the day of diagnosis?
   b. Where and by whom in the process should the day of surgery be announced?
2. How should the planning method be designed?
   a. How is the current planning method? Why is it not possible to give a surgery date on the day of diagnosis with the current planning method?
   b. Which planning methods are available and which concepts are applicable to this situation?
   c. What if the actual patient numbers are not equal to the expected ones? (How should empty reserved OR capacity be filled up? How is time created for a patient when the OR scheme is already filled?)
   d. How much OR capacity is needed for which operation (group) and within which (urgency) period? When should the capacity be reserved?

5.1 Preliminary Research

Although the planning process component is not the focus of this research, it is considered in a certain extent to answer the research question more completely. The two questions regarding the planning process are described in the first two sub sections, respectively. In the third sub section, the necessary changes in the planning method (question 2a) are shortly described.

5.1.1 Needed Changes in Planning Process

The current planning process is presented in Appendix III, for which service blueprinting was used as process technique. The information is obtained by approaching several stakeholders in the process. The process map is used to identify points for improvement to increase the reliability and acceptability of the new planning method. As turned out, planners are often waiting on test results or anesthesiologist approval before they can actually plan an operation. Because of this, it happens that patients are planned after the urgency period. Therefore, an important aspect of the new planning process is the change from a push process into a pull process. This would result in anticipating all the work of intermediary parties to the surgery date which is announced to the patient. To realize this, the earliest operating period (EOP) for each operation group is determined in such a way that all necessary tests can be executed before that period. As a result, the operation has to be planned within the planning window, which is the period between the EOP and the urgency period. In this way, the reliability and acceptability of the planning method would be increased.
During a brainstorm with two planners, several ideas came up regarding the planning process. Firstly, the idea is mentioned to handover the responsibility of planning the anesthesiology appointments from the anesthesiology department to the planners on the planning office. In this way, the planners would oversee the patient appointments and above all, the appointments can be made during one patient contact moment, which is preferable regarding patient service. The other planner came up with an idea for ‘healthy’ patients, who have a high chance for not needing any research during the

POS (mostly vts and DS patients). An EOP would not be needed, when an anesthesiologist would be present during the appointment on the outpatient department and immediately would give approval for the operation. However, this idea would need extra time of an anesthesiologist. So far, using the EOP is the most important process planning change which will also be used during simulation.
Another important process change concerns the operation adjustments during the WPM meeting. Partly, last-minute changes in the OR program will be overcome by introducing the EOP, since changes are often the result of accidental information coming from the POS. In case the surgery duration is unclear yet, the maximum estimated surgery duration should be reserved. In this way, the surgery duration can be changed down, so that no operation is needed to be cancelled. Further, shifts on the OR program will be restricted to the surgery date.

5.1.2 Announcement of Surgery Date

Further regarding the planning process, the question is concerned on which moment and by whom the surgery date should be announced. During several brainstorm sessions with two planners and a surgeon, the advantages and disadvantages were discussed of several scenarios. To start with, the scenario is considered that surgeons would announce the surgery date during their appointment with the patient on the outpatient department. This scenario has several advantages. To start with, patient and surgeon would postpone the surgery date less frequently. Namely for a patient, a surgeon has more authority than a planner. Regarding the surgeon, it would feel to have an appointment with the patient, instead of just executing all appointments which are placed in the agenda by the planner. Secondly, surgeons would observe the high waiting list by themselves and would not communicate too positive scenarios of the waiting time to the patient. However, a division in planning responsibilities should be reconsidered; which part is organized by a surgeon an which part is executed by the planner on the planning office. Secondly, the scenario is considered that planners would announce the surgery date to the patient. The advantage is that the surgery date allocation would remain centrally organized; planners have the oversight of all things which have to be organized around the operation. However, it is unclear how the patient would receive the surgery date, since it is impossible to let patients come by at the planning office in the current situation. Therefore, the idea was suggested to move the planning office to the outpatient department, to be able communicating the surgery date face-to-face with the patient. Another way would be by a phone call, comparable to the current situation. In this way, the idea is considered to announce the surgery date one day after the diagnosis. The advantage of this scenario is that patients would have the possibility to settle the idea of having an operation, to look into their agenda and to fine-tune the surgery date with their family. Additionally, planners would be able to slightly optimize the OR program by shuffling some patients on the OR program.
In all scenarios the patient service will increase compared to the current situation, by allocating the surgery date much earlier. Although the last mentioned scenario does not give a surgery date on the day of diagnosis, it needs the least changes regarding the current situation. Therefore, this scenario is also considered in the planning method, allowing patient sequencing for one day.

5.1.3 Needed Changes in Planning Method

Regarding the planning method, it is concerned why it is not possible to give a surgery date on the day of diagnosis in the current planning situation. The answer is obtained by approaching the planners and observing the situations happening at the planning office. It became clear that three important changes are needed to finally give a surgery date on the day of diagnosis. Firstly, in the new planning method it is not allowed anymore to place patients on a 'surgery date announcement waiting list'. This will result in a more difficult 'puzzle' to fill the operation program. Secondly, a variable planning horizon is needed, rather than the current one week horizon. The variable planning horizon will range from 2 weeks till about 12 weeks, depending on the patient urgency periods. A simple planning example presented in the box below indicates the consequences of these two changes in the planning method. It shows the importance of taking into account accurate estimations of patient arrivals. The third needed essential change concerns the surgeon availability. Once a surgeon is planned for an operation, no last-minute changes in the surgeon availability will be allowed anymore. In the current situation, it frequently happened that surgeons were asking for getting days off within six weeks. Obviously, it would never be possible to give a patient a reliable surgery date in advance on that way. Other details of the current planning method are described in the next section, by comparing the concepts of the new planning method.

Assume a simplified OR scheme for one OR and patients with simple characteristics. Patients have an expected surgery duration of 8 hours. So the available OR capacity is equal to five patients a week. Suppose patients should be treated within 1 or 2 week(s). Six patients arrive in week 0. In case of the current planning method, all patients who arrive are put on a list. The most urgent patients are selected and planned on the OR program. Using the new planning method, patients are immediately planned on the OR program. This situation is presented in Table 3. The patients are given in order of arrival. The sixth patient falls outside the urgency period since there is no available capacity left in the first week.

Patient Number	Urgency Period
1	1
2	1
3	1
4	2
5	2
6	1

Week	Mon	Tue	Wed	Thu	Fri
1	1	2	3	4	5
2	6				

Table 3: Ranked arrival of patients in week 0 and scheduling on OR program

5.2 Six Steps for Surgery Date Allocation

On the basis of the literature review and preliminary research, six consecutive steps for a reliable and acceptable surgery date allocation are defined; these form the redesigned planning method. Some details of the actual planning method are given for comparison. The execution of these steps is considered in the next section and in the simulation model which is described in the next chapter.

Step 0 *Finding out OR and surgeon availability*

The OR availability is stated in the MSS, which is the current six weeks cyclic OR scheme, including the resource allocation for each sub department. In this research, the MSS is known in advance. The two weeks cyclic surgeon scheme should be known six weeks in advance in the current situation. However, in the redesigned planning method, the availability of surgeons over a time period of twelve weeks is assumed to be known in advance. Surgeons need to communicate their availability each 4 weeks. In this way, the minimum and maximum availability are 8 and 12 weeks, respectively. With this rule, the planning horizon is at least known for more than six weeks in advance, since this is a frequently used urgency period. By communicating the availability each four weeks, planners have the flexibility for reserving OR time blocks for surgeons (step 3).

Step 1 *Defining operation groups*

Operation groups need to be defined according to their resource use, rather than using 'diagnosis groups' based on medical similarity which was currently used in Okapi. Therefore, operation groups are defined per sub department on planning window, needed surgeon and occurrence (and the standard deviation of the surgery duration to a less extent).

Step 2 *Checking whether capacity meets demand*

After the definition of operation groups, a rough analysis is needed whether capacity meets demand. The expected patient numbers are multiplied with the average surgery duration. When the amount of demanded hours for each sub department does not fit within its allocated hours according to the MSS, a reallocation of hours is considered within the available hours. The modification of the MSS occurs on the tactical level of planning. In the current situation, these decisions are not made according to expected demand-capacity checks, but according to observed operational problems.

Step 3 *Reserving time blocks*

A block scheduling strategy is introduced in which time blocks are reserved on the MSS. The allocated hours for each sub department, availability of surgeons, average surgery durations, planning window, and expected numbers of operations need to be taken into account. The time blocks are reserved in two ways: time blocks are reserved for both operation groups and surgeons. In practice, time blocks are reserved for surgeons and partly for some operation groups by creating dummies, which was described in chapter 2.

Step 4 *Admitting patients*

a. Admission Heuristic

   Patients need to be filled in the reserved blocks. In literature, some suggestions were given for admission, such as Best Fit or First Fit. However, a more realistic admission heuristic is preferred, concerning patient service. As seemed on the planning office, a patient is frequently not able to agree with the surgery date suggestion. Therefore, a patient chooses the surgery date within the most feasible surgery dates. So this sub step does not change in the redesigned planning method.

b. Surgery duration

   In literature, several ways to reserve time on the OR program were described. In the redesigned and current planning method, the surgery duration estimated by surgeons is used. However, since Epic is used, average historical surgery durations are used, which can be adapted by surgeons (in case of a more complex patient).

c. Admission Rule

   An operating day starts at 8:00 and generally, the OR is closed at 16:00. The admission rule specifies till what time is it allowed admitting a patient into the OR. In practice, it is allowed to plan operations of which the expected end time is before 16:00. So this sub step does not change in the original redesigned planning method.

Step 5 *Dealing with operation cancellations*

The cancellation rule, which comes into effect at the OR department, specifies till what time it is allowed to start operating the patient and when the operation should be cancelled. Obviously, an active operation cannot be interrupted. In practice, it is only allowed to continue the original OR program when the expected end time is before 16:00. So this step does not change in the original redesigned planning method.

Step 6 *Dealing with discrepancy demand and supply*

Compared to step 3, this step is focusing on demand and supply on the operational level. In the actual situation, this was not that important since patients can be shuffled on the OR program until one week in advance. For minimizing the amount of empty time slots on the OR program, a 'non priority fill patients list' is introduced. This list consists of patients who have a high urgency period. A week prior to the final OR program, 'non priority fill patients' are placed on the empty time slots by the planners.

When patients cannot be placed in a block which is reserved according their surgery group, a block from another surgery group with available time slots is opened for them. Although these are less feasible surgery options, in this way the patients still receive a surgery date on the day of diagnosis. A disadvantage is that blocks can be occupied for the intentioned patients, who may arrive later. This underlines the importance of a well-balanced demand and supply during the reservation of blocks. When there are really no empty time slots available for patients, in spite of the flexibility described above, surgery options are searched outside the patients' planning window. When the feasible surgery options exceed the planning horizon, the patient is placed on top of the 'fill patients' list, as 'priority fill patients'. Switching patients on the OR program is not taken into account in this planning method, regarding the allocation of a *reliable* surgery date.

5.3 Data Collection and Analysis

From the 'six steps for surgery date allocation' described in the previous section, it is clear that quantitative data is important for the planning method, especially for defining operation groups (step 1) and checking whether capacity meets demand (step 2). Furthermore, data is needed for loading historical surgical cases into the simulation model which will be described in the next chapter. Historical records are retrieved from the hospital databases via an internal consultant of Radboudumc (department 'Procesverbetering & Innovatie' (PVI). In the first sub section, the needed data is discussed and the way of dealing with the obtained data from two databases is described. After that, the coupling of the two databases is explained in the second sub section. Consecutively, a short analysis is done on the missing and corresponding data of the combined datasheet in the third sub section. In the fourth sub section, the reservation of time slots on the MSS is described.

5.3.1 Needed and Obtained Data

For defining operation groups and surgical case loading, data was requested for all operated and registered patients in the past three years. By analyzing the data of operated patients, realized data can be retrieved, such as the realized surgery duration. By analyzing the registered cases, the arrival pattern can be taken into account. Therefore, the surgical status was needed to be distinguished between registered and operated patients. Further, information about the patient flow was needed to remove all urgent patients.

For defining operation groups on the basis of resource use, information was requested with respect to the sub department, the planning window (EOP and urgency period), OR (central or DS OR), needed surgeon and surgery duration (and its standard deviation). Further, the registration date was requested to analyze the arrival rate of each patient group. For loading surgical cases into the planning model, the same information was needed as stated above, plus additional information with respect to the expected surgery duration. Supplementary, the surgery date was requested to calculate the realized waiting time, which is the difference between registration date and surgery date.

The requested information was for the most part available in two different hospital databases; Oksimed and Okapi, from which Excel sheets were obtained. Prior to the introduction of Epic, the collection of statistics was done by the management team OR, with the help of Oksimed. Okapi was the planning system used at the planning office. In the Oksimed sheet, all operations were presented which have been taken place in the period from the first week of January 2010 till the last week of August 2013. In the Okapi sheet, all surgical cases were presented which were registered for operation in the period of January 1^{st} 2010 till September 24^{th} 2013. The needed and obtained data are presented in Table 4.

	General	Defining Operation Groups	Surgical Case Loading	Oksimed	Okapi
Patient Flow	×			only urgent/ not urgent	only urgent/ not urgent
Operation Status	×				×
Patient Number	×			×	×
Surgery Date	×			×	×
Registration Date		×	×		×
Needed surgeon: Z numbers		×	×	×	
EOP		×	×		
UP		×	×		×
OR		×	×	×	
Estimated Surgery duration			×		×
Realized Surgery duration		×	×	×	×
Sub Department		×	×	only CHS	only CHS
Surgical Intervention: CTG codes				×	

Table 4: Needed data for defining operation groups and/or surgical case loading, obtained from Oksimed and/or Okapi

Some remarks about the table above were essential to take into account: Firstly, with respect to the patient flow, the systems only made a distinction between urgent and elective patients. In the third sub section is described how to deal with the other patient flows. Secondly, only the employee numbers (so-called Z numbers) of surgeons were stated in the information system. However, it seemed many (co-)assistants or unknown employees were registered. Therefore, this information is only partly usable in this research. Thirdly, the EOP is unknown from the systems. The current period between the day of POS and the surgery date would not be representative for the EOP. Therefore, the EOP is determined with the planners. Fourthly, with respect to the sub department, the systems only made a distinction between CHS and the other sub departments. The sub departments could just partly be retrieved from the corresponding surgeon. Therefore, the surgical intervention was requested to discover the sub department. The surgical intervention was expressed in text format in Oksimed, which means that this would have been time-consuming to analyze the information. Therefore, the CTG codes were requested, which are further described in Appendix IV. As can be concluded from the table, both databases were needed to perform the data analysis. Therefore, the coupling of the two Excel sheets is needed, which is described in the next sub section.

5.3.2 Coupling of Databases

Both obtained Excel sheets were coupled to each other, to perform the data analysis. In the Oksimed and Okapi sheets, 16,753 and 19,451 operations were denoted respectively, which showed not all individual surgical cases could have been coupled to each other. Therefore, to start with, a preliminary analysis was done on the obtained data to remove data which did not correspond with the data in the other sheet.

In the Oksimed sheet, information regarding the sub department was distinguished in three types: general surgery, child surgery and internal medicine. The operations of internal medicine fell beyond the scope of this research. Therefore, 37 data rows were removed from the Oksimed sheet. In Okapi, the surgical status was distinguished for each surgical case. 1,424 (7.3%) cases were cancelled (and not needed to take place within a period), 207 (1.1%) cases were cancelled for the time being ('parked'), 175 (0.9%) cases were registered and not planned yet and 291 (1.5%) cases were planned and not operated yet. These 2,097 surgical cases together did not correspond to the Oksimed data, since these surgical cases were not operated (yet). The remaining surgical cases in the system were operated. 16 surgical cases had the status of being in surgery ('end of surgery', 'recovery room' or 'in operation'), while the surgery date was already a long time ago. Most of these cases had a reasonable status elsewhere in the data sheet. Therefore, the surgical cases were deleted from the data sheet, assuming these were errors. Furthermore, both databases did not cover exactly the same time period, which resulted in the removal of 310 surgical cases from the Oksimed sheet. The analysis of missing and corresponding data is described in the next sub section.

The two database sheets were coupled by creating a unique number available in both sheets. Just the patient number was not unique, since some patients were operated several times in the given time period. The combination of patient number and surgery date was neither unique, since some patients were operated several times on the same day. Therefore, a number combination was created from patient number, surgery date and surgery time. The actual coupling was done by using the Microsoft Query Wizard in Excel 2010. The data in the Oksimed sheet was taken as the basis and the data of the Okapi sheet was denoted behind the Oksimed data. After a check on unique numbers, one number was found twice in the combined data sheet, since the sum of patient number, surgery date and time was accidentally the same. These numbers were corrected for the error by hand. The coupled data sheet contained 15,962 surgical cases for which the data in Oksimed and Okapi correspond with each other.

5.3.3 Analysis of Missing and Corresponding Data

After the coupling of databases, urgent patients, semi-elective patients and some errors were removed. This is described in detail in appendix IV. Consequently, 9,556 elective surgical cases were left in the coupled database. Further, to indicate the relevant amount of missing data; 417 elective surgical cases were present in Okapi, but not in Oksimed, especially around the turn of the year. There was no clear explanation found for this fact. The other way around; about 336 elective surgical cases were presented in Oksimed, but not in Okapi, especially in January 2010. This was explained by the fact these cases had a registration date prior to January 1st, 2010, while the Okapi sheet only contained operations which were registered from this date. The weekly number of elective operations denoted in each data sheet is presented in Figure 4.

So totally 753 surgical cases were missing in one of the two databases, which is equal to 7.3% regarding the total number of elective surgical cases. For defining operation groups, this was not considered as a problem since a high number of surgical cases are left to analyze the most important interventions. However, some caution is needed during surgical case loading.

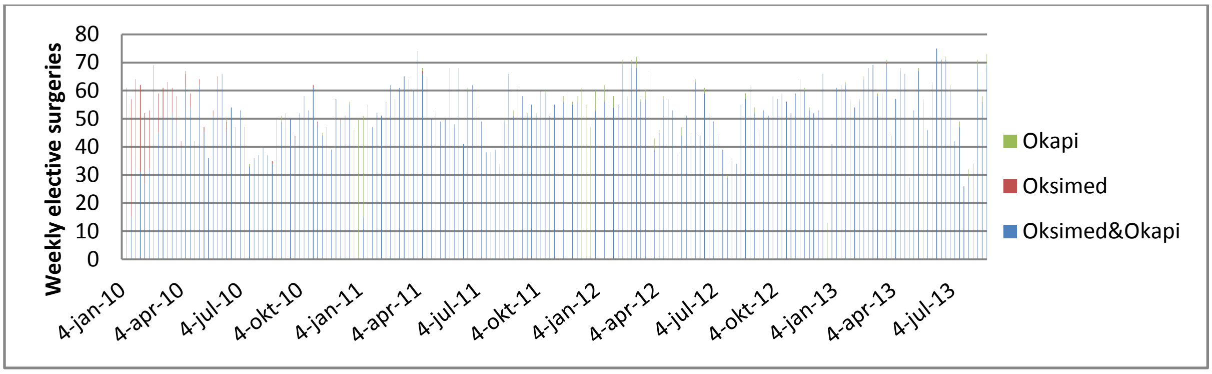

Figure 4: Number of elective operations per week, denoted in Okapi and/or Oksimed

5.3.4 Reserving Time Blocks

The definition of operation groups is described in appendix IV. The distribution of surgery durations for each operation group was analyzed by constructing box plots, which are also presented in appendix IV. Regularly, surgery durations of more than eight hours were shown in the database. When an operation exceeds the available eight hours of an OR, this is not at the expense of the remaining OR availability. Therefore, all operations which took more than eight hours were set equal to eight hours for reserving blocks. After that, a rough capacity check was done for each sub department, which is visualized in Figure 5.

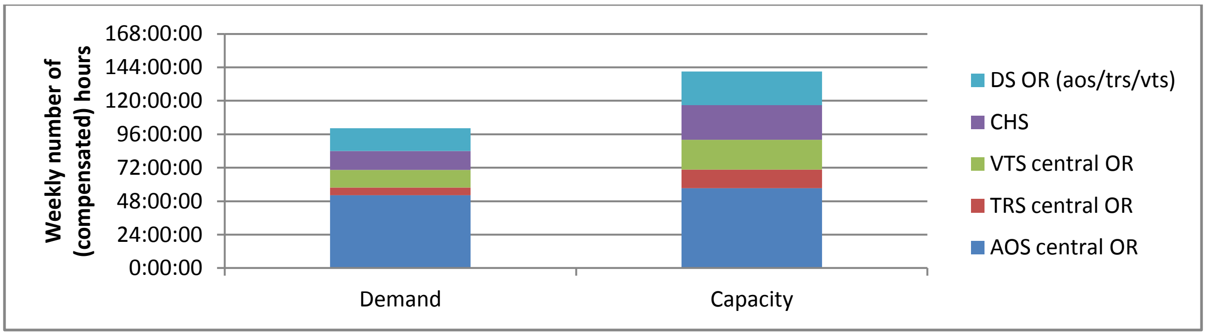

Figure 5: Capacity check for each sub department (and DS OR separately)

During the capacity check, the weekly demand was compared to the weekly available hours stated in the MSS. As can be seen, the overall demand fitted within the overall available capacity. However more specifically, aos seemed to have difficulties with fitting their demand in the allocated capacity. In practice, the match would be more difficult taking into account OR summer reduction, the patient waiting list, arrival patterns and keeping in mind that the OR occupancy could never be 100%.

Blocks of eight hours were made to reserve time blocks on the MSS. This means that the minimum amount of reserved time was equal to eighty minutes per week (one block per six weeks). The blocks were allocated for each operation group based on the weekly expected demand and the planning window. In some cases, a small planning window required more time to reserve than needed based on the demand. For example, this was the case for 'CEA' operations. The result of the average weekly allocated capacity compared to the average weekly demand is shown in Figure 6. As can be seen, for several aos treatments on the central OR is a capacity shortage. Within the created block allocation, HIPEC, PANCREAS MALIGNE, SARCOMEN and SCHILDKLIER would have a capacity shortage. Furthermore, HIPEC and SLOKDARM have a capacity shortage concerning the planning window. Further, LEVER and MAAG have barely enough capacity within this block allocation. However, within the current MSS this cannot be improved. On the other hand, 'TRSOVERIG' and 'KIND' seemed to have an adequate amount of capacity compared to their weekly demand.

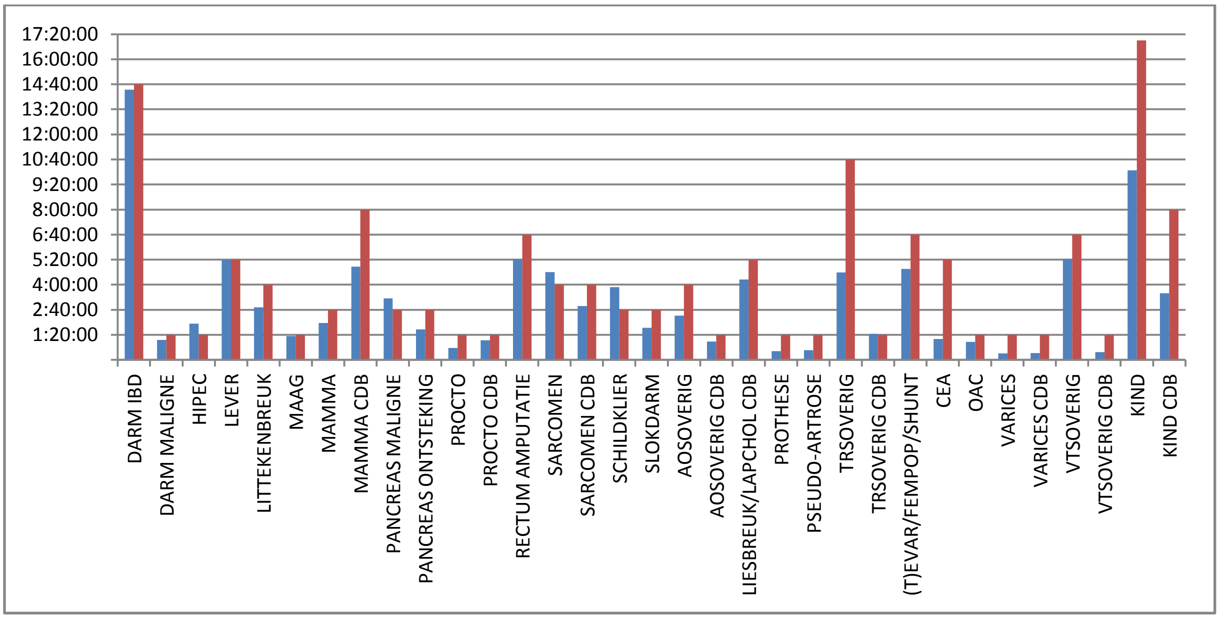

Figure 6: The average weekly allocated capacity (in red) compared to the average weekly demand (in blue)

After the allocation of OR time to each operation group, the blocks were equally spread over the MSS. The reservations of operation groups which are currently used already are placed in the same blocks on the MSS, such as LIESBREUK/LAPCHOL on Mondays at the DS OR. Simultaneously, the time blocks were also reserved for surgeons, taking into account the surgeon availability. Furthermore, the time blocks reserved for operation group and surgeon were needed to match with each other, taking into account the surgeon - operation group combinations. Otherwise it would not be possible to combine these block scheduling strategies in the simulation model. The MSS including reserved time blocks for operation groups and surgeons is presented in appendix IV, in Table 18 and Table 19.

6 Simulation Model

A simulation model is developed to schedule the elective patients into the OR's and to evaluate how several scenarios of the planning method would influence the planning performance. In the first section the simulation model development is described. The configuration of the model is explained in the second section, in which decisions are explained regarding the length of each simulation run, the length of the warm-up and cool-down period, and the number of independent simulation runs. In the third section, the model verification and validation for the current situation are described.

6.1 Model Development

The simulation model is developed in Microsoft Excel 2010 since this software is available within Radboudumc. Furthermore, many people are familiar with working in Excel and therefore, the simulation model would not discourage employees on the GS department to think along in the model development process. Moreover, modeling in Excel increases the opportunity that other hospital employees are going to use the simulation model in practice, for developing a planning instrument. The programming language Visual Basic for Applications (VBA) is used to realize the simulation. The simulation model is generic, which implies that the model can be used in other situations by changing the input. In this section, the components of the simulation model are further explained. In the first sub section, the input of the simulation model is described. In the second sub section, the planning method of the simulation is described. Finally in the third sub section, the performance measures are described, which presented the output of the simulation model. An overview of the input, planning method and output is shown in Figure 7.

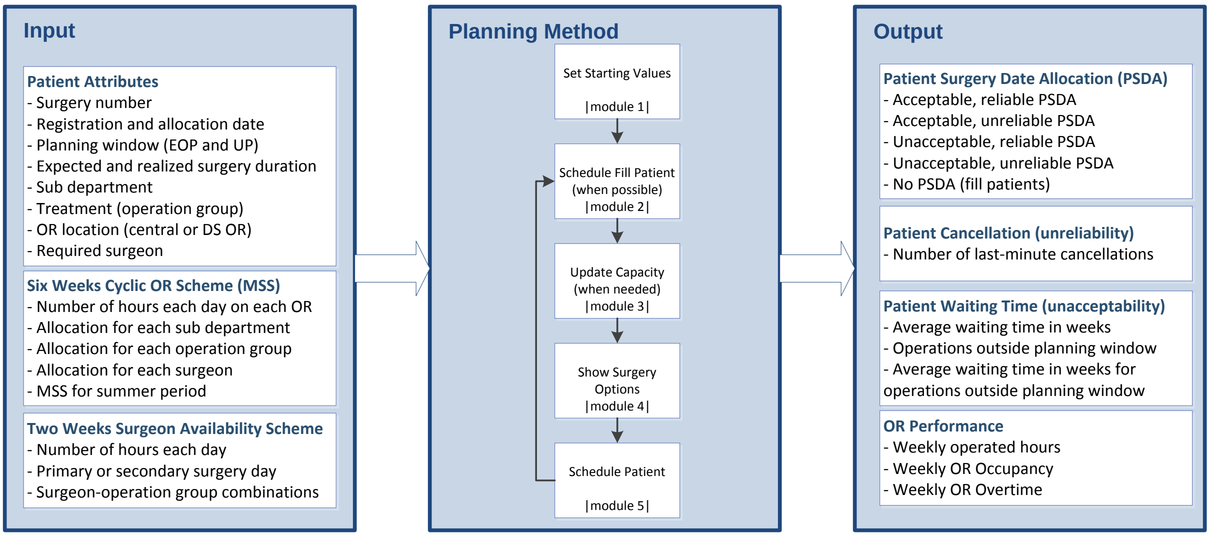

Figure 7: The input, planning method and output of the simulation model

6.1.1 Input

The input of the simulation model includes the patient attributes, the MSS and the two weeks cyclical surgeon availability scheme. These are needed to be known before running the simulation model. The input is presented in several Excel sheets. Firstly, the 'patients' sheet contains all patients with its attributes. For each patient, the planning window is filled in by reading the 'Lookup patient groups' sheet. Secondly, the OR availability is presented in the 'OR capacity' sheet, which is filled by reading the 'Lookup OR scheme' sheet containing the MSS. In the same way, the surgeon availability is presented in the 'surgeon capacity' sheet, which is filled by reading the 'Lookup surgeon scheme' sheet containing the two weeks cyclical surgeon availability scheme.

Several patient attributes are needed for simulation. Firstly, a unique operation number is defined as patient attribute, to distinguish the operations. Secondly, the registration date is needed on which the patient receives the surgery date. In some cases it is needed to distinguish the registration date and the allocation date when they do not correspond. Therefore, the allocation date is added to the simulation model as patient attribute. Thirdly, the planning window is needed, which is the period in which the surgery date should be scheduled. These are obtained from the defined operation groups. Fourthly, the surgery duration expected by the surgeon is used as patient attribute. In the simulation model, the realized surgery duration is needed to be known to calculate the OR overtime. Therefore, the realized surgery duration is added as patient attribute. In appendix IV is described how is dealt with realized surgery duration outliers. Fifthly, the sub department of the patient is needed to be known, which is obtained from the data analysis described in the previous chapter. Sixthly, the treatment of a patient is defined as a patient attribute, which is taking into account by looking up the defined patient group. Further, whether the operation must be performed in the central or DS OR is needed to be known in advance. Additionally, an eventually required surgeon is defined as patient attribute.

The second part of the input consists of the MSS, which contains the number of available hours each weekday on each OR and the allocation for each sub department. Further, the MSS is specified with reserved blocks for operation groups and surgeons. An adapted MSS is used during summer holidays, since the OR capacity is reduced for six weeks during that period.

The third part of the input consists of the two weeks surgeon availability scheme, including the number of available hours each day for even and odd weeks. Primary and secondary availability is distinguished, which indicates which surgeon has priority to plan in an OR. This is currently in use on the planning office. Furthermore, the specializations of surgeons have to be taken into account. Therefore, a scheme is made which contains the information which combinations of surgeon and operation group are possible.

6.1.2 Planning Method

The planning method of the simulation model is written in six modules (divided in six steps): setting all starting values in the Excel sheets, scheduling the fill patients, updating the capacity values, showing the surgery options of a patient, scheduling the patient and calculating the output. The first five modules are described in this section. The sixth step which contains the output is described in the next sub section. An extended flow chart of the simulation model is presented in Appendix V.

Module 1: Setting Start Values

The simulation model starts with setting all values in the Excel sheets. This includes the increased sorting of the patient registration dates, and the filling of the 'OR capacity' and 'surgeon capacity' sheets with availability for twelve weeks, counting from the earliest registration date.

Module 2: Schedule Fill Patients

After the first module, the model considers once a week (on Mondays before the first patient arrives) whether there are 'fill patients' who can fill up the OR program for coming week. As described in the last step of the six steps for surgery date allocation, 'non priority fill patients' and 'priority fill patients' are distinguished. The last group of patients is placed on top of the 'fill patients' list, since these patients have a higher urgency. For 'non priority fill patients', a replica is added to 'patients' sheet for the last eight weeks of the patients' urgency period. In this way, these patients have more certainty to be planned within the planning window.

'Fill patients' can be planned in the OR when their EOP is elapsed, there is sufficient OR time left and the OR block is reserved for the patients' sub department. When this is the case, the surgeon options are checked regarding availability, surgeon-operation group combination and required surgeon. Further, a priority is given to the surgeon who has a primary surgery day, and more priority is given to the surgeon for whom the OR block is reserved. The working of priorities is further explained in the fourth module. The choice of a surgery date and the cancellation rule are further described in the fifth module. When the operation will not be cancelled, the patient is removed from the 'fill patient' list, otherwise the 'fill patient' is considered again in the following week.

Module 3: Updating Capacity Values

After four weeks of planning, the 'OR capacity' and 'surgeon capacity' sheets are updated with four weeks of new capacity, reading from the 'Lookup OR scheme' and 'Lookup surgeon scheme' sheets, respectively. In step zero of the six steps for surgery date allocation, the choice for the amount of weeks was described.

Module 4: Showing Surgery options

In the fourth module, a patient from the patient list is considered. All surgery options within the planning window of the patient are checked for feasibility. With respect to the OR, the surgery option must satisfy the allocation for sub department. Further, the available capacity should be sufficient for the expected surgery duration. In this situation, the admission rule is applied; it is not allowed to plan operations which are *expected* to be finished after 16:00. After that, increasing priority is given to the OR option which is reserved for the operation group and the OR option of a block on which a patient is already scheduled (based on the bin-packing theories), respectively. With respect to the surgeons on a feasible surgery option, the surgeon should have sufficient availability left, and the surgeon-operation group combination and surgeon requirement should satisfy. After that, increasing priority is given to the surgeon who has a primary operation day and the surgeon option of a block which is reserved for the surgeon, respectively. The flow chart presented in appendix V shows how the model assigns OR values and surgeon values to the OR and surgeon options, respectively. On the basis of the total values, the model assigns a particular color to the surgery option. In Table 5, an example is given of some feasible surgery options shown in the 'OR capacity' sheet, after running module 4. For this patient, Tuesday in OR5 is the best surgery option. The number of feasible surgery options, distinguished for each color, is also denoted in 'patients' sheet.

When there is no feasible surgery option within the planning window, the model adds three days to the urgency period so that it searches for a surgery date three days after the planning window. This process repeats until a feasible surgery option is found. When this happens too often, the urgency period exceeds the planning horizon. In this situation, the patient is placed on top of the 'fill patients' list, and at the bottom of all 'priority fill patients' who arrived before.

Week number	Weekday	DAY	OR3	OR4	OR5	OR8	OR16	OR34	OR36
32	Mon	5-8-2013	8	8	8	0	0	0	8
32	Tue	6-8-2013	0	8	8	8	8	0	8
32	Wed	7-8-2013	0	8	8	8	8	0	8
32	Thu	8-8-2013	0	8	8	8	0	8	0
32	Fri	9-8-2013	8	8	0	0	5	0	0
32	Sat	10-8-2013	0	0	0	0	0	0	0
32	Sun	11-8-2013	0	0	0	0	0	0	0

Table 5: Different colors show the highest (green) to the lowest (red) feasible surgery options in the 'OR capacity' sheet

Module 5: Scheduling Patient

When module 4 has found a feasible surgery option, a patient is planned in the fifth module. In practice, the patient can choose a surgery option from the best feasible ones. The actual choice process of a patient is mimicked by a random choice between the best feasible surgery options. The surgery date, OR and surgeon of the chosen surgery option are denoted in the 'patients' sheet. Additionally, the 'OR capacity' and 'surgeon capacity' sheets are updated by subtracting the expected surgery duration. Then, the cancellation rule is applied: In this rule the actual operation day is simulated, where at some point all realized surgery durations of earlier patients are known (denoted in the 'OR program' sheet). If at that moment the expected finishing time of the patient is after 16:00, the patient should be cancelled. When the patient is cancelled, a new data row is added to the 'patients' sheet with the allocation date equal to the (cancelled) surgery date. When the patient is operated, the realized surgery duration is added to the 'OR program' sheet. When the patient is a replica of the fill patient, the patient is removed from the fill patient list. The simulation continues by running the second module for the next data row in 'patients' sheet until all patients are operated.

6.1.3 Output

The performance measures are calculated from 'patients' sheet in which the surgery date, OR and surgeon are denoted behind each patient, and from 'OR program' sheet in which all realized surgery durations are denoted. The performance measures are presented in the 'output' sheet. Four categories of performance measures are considered, which follow from the research objectives: patient surgery date allocation (PSDA), patient cancellation, patient waiting time and OR performance. These are described in this sub section.

Firstly, patient surgery date allocation (PSDA) is defined as the number of patients who received a surgery date on the day of diagnosis. A distinction is made between PSDA regarding acceptability and reliability. All patients who not received a surgery date on the day of diagnosis were 'fill patients'. A distinction is made between the 'non priority fill patients' and the 'priority fill patients'. Further, regarding the overall performance measure, a distinction is made between operation groups, expressed in number of patients and percentages.

Secondly, operation cancellation is defined as the number of operations which were planned in advance and were cancelled on the day of surgery due to overtime of prior operations. This performance measure expresses the (un)reliability of the planning method. A distinction is made between all operation groups, expressed in number of patients and percentages.

Thirdly, patient waiting time is defined as the number of weeks a patient had to wait between the registration date (day of diagnosis) and the surgery date. This performance measure gets significant meaning when the patient urgency period is taken into account. Therefore, the number of patients operated outside the planning window is calculated and is expressed in number of patients and percentages. This performance measure expresses the (un)acceptability of the planning method. Further, the average waiting time of the patients operated outside the planning window is given. Regarding the overall performance measure, a distinction is made between operation groups.

Finally, performance measures are defined concerning the OR performance. The weekly operated hours are the sum of all realized surgery durations for every OR in one week. The OR occupancy is defined as the part of the available OR capacity that was actually used for production. The weekly operated hours are compensated for operation overtime, so that the OR occupancy cannot exceed 100%. This number is divided by the weekly available OR capacity stated in the MSS. The weekly overtime is defined as the number of OR overtime hours.

Further, the length of the patient waiting list at the beginning and at the end of the simulation is interesting for analyzing the throughput. The waiting list is not automatically generated by the simulation model, but is calculated by hand from the generated information in the patients list. In the same way, information regarding the feasibility of surgery options is obtained to find out whether patients could actually choose between surgery options.

6.2 Model Configuration

After developing the simulation model which was explained in the previous section, the runs can be made. In this section, the simulation model configuration is discussed, regarding the length of each simulation run, the length of the warm-up and cool-down period, and the number of independent simulation runs.

The situation on the planning office is very dynamic, also regarding the OR and surgeon capacity. For example, one extra surgeon would increase both inflow of patients for operation (due to an increase in appointments on the outpatient department) and outflow of patients by operating them. However, this is dependent on the availability of OR capacity as well. Therefore, the length of each simulation run is mainly defined on the basis of input tenability, which is also desired regarding the model validation. Historical records of patients who needed to be operated after January 1st, 2013, are loaded into the simulation model from the combined datasheet. On August 31st, 2013, no patients are allowed to arrive in the simulation model. Consequently, 1974 patients are loaded into the simulation model. The simulation model stops running when all patients have been planned.
The weekly operated hours are presented in Figure 8. It seems no warm-up period has to be taken into account at all. This can be explained by the fact 439 patients arrived prior to January 1st, 2013, who filled up the empty OR program at the start of the simulation. However, these patients received the surgery date quite easily, which would give wrong premises (too positive) of the PSDA stated in the output. For that reason, a warm-up period has to be taken into account. A warm-up period of one month is chosen, which means the output was registered from February 1st, 2013. As can be seen in the figure, there are still patients operated after the last patient arrival. The last patient was planned in October. In reality, these patients were planned before August 31st. Obviously; the

planning in the simulation becomes easier when no patient arrives in the meantime. Therefore, the output is registered until September 1st, 2013.

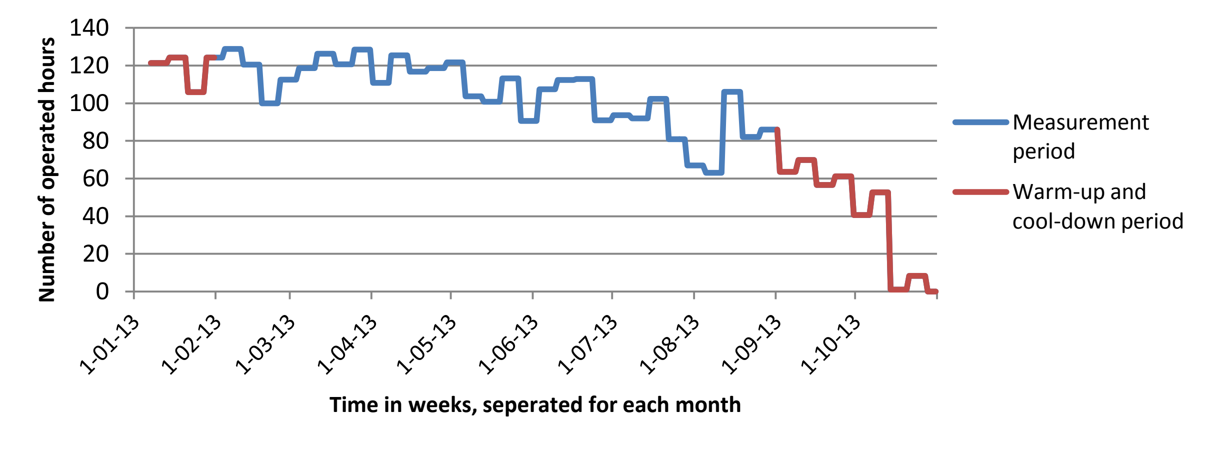

Figure 8: Weekly operated hours

Since random numbers are used during the admission heuristic, each simulation run gives some different results. Therefore, five independent simulations are run, to analyze the differences in output. The coefficient of variation (CV) is calculated by the quotient of the standard deviation and the average. The CV shows the relative dispersion and is presented in Table 6, together with the simulation results. As can be seen from the CV, the results are comparable for each run. This can be explained by the fact that 71% (based on the first run) of all (executed) operations had only one surgery option, which means no random numbers were generated for these operations. Therefore, it is decided that one replication is sufficient to make confident conclusions on the basis of the simulation results.

	Runs					
	1	**2**	**3**	**4**	**5**	**CV**
Run duration (in minutes)	38.5	36.2	34.9	37.4	36.4	0.037
# Operated patients during simulation period	1567	1556	1568	1572	1581	0.006
# Operated hours during simulation period	3243	3257	3254	3270	3302	0.007
Waiting list on 01-02-2013 (in # patients)	424	419	423	423	422	0.005
Waiting list on 01-02-2013 (in expected hours)	961	953	948	956	949	0.006
Waiting list on 01-09-2013 (in # patients)	134	140	132	128	118	0.063
Waiting list on 01-09-2013 (in expected hours)	352	330	328	320	282	0.079
Reliable and acceptable PSDA (in % of operated patients)	45%	44%	45%	45%	46%	0.016
Unreliability: patient cancellation (in %)	13%	13%	13%	12%	12%	0.043
Unacceptability: outside planning window (in %)	45%	45%	45%	45%	44%	0.010
Average waiting time (in weeks)	6.3	6.2	6.2	6.1	6.3	0.013
Unacceptable average waiting time (in weeks)	7.9	8.0	7.9	7.9	8.1	0.011
Average weekly occupancy (in %)	76.9%	77.1%	76.7%	76.8%	77.8%	0.006
Average weekly overtime (in hours)	2.08	2.12	2.53	2.56	2.27	0.097

Table 6: Output of five independent replications

6.3 Verification and Validation

Model verification is concerned with determining whether the simulation model is working as intended, while model validation is concerned with determining whether the simulation model is an accurate representation of the actual system being studied (Law, 2007). These are described in this chapter.

6.3.1 Verification

Law (2007) described eight techniques which can be used to debug the computer program of a simulation model. Most of them are also used during the development of the simulation model of this research. To start with, an interactive debugger is used in VBA. When a certain type of error was in the code, the simulation run stopped at that point in time. Further, the function 'toggle breakpoint' is used frequently to discover the values of some variables at a selected point in time.
Secondly, the simulation model is written in six modules which were described in the first section of this chapter. In this way, the model is debugged in several steps by only running a particular module. In the beginning, the model only consisted of modules 1, 4 and 5 and was later extended with the other modules after debugging the simplified model. Furthermore, the modules itself were programmed less detailed in the beginning and were later extended after debugging.
Thirdly, the simulation model is run under a variety of settings of the input parameters and is checked for a reasonable output. For example, the PSDA is computed by hand from the patient sheet containing the registration and surgery dates, and is compared with the model output. Further, the model is run under simplifying input parameters. In the beginning of the model development, only a couple of OR's, surgeons and patient groups were taken as input.
Fourthly, a simple animation for the most important steps in the simulation model is made. During the animation, one observes the different surgery options for a patient in different colors (step 4) and subsequently the chosen surgery option (step 5). In this way, there is checked whether the simulation model considers the right surgery options for a patient.
Another technique described in Law (2007), but not considered in this research, is reviewing the computer program by more than one person. This would avoid the writer gets into mental rut. To a certain extent, this is done by the first supervisor of this research. Additionally, the author mentioned comparing historical mean and variance with the simulation input probability distribution, and using a commercial simulation package. However, these two are not applicable to this research.

6.3.2 Validation

Law (2007) highlighted that there is no absolute model validity. Therefore, the author described several techniques for *increasing* the validity of a simulation model. The most important of them are also applied to the simulation model of this research. To start with, high-quality information and data is collected, in several ways: initially, conversations are held with so-called subject-matter experts. During the project, there is worked closely with the planners of the planning office and information is obtained from surgeons from each sub department. Furthermore, especially in the first months of the research period, the way of working at the planning office is observed to get an idea of the current planning method. Additionally, data from historical records are obtained and discussed several times with an internal PVI consultant.

Furthermore, the output of the simulation model is validated with the output of the existing system. However, the simulation model is not reprogrammed to a model containing exactly the current planning method, since the focus of giving a surgery date on the registration date is too dominant in the simulation model. Further, the current block scheduling method (reserving time for some treatments and not for others) is not exactly copied into the model. Therefore, some differences in output can be expected in advance. The summarized results are presented in Table 7. The presented numbers of the simulation model are the average numbers of the five independent replications described before. The results of the existing system are summarized from Appendix VI, in which the output of the existing system is described in more detail.

As can be seen in the table, more patients were operated in the existing system than during the simulation period. This can be explained from the fact that arriving patients who were not yet operated on September 1st, 2013, are not included in the simulation model. In reality, 460 patients were waiting for an operation and 269 of them arrived in July and August. Probably, if these would have been included in the simulation model, the number of operated hours in August after the holiday period would be higher (Figure 8) and would approach the number of operated hours of the existing system (presented in appendix VI). Partly, this can also be explained by the actual planning method; by waiting one week prior to the final OR program, a full program can be developed by shuffling patients till the last moment. Most likely, the higher amount of patients results in a higher weekly OR occupancy and a higher weekly OR overtime compared to the simulation model. However, the difference between these numbers is probably smaller since the results of the existing system are obtained from Oksimed, which includes semi-elective patients as well.

Another remarkable result from the table is the higher (unacceptable) average waiting time in the existing system compared to the simulation model. It could be that the (unacceptable) waiting time of the simulation model increases when the patients who are operated after the simulation period are included. However, this influence is expected to be marginal concerning the number of operated hours and number of patients. Additionally, the higher average waiting time can partly be explained from the fact that the actual planning method is less able to focus on the planning window than the simulation model. Further, the actual urgency periods can vary in practice, while the urgency periods for the simulation model are the same for each patient within an operation group. A surgeon can decide that it is medical sound to wait longer with operating the patient. This would explain the much higher unacceptable waiting time.

Furthermore, the table shows similar percentages for unacceptable operations. This can be explained by the high patient waiting list in both situations: not all patients fit in the available capacities on time. Unfortunately, the patient cancellation specified for the reason of OR overtime was not obtained from the existing system. As a conclusion; although the simulation model is not completely validated, there is a good explanation for the differences with the output of the existing system.

	Simulation Model	Existing System
Operations during simulation period (in #patients | operated hours)	1569 | 3265	1706 | 3596
Unacceptability: outside planning window (in %)	45%	45%
Average waiting time (in weeks)	6.2	7.6
Unacceptable average waiting time (in weeks)	8.0	12.4
Average weekly occupancy (in %)	77.1%	86%
Average weekly overtime (in hours)	2.31	7.55

Table 7: Output simulation model vs. realized performance existing system (Oksimed&Okapi, Oksimed)

7 Scenarios for Simulation

In this chapter, six scenarios of the redesigned planning method are described which are simulated to analyze how they influence the output. Most scenarios are variations of the six steps described in section 5.2. Consequentially, keeping the research question in mind, six sub questions for simulation are defined. These questions are presented in the overview below. In the last section of this chapter, the resulting number of planning method variations is shortly described.

Sub Questions for Simulation

- How do the admission and cancellation rules affect the planning performance?
- How do the four block scheduling strategies affect the planning performance?
- How does the sequencing of patients for one registration day (giving a surgery date *after* the day of diagnosis) affect the planning performance?
- How does a modification of the resource allocation of sub departments affect the planning performance?
- How does the OR flexibility of ‘fill patients’ affect the planning performance?
- How does a patient waiting list reduction affect the planning performance?

7.1 Admission and Cancellation Rules

The first scenario includes several variations of the admission (step 4c) and cancellation rules (step 5). The current admission rule allows planning operations until the given end time of the OR (mostly 16:00). Accordingly, it is allowed to plan for (mostly) eight hours. The variation of the admission rule allows some OR overtime and permits to plan operations of which the expected end time is before (in most cases) 16:30. By adding a bit more extra time for the admission rule during the simulation, some improvement can be expected on acceptability. Fei et al. (2010) considered a slightly similar concept in their paper, by including the ‘fuzzy constraint’ in their heuristic when no sufficient OR time was left. In that case, the patient was assigned to the OR with the most remaining time left, taking into account some limited overtime (defined as Min{15 minutes, the OR’s maximum overtime}). In this research, the OR’s maximum overtime is defined during the cancellation rule.

Under the current cancellation rule, operations are cancelled last-minute when the expected end time of operation exceeds the end time of the OR (mostly 16:00). Two variations of the cancellation rule are considered which allow some expected OR overtime. The expected end time of an operation is allowed to be half an hour or one hour after the end time of the OR. In practice, the variations of the cancellation rule seem reasonable. Explicitly, at the latest moment it can turn out that operation overtime occurs. On that moment, the following patient is probably already present at the OR department, ready for the operation. It would be implausible to cancel this patient because the operation is expected to end five minutes after 16:00. After all, it is possible that the operation is finished earlier than expected. Furthermore, the decision to go through is even more likely in case the patient has been cancelled before, or in case the patient already falls outside the planning window. For that reason, some improvements can be expected on reliability. The admission and cancellation rules are considered together, since they depend on each other.

7.2 Block Scheduling Strategies

A second scenario includes the variations in block scheduling strategies, in which time blocks are reserved for surgeons and/or operation groups (step 3). Four different block scheduling strategies are considered. In strategy 1, no blocks are reserved and the operation planning is only restricted to the allocation per sub department. In strategy 2 and 3, time is only reserved for operation groups and surgeons, respectively. In strategy 4, time is reserved for both operation groups and surgeons, which is the case in the redesigned planning method so far.

Generally, as turned out from literature, strategy 1 results in lower OR occupancy and higher patient cancellations than a strategy with block reservations (Pham & Klinkert, 2008). Hans et al. (2008) showed that OR capacity can be freed within the limits of the risk of overtime by clustering operations with similar duration variability (portfolio effect). This leaded to OR blocks on which the same type of operations were performed, which is similar to block scheduling strategy 2 and 4. Surgeon capacity restrictions were ignored in the study, but the authors expected an additional advantage by coupling one surgeon to the same type of operations on an OR day (strategy 4). Namely, the surgery duration would be reduced because of the repetitive nature of the work for surgeons (Hans et al., 2008). That surgeon capacity restrictions should be taken into account under strategy 1 and 2, underlined the literature study of Dexter et al. (2001). The authors showed that a scheduled delay between two surgeons' operations improved the likelihood that a second surgeon's operation starts on time. For strategy 3 and 4, a scheduled delay within blocks is not needed.

Unfortunately, OR idleness because of waiting for an occupied surgeon on another OR is not registered in the simulation model. Therefore, the simulated OR occupancy under strategy 1 and 2 is expected to be higher than it would be in reality. Additionally, possibly reduced surgery durations as expected by Hans et al. (2008) under strategy 4 are not taken into account. Therefore, one should be careful with comparing the simulated results of the block scheduling strategies. Probably, slightly better simulation results upon reliability can be expected under strategy 3 and 4 regarding the portfolio effect. Further, better simulation results upon PSDA can be expected under strategy 2 and 4, since these strategies leave empty time slots open for patient groups with small planning windows.

7.3 Patient Sequencing

Thirdly, to know whether it would be beneficial to allocate the surgery date one day *after* the day of diagnosis, patients are sequenced within the same date of registration. In the 'patients' sheet of the simulation model, a first sorting is done on the urgency period (the highest urgency patients on top), a second sorting on surgery duration and a third sorting on surgeon requirement (a surgeon requirement on top). Two variations are considered regarding the second sorting: sequencing on longest processing time (LPT) first and shortest processing time (SPT) first.

By sorting the patients by urgency period from nearest to furthest, a slightly improvement can be expected on acceptability. Testi et al. (2007) considered both LPT and SPT sequencing rules on the operations which were planned on the same day and OR. LPT showed decreased performance on overruns and shifted operations compared to the situation in the authors' case study, while SPT showed improved performance on the number of operations, overruns and shifted operations. The sequencing rules are expected to have less impact than in the research above, since the sequencing rules are used for the order of patients who receive a surgery date first, rather than the order of patients who is operated first on a surgery date.

7.4 Resource Allocation Adjustments

The resource allocation adjustments include the fourth and fifth scenario: a modification of the MSS and the 'fill patient' OR flexibility. On forehand, scarcity of aos OR capacity and some empty time slots for trs and chs on the OR program can be expected regarding the capacity check which was described in section 5.3. Therefore, a modification of the MSS is considered, by reallocating hours within the following sub departments (step 2): 32 hours are reallocated from TRSOVERIG to HIPEC (16 hours), PANCREAS MALIGNE (8 hours) and LEVER (8 hours). Further, 28 hours are reallocated from KIND to SARCOMEN (5 hours), SCHILDKLIER (1 block of 8 hours), SLOKDARM (5 hours) and MAAG (5 hours). With the MSS modification, better simulation results can be expected upon PSDA and acceptability for aos, without worsening the performance for trs and chs.
The OR flexibility of 'fill patients' implies whether the 'fill patients' can be admitted in all OR's (only constrained for central and DS OR) or only in the OR of their own sub department which is the case in the current simulation model (step 6). Pham and Klinkert (2008) defined add-elective cases as elective patients who fill up OR blocks of the next surgery day in order to maximize OR occupancy. Including the 'fill patients' flexibility to the simulation, an increased OR occupancy can be expected for aos, vts and chs. It is interesting to combine this scenario with the MSS modification, since the trs sub departments hands in many hours during the reallocation. However, in practice this requires some flexible availability of surgeons, since the surgeon program is known one week in advance.

7.5 Reduced Waiting List

The historical waiting list includes all registered patients from the combined datasheet who were not operated yet on January 1st, 2013. This includes 439 patients who demanded 998 hours of (expected) surgery duration. The left circle diagram of Figure 9 shows how this number of demanded operation hours is divided among each sub department and central (COK in the figure) or DS OR (CDB in the figure). As can be seen, the aos treatments were responsible for 70% of this waiting list. The aos patients on the central OR demanded almost 580 operation hours. Subsequently, 169 patients of the waiting list had to be planned immediately according their urgency period. Of these patients, 69 percent belonged to the aos sub department.
Considering the MSS, his implies that it would take more than ten weeks to operate all aos patients on the central OR, without operating patients who are arriving at the meantime and assuming an OR occupancy of 100%. As concluded from the capacity check during the reservation of operation groups, the waiting list can hardly be caught up. Namely, the average weekly demanded hours from arriving patients meet the weekly OR capacity allocated for the aos sub department, without leaving many time slots open on the OR program. As a result, the simulation results are expected to be disappointing on the performance measures acceptability (operated within planning window) and reliable & acceptable PSDA, especially for aos.

To analyze the influences of a planning without an enormous waiting list, the reduced waiting list is added to the scenarios. For the reduced waiting list at the start of the simulation, all patients who fell outside their planning window on January 1st, 2013 are assumed they have been operated and were left out of the simulation model. As a result, the waiting list is reduced with 38%, to 270 patients. These patients demanded in total 580 hours of expected surgery duration, which is a reduction of 42% compared to the historical waiting list. The right circle diagram of Figure 9 shows the portions of each sub department and OR. As can be seen, the proportion of the sub departments to each other is comparable to the historical waiting list. Still, the aos treatments on the central OR demanded more than 300 hours. 45% of them were DARM IBD patients. Including the reduced waiting list, the simulation results are expected to perform better on the acceptability and reliable & acceptable PSDA.

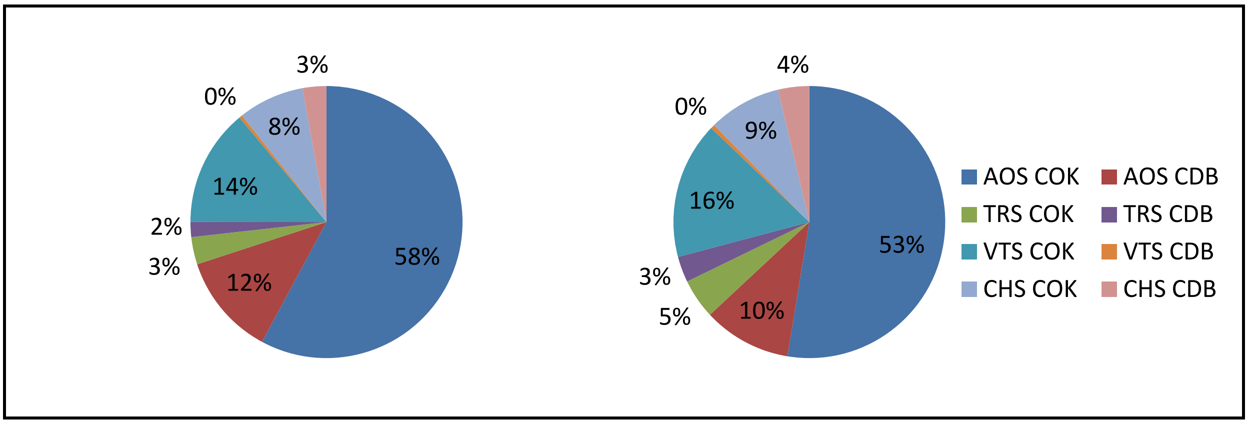

Figure 9: Historical (left) and reduced (right) waiting lists on 01-01-2013 in expected surgery durations

7.6 Number of Planning Method Variations

In Figure 10 the positions are visualized of the six planning method modifications within the simulation model. The six scenarios and its variations which are described in the previous sections can all be combined to different planning methods for the simulation model. As a result, there would be 480 possibilities of the planning method. (This is a multiplication of 5 variations during admission and cancellation rules, 4 block scheduling strategies, 3 variations of (no) patient sequencing, 4 variations of resource allocation adjustments and 2 variations of the waiting list.) Therefore, during the analysis of the results, some possible methods are excluded on forehand. Furthermore, it is not needed to analyze all possibilities of the planning method to make confident conclusions about the influence of a planning method modification. The structure of the scenarios during the simulation is described in the next chapter.

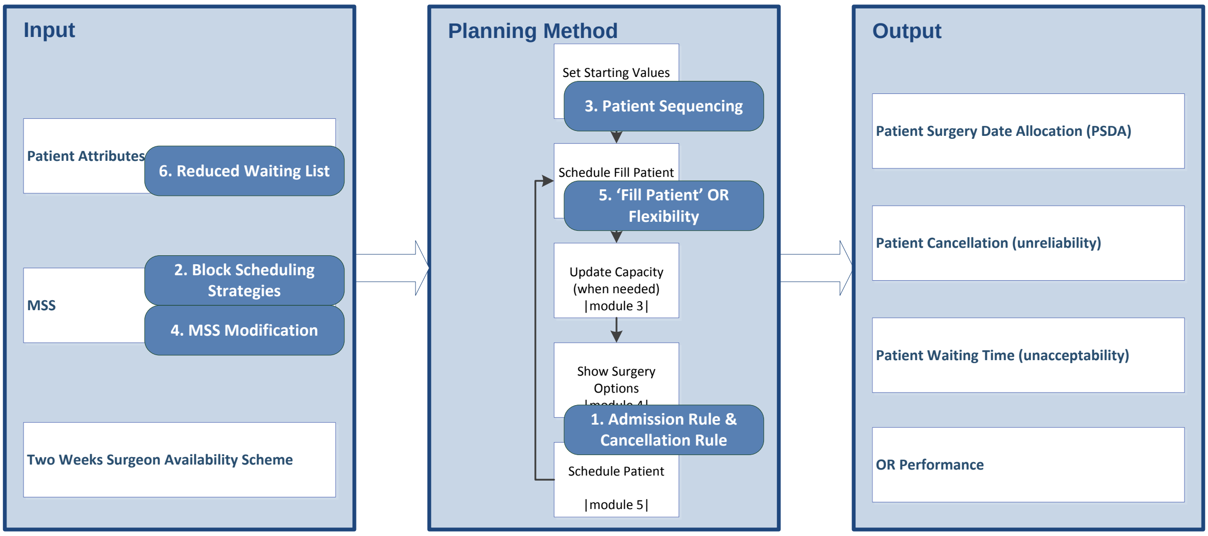

Figure 10: A visualization of the complete simulation model with its scenarios of the planning method

8 Results

In the previous chapter, all modifications of the planning method were described. To have a quick overview of the run which is discussed, names are given to the modifications in the following order: *admission rule - cancellation rule / block scheduling strategy / patient sequencing / fill patient flexibility - MSS / waiting list*. So far, the run *8-8/4/0/0-historical/historical* is considered.
Since October 2013, the GS department allocated four extra hours on Fridays on the DS OR for abdominal surgery. Therefore, extra hours for MAMMA, SARCOMEN, PROCTO and AOSOVERIG are added to the historical MSS described before. As can be seen in Table 8, the 24 hours addition to the MSS has generally a positive influence on (reliable and acceptable) PSDA and acceptability. However, the weekly OR occupancy is decreased. All further described modifications of the planning method are based upon the actual MSS including the 24 hours increase of OR capacity.

	MSS	
	Historical	**Actual (+ 24 DS)**
Run duration (in minutes)	36.7	33.9
# Operated patients | hours during simulation period	1569 | 3265	1546 | 3225
Waiting list on 01-02-2013 (in # patients | in expected hours)	422 | 953	413 | 933
Waiting list on 01-09-2013 (in # patients | in expected hours)	130 | 322	144 | 342
Reliable and acceptable PSDA (in % of operated patients)	45%	53%
Unreliability: patient cancellation (in %)	13%	14%
Unacceptability: outside planning window (in %)	45%	36%
Average waiting time (in weeks)	6.2	5.9
Unacceptable average waiting time (in weeks)	8.0	8.7
Average weekly occupancy (in %)	77.1%	74.3%
Average weekly overtime (in hours)	2.31	2.14

Table 8: 8-8/4/0/ 0 - ... /historical

This chapter is organized by presenting the results of the historical patient waiting list in the first section, and the results of the reduced waiting list in the second section. In each section, the order of scenarios is structured according Figure 11.

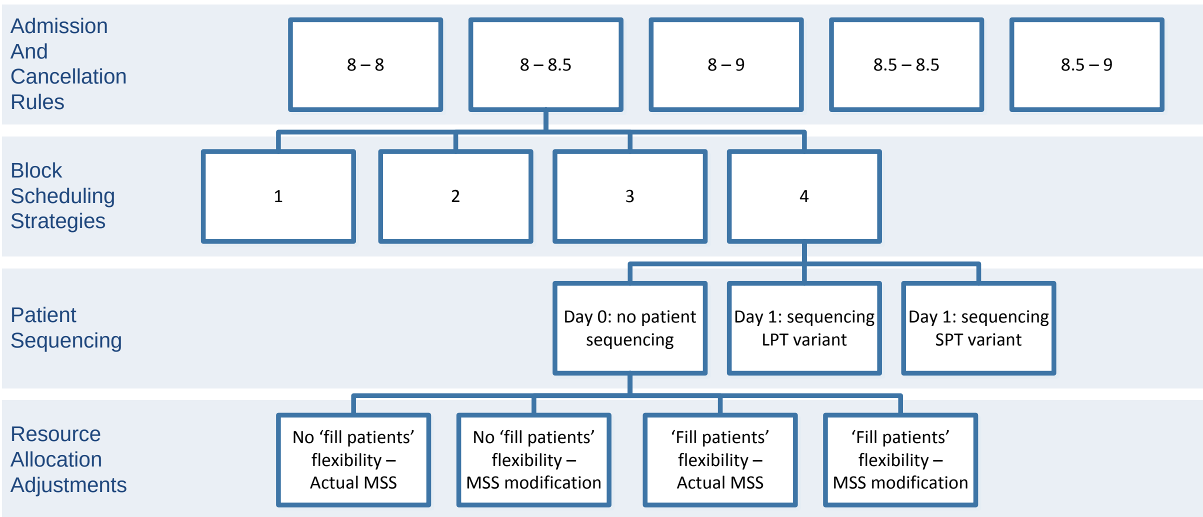

Figure 11: Structure of the scenarios which are simulated for the historical and reduced waiting list

8.1 Historical Waiting List

In this section, the results of each planning method scenario are presented, including the historical waiting list. As can be seen from Figure 11, the admission and cancellation rules are the first scenarios to consider, so these are described in the first sub section. In the consecutive sub sections, the results are given of the four block scheduling strategies, the patient sequencing rules and the resource allocation adjustments.

8.1.1 Admission and Cancellation Rules

The results of the admission and cancellation rules modifications are shown in Table 9. The variation of the cancellation rule causes a slightly increase of operations. Furthermore, improvements are shown for PSDA, reliability and to a less extent for acceptability and OR occupancy. The counterpart is the increased average OR overtime. The variation of the admission rule causes improvements for PSDA and acceptability. However, weekly OR overtime increases. There are no significant changes in the weekly OR occupancy. By increasing the difference between the cancellation rule and the admission rule, the reliability increases. The highest reliability is obtained by combining the 'lowest' admission rule and the 'highest' cancellation rule.

As can be seen, the biggest relative improvement can be obtained by keeping 8 hours for the admission rule and increasing the number of hours for the cancellation rule until 8.5. In this way, the highest increase in PSDA, reliability, acceptability and occupancy are obtained with the less OR capacity modifications and slightly OR overtime. The OR 'loss' in overtime is earned back by the higher weekly OR occupancy. Therefore, all further modifications of the planning method in this section are simulated based upon these settings for the admission and cancellation rules.

Admission rule	8	8	8	8.5	8.5
Cancellation rule	**8**	**8.5**	**9**	**8.5**	**9**
Run duration (in minutes)	33.9	26.4	25.8	24.2	22.9
# Operated patients during simulation period	1546	1588	1604	1598	1617
# Operated hours during simulation period	3225	3328	3365	3334	3400
Waiting list on 01-02-2013 (in # patients|hours)	413|933	406|916	397|904	399|909	395|891
Waiting list on 01-09-2013 (in # patients|hours)	144|342	95|222	70|173	78|209	55|125
Reliable, acceptable PSDA (in % of operated patients)	53%	57%	59%	59%	60%
Unreliability: patient cancellation (in %)	14%	7%	4%	12%	7%
Unacceptability: outside planning window (in %)	36%	34%	32%	30%	30%
Average waiting time (in weeks)	5.9	5.9	5.9	5.8	5.8
Unacceptable average waiting time (in weeks)	8.7	8.9	9.0	9.2	9.3
Average weekly occupancy (in %)	74.3%	76.4%	76.4%	76.0%	76.6%
Average weekly overtime (in hours)	2.14	2.99	4.04	3.62	4.98

Table 9: … - … /4/0/0-actual/historical

8.1.2 Block Scheduling Strategies

The results of the different block scheduling strategies are presented in Table 10. As can be seen, the results are comparable for the four strategies. Strategy 4 only shows slightly better performance on PSDA, reliability, acceptability and occupancy. To see how well the different strategies actually perform, the allocation of the different feasible surgery options is analyzed.
In Figure 20 of the appendix, the proportions are presented of the allocated feasible surgery options to the operated patients specified for the different strategies. Under strategy 4, 68% received a surgery date as supposed, namely reserved for both operation group and surgeon. Specifically, 84% and 70% received a surgery date which was reserved for surgeons or operation groups, respectively. Remarkably, these are about the same percentages for strategy 3 and strategy 2, respectively. Even taking into account strategy 1: 93% of the patients received an operation from a primary surgeon. This is the same percentage found under strategy 4.

As described in chapter seven, the real OR occupancy would probably lower under strategy 1 and 2 than is presented in the table. Nevertheless in practice, it is preferred reserving time blocks for surgeons, so that surgeons can operate a whole day without interruptions. Regarding this preference, slightly better performance of strategy 4 and similar surgery option allocation, all further modifications of the planning method in this section are simulated based upon the fourth strategy.

	Strategies			
	1	2	3	4
Run duration (in minutes)	27.3	30.5	30.2	26.4
# Operated patients | hours during simulation period	1577|3313	1590|3311	1575|3301	1588|3328
Waiting list on 01-02-2013 (in # patients | hours)	401 | 930	407 | 923	404 | 912	406 | 916
Waiting list on 01-09-2013 (in # patients | hours)	101 | 251	94 | 246	106 | 237	95 | 222
Reliable and acceptable PSDA (in % of operated patients)	56%	55%	56%	57%
Unreliability: patient cancellation (in %)	8%	8%	8%	7%
Unacceptability: outside planning window (in %)	34%	35%	35%	34%
Average waiting time (in weeks)	5.8	6.0	5.8	5.9
Unacceptable average waiting time (in weeks)	8.9	8.9	8.5	8.9
Average weekly occupancy (in %)	76.1%	76.0%	76.0%	76.4%
Average weekly overtime (in hours)	2.83	2.92	2.83	2.99

Table 10: 8-8.5/ … /0/0-actual/historical

8.1.3 Patient Sequencing

In Table 11, the results are shown for no sequencing and sequencing on LPT and SPT (in the second sorting). As can be seen, the results are comparable to each other. No sequencing shows even slightly better results, but these are not significant. Analyzing the results more specifically, some shifts in percentages among operation groups are remarkable. For example, MAMMA shows the following performance on PSDA and unacceptability: 38% and 62% under no sequencing, 37% and 63% under LPT sequencing and 47% and 53% under SPT sequencing. However, the improvements for MAMMA by adding the SPT aspect are at the expense of other operation groups. Since there are no overall performance improvements observed under patient sequencing and the intention is to give a surgery date on the day of diagnosis, further modifications are based upon no patient sequencing.

Days after diagnosis	Day 0	Day 1	
Sequencing		LPT	SPT
Run duration (in minutes)	26.4	27.7	30.0
# Operated patients | hours during simulation period	1588|3328	1574|3290	1581|3310
Waiting list on 01-02-2013 (in # patients | expected hours)	406 | 916	400 | 921	396 | 921
Waiting list on 01-09-2013 (in # patients | expected hours)	95 | 222	103 | 266	92 | 246
Reliable and acceptable PSDA (in % of operated patients)	57%	55%	55%
Unreliability: patient cancellation (in %)	7%	8%	8%
Unacceptability: outside planning window (in %)	34%	35%	34%
Average waiting time (in weeks)	5.9	5.9	5.9
Unacceptable average waiting time (in weeks)	8.9	8.5	9.1
Average weekly occupancy (in %)	76.4%	75.6%	76.0%
Average weekly overtime (in hours)	2.99	2.81	2.95

Table 11: 8-8.5/4/ … /0-actual/historical

8.1.4 Resource Allocation Adjustments

In Figure 21 of the appendix, the average weekly OR occupancy is specified for each sub department. This confirmed the expectations described in the previous chapter: the aos department uses all its capacity and still cannot operate the patients within their planning window, while the trs and chs sub departments showed opposite performance. Therefore, it is useful to consider the resource allocation adjustments, of which the results are shown in Table 12.

The MSS modification shows an increased throughput and OR occupancy, without much extra overtime. Additionally, the modification shows improved performance on the unacceptable average waiting time. However, the results regarding PSDA, acceptability and average waiting time show decreased performance and a marginally improvement on reliability. 'Fill patients' flexibility shows a similar increase in throughput and OR occupancy regarding the modified MSS. Nevertheless, no overall improvements are shown on PSDA, reliability and acceptability. Only the (unacceptable) average patient waiting time slightly reduces.

'Fill patients' flexibility	0	0	1	1
MSS Adjustments	Actual	Modification	Actual	Modification
Run duration (in minutes)	26.4	38.9	22.6	22.2
# Operated patients during simulation period	1588	1636	1625	1640
# Operated hours during simulation period	3328	3441	3431	3470
Waiting list on 01-02-2013 (in # patients | hours)	406|916	417|915	390|901	394|899
Waiting list on 01-09-2013 (in # patients | hours)	95|222	58|108	42|104	31|64
Reliable and acceptable PSDA (in % of operated patients)	57%	55%	55%	52%
Unreliability: patient cancellation (in %)	7%	6%	8%	8%
Unacceptability: outside planning window (in %)	34%	36%	34%	38%
Average waiting time (in weeks)	5.9	6.2	5.8	5.9
Unacceptable average waiting time (in weeks)	8.9	7.9	8.3	7.8
Average weekly occupancy (in %)	76.4%	78.9%	78.8%	79.6%
Average weekly overtime (in hours)	2.99	3.23	3.30	3.35

Table 12: 8-8.5/4/0/ … - … /historical

To know the influence of the extra aos hours on its performance, the results are further specified for each sub department, which are presented in Table 22 of the appendix. As can be seen, the overall increase in OR occupancy by the MSS modification is caused by a sufficient increase for trs and chs OR occupancy. The ‘fill patients’ flexibility shows slightly lower improvements on the OR occupancy, especially for trs. This can be explained by the fact that trs patients are operated in the OR’s of other sub departments as well. Further, no trs patients were left in the waiting list at the end of the simulation period. Looking at the aos performance specifically, the resource allocation adjustments show small improvements regarding PSDA and acceptability. The (unacceptable) average patient waiting time shows a significant decrease. However, this improvement for aos is at the expense of the same performance measures for chs. The effects are seen even more clearly on the level of operation groups, for which a change in allocated hours occurred.

8.2 Reduced Waiting List

As can be seen from the results presented above, the planning method modifications so far did not substantially improve the overall performance. Especially an increase is desired in the performance of PSDA and acceptability. Therefore, the scenarios are considered in a reduced waiting list situation. To be certain that one replication is still sufficient to make confident conclusions on the simulated results, the results of five independent replications are analyzed. The results in Table 23 of the appendix show similar run variations compared to the replications described in the model configuration. In case of the reduced waiting list, 65% of all (executed) operations had only one option for operation, which limits the influence of random numbers. The sub sections are classified according to the same structure as in the previous section. Consecutively, the admission and cancellation rules, block scheduling strategies, patient sequencing and resource modifications are discussed.

8.2.1 Admission and Cancellation Rules

The results of the admission and cancellation rule modifications are shown in Table 13. Under a reduced waiting list, the variation of the cancellation rule shows insignificant effects regarding the throughput. Probably, that is the reason why the average weekly OR occupancy decreases this time. However, improvements are shown for PSDA, reliability and acceptability at the expense of some overtime under a reduced waiting list as well. Further, the (unacceptable) average waiting time slightly reduces. The variations of the admission rule show insignificant changes regarding PSDA, in contrast with the historical waiting list. However, improvements are shown for acceptability under a reduced waiting list as well. Similarly, marginal changes are shown for OR occupancy under a slightly increased overtime. Still, the highest reliability is obtained (the same percentage of 4%) by combining the ‘lowest’ admission rule and the ‘highest’ cancellation rule.

For the same reasons as described in the previous section, all further modifications of the planning method are simulated based upon 8 and 8.5 hours during the admission and cancellation rule, respectively. Although the benefits of the average weekly OR occupancy were not present this time, the modifications result in significant improvements regarding PSDA, reliability, acceptability and (unacceptable) average waiting time.

Admission rule	8	8	8	8.5	8.5
Cancellation rule	**8**	**8.5**	**9**	**8.5**	**9**
Run duration (in minutes)	9.7	8.6	8.1	8.8	8.1
# Operated patients during simulation period	1500	1477	1475	1498	1500
# Operated hours during simulation period	3102	3082	3060	3096	3107
Waiting list on 01-02-2013 (in # patients | hours)	276|578	257|552	248|531	260|557	260|548
Waiting list on 01-09-2013 (in # patients | hours)	53|110	57|105	50|106	39|94	37|75
Reliable and acceptable PSDA (in % of operations)	72%	77%	82%	77%	83%
Unreliability: patient cancellation (in %)	11%	7%	4%	10%	6%
Unacceptability: outside planning window (in %)	17%	12%	8%	10%	5%
Average waiting time (in weeks)	4.7	4.4	4.2	4.3	4.1
Unacceptable average waiting time (in weeks)	6.2	5.2	4.9	5.8	5.0
Average weekly occupancy (in %)	71.8%	70.9%	69.9%	71.4%	70.7%
Average weekly overtime (in hours)	1.84	2.76	3.12	2.87	3.91

Table 13: … - … /4/0/0-actual/reduced

8.2.2 Block Scheduling Strategies

Correspondingly to the historical waiting list, the different block scheduling strategies do not show significant effects, as can be seen in Table 24 of the appendix. Again, the allocated feasible surgery options are analyzed to see how well the strategies perform under the reduced waiting list. The proportions are given in Figure 22 of the appendix. Under strategy 4, 79% received a surgery date as supposed. This is an improvement compared to the performance shown under the historical waiting list. Again, strategy 4 shows comparable performance in the allocation of feasible surgery options regarding the other strategies. Also concerning the preference for reserving time for surgeons as described in the previous section, there is chosen to keep simulating with the fourth strategy.

8.2.3 Patient Sequencing

In Table 14, the results are shown for no sequencing and the sequencing variants on LPT and SPT. In contrast to historical waiting list situation, the sequencing rules, in particular the LPT sequencing variant, show slightly better results regarding PSDA, reliability, acceptability and average weekly OR occupancy. However, the effects are small so one should be careful concerning significance.

More specifically, MAMMA operations show the following performance on PSDA and unacceptability: 63% and 37% under no sequencing, 78% and 22% under LPT sequencing, and 68% and 32% under SPT sequencing. So this time, in contrast with the historical waiting list situation, the LPT sequencing variant shows better results for MAMMA operations (while these operations have a relatively short surgery duration).

Despite the slightly better results of the LPT variant of patient sequencing, further modifications of the planning model are simulated without patient sequencing. After all, the intention is to give a surgery date on the day of diagnosis.

	Days after diagnosis	Day 0	Day 1	
	Sequencing		LPT	SPT
Run duration (in minutes)		8.6	10.6	10.2
# Operated patients | hours during simulation period		1477|3082	1486|3097	1495|3101
Waiting list on 01-02-2013 (in # patients | hours)		257 | 552	258 | 559	264 | 563
Waiting list on 01-09-2013 (in # patients | hours)		57 | 105	49 | 96	46 | 96
Reliable and acceptable PSDA (in % of operated patients)		77%	79%	78%
Unreliability: patient cancellation (in %)		7%	6%	6%
Unacceptability: outside planning window (in %)		12%	9%	11%
Average waiting time (in weeks)		4.4	4.3	4.4
Unacceptable average waiting time (in weeks)		5.2	5.6	5.5
Average weekly occupancy (in %)		70.9%	71.2%	71.5%
Average weekly overtime (in hours)		2.76	2.77	2.80

Table 14: 8-8.5/4/ … /0-actual/reduced

8.2.4 Resource Allocation Adjustments

The results of the resource allocation adjustments are shown in Table 15. For the MSS modification, the mean of five replications is given with its 95% confidence interval (CI) between brackets in order to indicate the reliability of the results. This is only presented for the MSS modification, since this planning method modification gives the best results regarding reliable and acceptable PSDA. In contrast with the historical waiting list situation, the resource allocation adjustments show no significant changes regarding throughput, OR occupancy and unacceptable waiting time. Furthermore, the MSS modification shows an increased performance regarding PSDA. Acceptability and reliability only increase, while the average waiting time only slightly decreases under non OR flexibility for 'fill patients'. The 'fill patients' flexibility modification shows slightly improvements for OR occupancy and average waiting time. The acceptability increased under the actual MSS, while it decreased under the modified MSS. The reliability only decreased under the modified MSS.

	Fill patients flexibility	0	0	1	1
	MSS Adjustments	Actual	Modification (CI)	Actual	Modification (CI)
Run duration (in minutes)		8.6	8.8 (±0.2)	7.4	7.5 (±0.2)
# Operated patients during simulation period		1477	1483 (±13)	1499	1489 (±16)
# Operated hours during simulation period		3082	3077 (±16)	3116	3085 (±11)
Waiting list on 01-02-2013 (in # patients)		257	266 (±6)	252	246 (±8)
Waiting list on 01-02-2013 (in expected hours)		552	552 (±12)	556	530 (±8)
Waiting list on 01-09-2013 (in # patients)		57	60 (±8)	30	35 (±12)
Waiting list on 01-09-2013 (in expected hours)		105	109 (±9)	74	79 (±17)
Reliable and acceptable PSDA (in % of operated patients)		77%	80% (±0.9%)	78%	80% (±1.3%)
Unreliability: patient cancellation (in %)		7%	6% (±0.5%)	7%	10% (±0.7%)
Unacceptability: outside planning window (in %)		12%	8% (±1.7%)	10%	10% (±1.2%)
Average waiting time (in weeks)		4.4	4.8 (±0.1)	4.1	4.1 (±0.1)
Unacceptable average waiting time (in weeks)		5.2	6.0 (±0.4)	5.5	6.0 (±0.2)
Average weekly occupancy (in %)		70.9%	70.9% (±0.5%)	71.8%	71.2% (±0.3%)
Average weekly overtime (in hours)		2.76	2.44 (±0.16)	2.75	2.48 (±0.26)

Table 15: 8-8.5/4/0/ … - … /reduced

Since most effects are in contrast with the effects in the historical waiting list situation, the results are again specified per sub department, which are presented in Table 25 of the appendix. The MSS modification with and without flexibility for 'fill patients' shows improvements for PSDA, reliability, acceptability and (unacceptable) waiting time for aos, while the chs sub departments shows the opposite effects, especially for PSDA and acceptability (note that the range of the 95% CI is big for these chs performance measures). The trs sub departments shows neither improvements on these measures, but the deterioration is marginal. However, it shows decreased reliability in combination with the OR flexibility for 'fill patients'. (The trs PSDA percentage is only registered for the 'non priority fill patients' replicas on the 'patients' sheet.) The performance measures for vts do not change much. Additionally, it is worth mentioning that the aos department is mainly responsible for the OR overtime, which is slightly smaller under the MSS modification. The MSS modification without flexibility for 'fill patients', causes lower OR occupancy for aos, higher OR occupancy for trs and chs, and marginal changes for vts. No significant changes in throughput are shown. Including the flexibility for 'fill patients', the OR occupancy increases for the aos, trs and chs sub departments, except for the trs sub department. This can be explained from the fact that trs patients are operated in the OR's of other sub departments as well. Under the flexibility modification, there were no trs patients left in the waiting list at the end of the simulation period.
Consequently, regarding the research objectives, the preference is given to the scenario in which the MSS is modified and no 'fill patients' flexibility is used, since this scenario gives the highest performance regarding PSDA, reliability and acceptability.

Accordingly, the reduced waiting list caused the highest increase regarding the overall performance on the allocation of a reliable and acceptable surgery date on the day of diagnosis. In Figure 12, the PSDA is specified for the best scenarios under the historical and reduced waiting list. As can be seen, the number of patients who is given a reliable and acceptable surgery date is increased from 57% to 80%. The number of patients who is given a reliable surgery date outside their planning window, is decreased from 29% to 6%. In both situations, 4% is given a surgery date which was cancelled last-minute. Further, 9%/10% is not given a surgery date, since these patients were 'non priority fill patients'. In the historical waiting list situation, 1% is given a surgery date a week before the operation, since there was no surgery date found within the planning horizon ('priority fill patients').

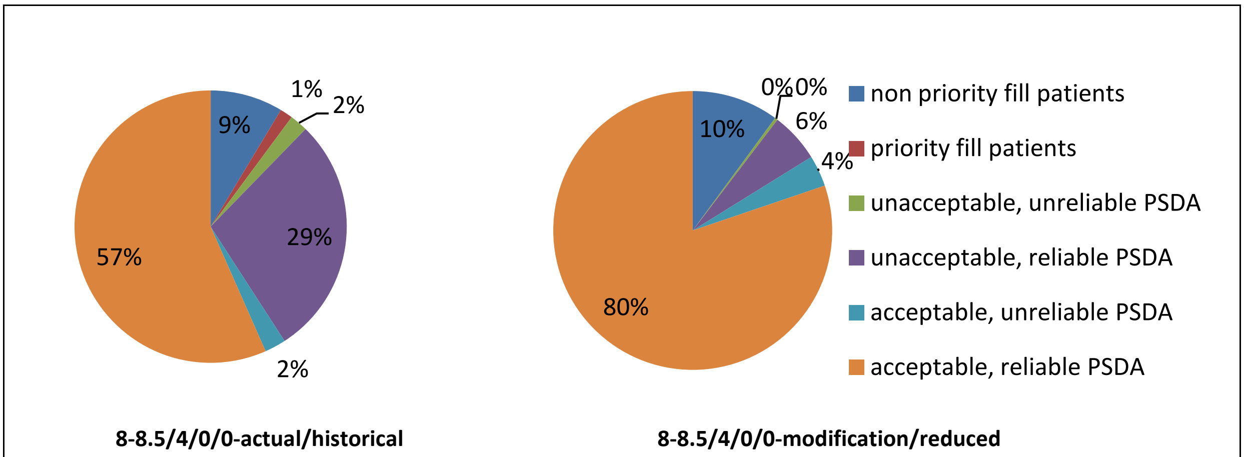

Figure 12: Overall PSDA for the historical and reduced waiting list

9 Conclusions and Implications

This chapter includes the conclusions from this research and both managerial and scientific implications for giving the patient a reliable and acceptable surgery date on the day of diagnosis. A general scientific implication was already described in the literature overview: more future research should include surgery date allocation on the day of diagnosis, regarding the need for patient service in practice. In the first sections, the conclusions and implications are described regarding the preliminary research and the simulated scenarios of the planning method, respectively. In the last section, some ideas are described for using the simulation model as a planning instrument. All implications are summarized in the overview concluding this chapter.

9.1 Preliminary Research

In this section, answers are given on the sub questions of the research question, regarding the preliminary research: 'How should the planning process – and planning method be designed?'
From section 5.1, the first sub question was answered. Firstly (1a), it turned out that the introduction of an EOP is needed, so that all necessary tests can be executed within this period and planners can allocate a surgery date which is after this period. The length of the EOP is needed to be discussed with all stakeholders (mainly anesthesiologists). It would also reduce the number of changes during the WPM. Other modifications during the WPM regarding patient shifts on the OR program, should be restricted to the allocated surgery date. Secondly (1b), the announcement of the surgery date is considered. The suggestion is to start with the scenario in which planners give a surgery date to the patients on the phone, one day after the day of diagnosis. The planning method itself is already a drastic change, so in this way, the least changes are needed regarding the surgery date announcement in the current situation. In the meantime, facility changes should be considered for announcing the surgery date *on* the day of diagnosis. In case of announcement by a surgeon or a planner, the division in planning responsibilities or extra space on the outpatient department should be considered, respectively.

From chapter 5, the second sub question was answered. Firstly (2a), from preliminary research it turned out that three important planning method changes are needed. Removing the 'surgery date announcement waiting list' and dealing with a variable planning horizon inevitably happen when starting the new planning method. However, the third needed change needs attention: no last-minute changes in the surgeon availability are allowed anymore once a surgeon is planned for an operation. Secondly (2b), useful planning concepts from literature were adopted, regarding the definition of operation groups according to their resource use, several block scheduling strategies and ways to deal with scenarios in which demand and capacity are not balanced. These were used for the development of six consecutive steps for allocating a surgery date. Additionally (2c), in the last step special attention was paid to the way of dealing with discrepancy demand and supply. 'Fill patients' were introduced to fill empty OR blocks in the last week. An OR block reserved for another operation group was opened in case no OR time was left (less feasible surgery options), and when this was neither possible, surgery dates were searched after the urgency period. This is an innovative way of flexible block scheduling. Finally (2d), from the data collection and analysis it turned out how much OR time blocks on the MSS were needed to be reserved for each operation group.

9.2 Simulation

In this section, the sub questions of the research question regarding the simulation are answered. Firstly, the performance of the waiting list is discussed. The other modifications regarding admission and cancellation rules, block scheduling strategies, patient sequencing and resource allocation adjustments showed smaller effects on the performance. However, they can be used for fine-tuning the planning method. They are discussed afterwards.

Firstly, as can be concluded from the simulation results, the historical waiting list is a serious problem on the GS department, especially for aos treatments. About 46% - 51% was operated on an unacceptable surgery date. More generally for all sub departments, 30% - 38% was operated outside the planning window and 52% - 60% received a reliable and acceptable surgery date. As these ranges in percentages show, the modifications of the planning method could not largely improve this performance. By removing the unacceptable patient list, on which patients are placed of whom their planning window is expired, impressive improvements were achieved regarding PSDA and acceptability. Depending on the planning method modifications, only 5% - 17% was operated outside the planning window and 72% - 83% received a reliable and acceptable surgery date. Taking into account that 10% included ‘fill patients’, the percentage of PSDA is quite high. Further, the reduced waiting list resulted in a substantial decrease of the overall (unacceptable) average patient waiting time. The OR occupancy and overtime decreased to a small extent as a result of operating less patients and hours. Therefore, to be able giving the patient a reliable and acceptable surgery date, it is highly recommended to temporary create extra (OR) capacity (for example during the weekends, or performing operations at another hospital) to realize the patient waiting list reduction. At least, all patients of whom their planning window is expired should be operated soon, apart from the current OR availability which is needed for the arriving patients.

Secondly, by varying the admission and cancellation rules, significant improvements were obtained regarding reliability and acceptability. A high reliability percentage was obtained by having a substantial difference in hours between those two rules. Similar results were shown for both waiting lists. Additionally, by increasing the number of hours during the admission and cancellation rules, the acceptability percentage increased with a few percentages. However, the improvements for reliability and acceptability are at the expense of some weekly overtime. Nevertheless, the OR overtime is much smaller than the created OR time by varying the rules. Furthermore, the simulated overtime satisfies the requirement of maximum 5%. Consequently, it is recommended to create a cancellation rule which adds half an hour to the OR availability, regarding the relative planning improvements for reliability and acceptability. At least, it is suggested not focusing too much on the limitation of the cancellation rule, when searching for ways to minimize OR overtime.

Thirdly, combining the two ways of reserving time blocks worked well regarding the several feasible surgery options and worked the best for a reduced waiting list: for strategy 4, 79% was operated on a time block as intended. Furthermore, the strategy of reserving blocks according to either surgeons or operation groups, did not work better than the strategy of combining them. Probably, that is a reason why there were no significant effects found in performance. Taking into account the limitation of the simulation model regarding OR idleness, which was described in chapter seven, even the expected effects on reliability caused by the portfolio effect (strategy 3 and 4) and on PSDA (strategy 2 and 4) were not found. Although the benefits of operation group reservation on the MSS have not been proven in this research and the MSS is needed to be further optimized, it is worth considering block scheduling on the basis of surgeon and operation group reservation. In this way, OR time is left open for operations with small planning windows, a surgeon can operate the whole day without interruptions and the planning of an additional surgeon or specialism in the OR block is easier and more transparent.

Fourthly, the sequencing rules showed slightly better results regarding PSDA, reliability and acceptability. However, these effects were only shown in case of the reduced waiting list and one should be careful concerning significance. The most remarkable effect is the improvement of acceptability for the LPT sequencing variant. This can be explained by the following. Patients who have higher urgency and longer expected surgery durations are given a surgery date as first, so that the other patients cannot take their time slots. Apparently, the sequencing rules in this stage of planning have the opposite effect regarding sequencing on the surgery date itself. Therefore, it is recommended to order patients consecutively on the longest surgery durations and highest urgency, when allocating the surgery date one day after the diagnosis.

The fifth and sixth modification included the resource allocation adjustments. The MSS modification resulted in substantial improvements for PSDA, reliability, acceptability and (unacceptable) waiting time for aos. However, it resulted in opposite effects for chs, and to a marginal extent for trs. Further, it decreased the OR occupancy for aos and largely increased the occupancy for chs and trs. Probably, too many time blocks were reallocated from the chs sub department, since the chs patients suffer from the reallocation. These results applied for both waiting lists. This can be explained from the fact that the chs arrival pattern fluctuated during the simulation period.
The ‘fill patients’ flexibility increased the OR occupancy for aos, vts an chs sub departments since trs patients are operated in the OR’s of other sub departments as well. As a result, the OR occupancy for trs decreased drastically. However, these results were different for aos and trs in combination with the actual MSS and the historical waiting list; there were probably not enough empty aos time slots left for filling the OR program. The ‘priority fill patients’ were even planned on the trs time slots. In combination with the MSS modification, it showed decreased performance on reliability for trs patients. This can be explained by the fact that they were planned as last patients on the OR program, so the probability to be cancelled is higher.
Although the modified MSS included in the simulation model is not optimal, regarding the improvements for aos and marginal influences for trs, it is highly recommended to reallocate at least 32 hours per six weeks from the trs to the aos sub department. Further, hours can be reallocated from chs to the aos sub department. However, the exactly amount should be reconsidered. The combination with the ‘fill patients’ flexibility did not show overall improvements.

9.3 Simulation Model as Planning Instrument

A sequel of the generic simulation model is the development of a planning instrument, which is eventually applicable for other hospitals as well. It would work more pleasant and efficient for a planner to have one system which includes all patients, OR and surgeon availability. Thereby, the planning instrument would figure out the best surgery options for each patient much faster than a planner could do. Furthermore, an advantage is that demand and capacity is monitored for each sub department, so that it is easier to respond to an expected shortage of capacity of a certain sub department. Additionally, the expected available capacity overtime for each operation group and surgeon is clearer, so that expectancy management can be improved. In this way, it is quite possible that a surgeon decides to plan the operation for another surgeon, when the urgency period would not be achieved when the surgeon would perform the operation oneself.

However, some changes need to be performed to actually use the simulation model in practice. Firstly, the usual OR and surgeon availabilities are denoted in the 'Lookup OR scheme' and 'Lookup surgeon scheme' sheets. In practice, changes to the usual schemes should be filled in the 'OR capacity' and 'surgeon capacity' sheets. To be able changing the primary surgeon into a secondary surgeon for a certain week, the simulation model should be extended. Secondly, the patients who need to be operated, should be inserted from Epic into the 'patients' sheet of the model. Thirdly, it is needed to change the simulation model in a way that the patient can be planned on a surgery date by selecting the feasible surgery option, instead of generating a random number. Fourthly, it is needed to create a possibility to show and select the surgery options for 'fill patients' at any moment. Last but not least, the model should be made robust for the user. To successfully implement the planning instrument, a person with knowledge of simulation models should be appointed to transform the simulation model into a planning instrument.

Managerial Implications

- Introduce an EOP in which necessary tests can be executed
- Restrict patient shifts on the OR program to the surgery date, during the WPM
- Start announcing the surgery date by planners one day *after* the day of diagnosis, and consider facility changes for announcing the surgery date *on* the day of diagnosis
- Stop allowing last-minute changes of surgeon availability once a surgeon is planned
- Remove the unacceptable patient waiting list by temporary creating extra OR capacity
- Create a cancellation rule which adds half an hour to the OR availability
- Consider reserving blocks for more operation groups, besides reservation for surgeons
- Order patients on highest urgency and longest surgery duration within the urgency category, when announcing the surgery date one day *after* the day of diagnosis
- Reallocate hours of the MSS from trs and chs to aos
- Appoint a responsible person to build a planning instrument of the simulation model

Scientific Implications

- Consider a new way of flexible block scheduling, in which patients are placed in another reserved OR block by taking into account less feasible surgery options.
- Include early surgery date allocation as research goal, regarding patient service
- Investigate the composition of the waiting list since the success of early surgery date allocation highly depends on it
- Increase the difference in hours between the admission and cancellation rules, to improve the planning reliability
- Consider to reserve blocks on the MSS for both operation groups and surgeons, since reserving blocks according to one of them do not necessarily work better
- Include sequencing rules for the surgery date allocation into research, rather than using the sequencing rules mainly during online scheduling
- Consider resource allocation adjustments to optimize the planning performance

10 Limitations and Recommendations for Further Research

Some scientific implications which resulted from the simulation results were already described in the previous chapter. In this chapter, several limitations of this research and corresponding interesting topics to include for further research are depicted. To start with general points of improvement, further research can be done to find an optimal MSS. In literature, Vissers et al. (2005) generated an optimal patient admission profile by translating the problem to an integer linear program. Additionally, although this research is innovative regarding the research goal, it did not show the difference in performance between a one week planning horizon and a flexible planning horizon which is needed for early surgery date allocation, as analyzed by Vissers et al. (2007) on strategic level. Other limitations and corresponding recommendations are divided into the topics data and simulation (model). Extended recommendations for further research are described in appendix VIII.

10.1 Data

Regarding the data collection and analysis, it would be interesting to include several points of interest. Firstly, it is useful to add an analysis of patient arrival patterns per operation group. Applied to this research; although the *average* weekly capacity check allowed the reallocation of hours from the chs sub department, it turned out from the simulation results that the sub department suffered from the MSS modification. Including the proposed analysis, it can be investigated whether it is useful to apply a variable MSS, in which hours are reallocated between sub departments depending on their demand pattern. It should be taken into account that the arrival pattern is strongly dependent on the number of appointments at the outpatient department.

Secondly, it is useful to take into account the patient diagnosis in combination with the CTG codes, in order to define operation groups more precisely. In this research, similar interventions are executed by both oncology and abdominal surgeons. However, it is not clear from the CTG code whether it was an oncology or abdominal treatment, while this is essential planning information regarding the needed surgeon and urgency period. As a result, probably slightly too many operations were identified as 'abdominal' in this research.

Thirdly, it would be interesting to analyze how the number of operation groups (and their reservation on the MSS) would influence the planning performance. In hindsight, less vts operation groups could have been defined in this research, since the expected benefits of the portfolio effect failed to appear. By combining the groups (T)EVAR/FEMPOP/SHUNT, OAC and VTSOVERIG, less capacity could be reserved on the MSS.

Fourthly, the inclusion of mornings and afternoons to the MSS blocks could be useful. In this way, operation groups with a short planning horizon and a low arrival pattern could be reserved on the MSS for a short duration (for example, CEA operations), so that less capacity could be reserved on the MSS. Furthermore, several surgeons are only part-time available and could also be reserved on the block scheme in this way. However, OR idleness as a result of waiting on another surgeon should be taken into account.

Finally, AOSOVERIG patients are easily planned during the simulation, since every surgeon is able to perform the operation. However in reality, this group includes the complex operations which are unique and require specialized surgeons. The model validity could be increased when the surgeon requirements were known from the data. This also holds for the fact that in practice, it often occurs that the surgeon on the outpatient department wants to operate the patient by himself.

10.2 Simulation (Model)

Several limitations of the simulation model and the corresponding simulation can be depicted. Firstly, the simulation model does not register OR idleness as a result of surgeon changeover time, which is described in section 7.2. To analyze the influence of block scheduling strategies 1 and 2 in a better way, a 'surgeon program' sheet should be added to the simulation model, in which the executed operations for each surgeon are denoted. In this way, it can be checked whether the needed surgeon is ready with the previous operation, before the actual operation can start.

Secondly, the simulation could be more focused on the availability of surgeons. In the current model, priority is given to the surgery option for which a primary surgeon is available. However, when a secondary surgeon is planned on that surgery option, it would be preferred to change the secondary surgeon into a primary surgeon and the other way around. In this way, it better meets the needs of scheduling one surgeon into one OR.

Thirdly, sequencing is done at the start of simulation, to save run time. However, the influence of sequencing can be better simulated when sequencing is done at the beginning of each day. In contrast with the current simulation model, the cancelled patients would be concerned as well.

Fourthly, concerning the number of simulation runs, more reliable effects could have been obtained when running more simulation replications and placing the results in confidence intervals, for all scenarios. Further, the patients could be randomly shuffled on the patient list within the same patient group, to vary the patient attributes of the input during each replication.

Fifthly, regarding the programming of the simulation model, the runs could be much faster taking into account the following two points. First of all, the traffic between VBA and the Excel worksheets should be minimized. The programming code could be improved by reading the blocks of data in one single operation, instead of reading each cell individually in a loop. This is for example the case in checking all surgery options for a patient. Further, module 3 (updating capacity values) represents how it could work in practice, by filling the capacity values each four weeks to an availability of 12 weeks. However, it could be faster to exclude this module and fill the capacity values during module 1 for the whole simulation period.

Sixthly, concerning model validity; the simulation model would be more valid by including all registered patients in the model, rather than all operated patients. This can be seen Figure 18 of the appendix, the operated patients are not representative for the arriving patients in July and August. Most likely, the simulation model could better approach the results of the current system when the simulation period was shortened to July 1st, 2013.

Finally, there should be paid special attention to the actual behavior of patients, which is tough to put into a simulation. In the current simulation, several choices of patients are assumed, which can be different in practice. Firstly, 'fill patients' select one of the most feasible surgery options for that week. However, actual patients on the 'fill patients' list have a low urgency and would cancel the appointment faster when they know they can be approached the next week too. Secondly, actual patients could decide to go to another hospital when it becomes clear that their operation falls outside their planning window. Thirdly, a less feasible surgery date can be chosen in practice as well. For example, when all best feasible surgery options are on Mondays, while the patient is not available on this weekday. Fourthly, patients of more urgent operation groups would possibly always choose the first feasible surgery option. In these cases, possibilities for the choice of surgery options could be included in the model.

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List of Tables and Figures

Appendices

Appendix I: Ishikawa Diagram

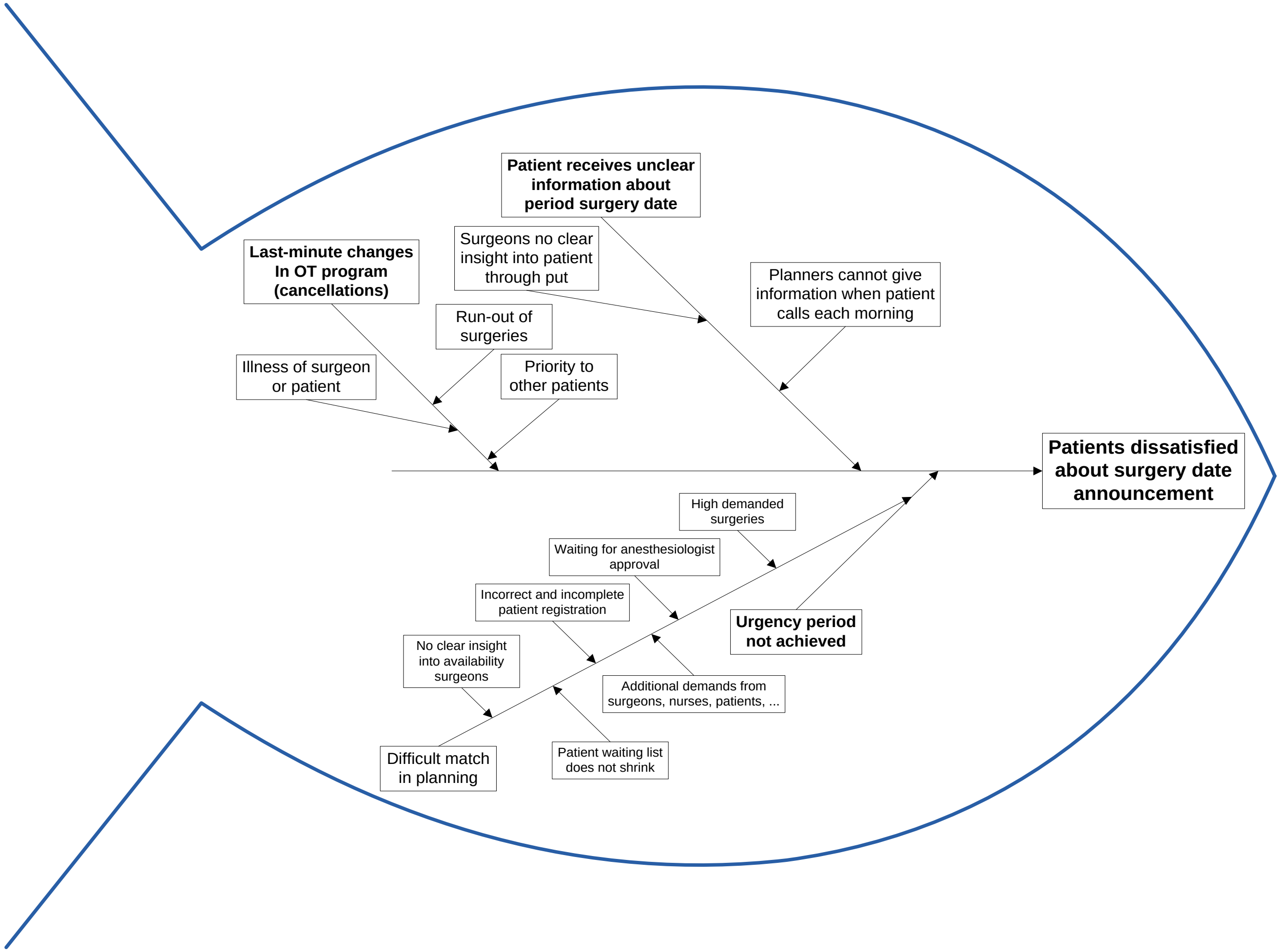


Figure 13: Problem analysis stated in Ishikawa (fish-bone) diagram

Appendix II: Question Tree

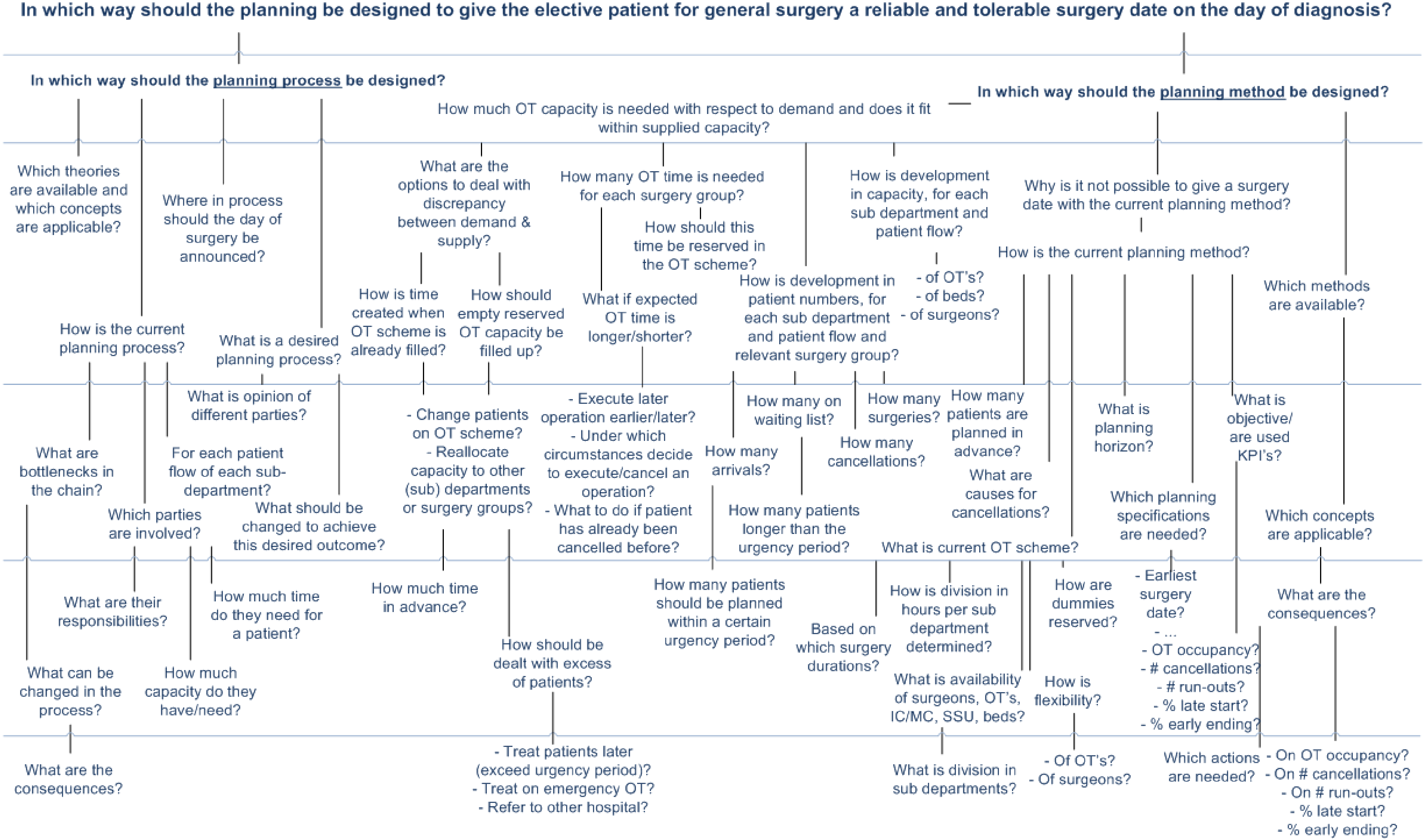


Figure 14: Question tree with sub questions

Appendix III: Service Blueprint

Bitner, Ostrom and Morgan (2007) described service blueprinting, which is defined as a customer-focused approach for service innovation and service improvement, in the increasing need for service innovation. The service processes are visualized taking into account five levels. “Customer actions” present the steps customers take in the delivery process. The onstage level indicates the points of customer contact. The backstage level shows the invisible contact employee actions. In the lowest level, supporting processes are denoted which carry the service execution. The physical evidence that customers come in contact with is described at the top of the blueprint (Bitner, Ostrom, & Morgan, 2007). The customer actions are presented in blue. The employee actions are presented in green except for the ones executed by the planners; those are in red. The less relevant actions with respect to the planning process are light-colored.

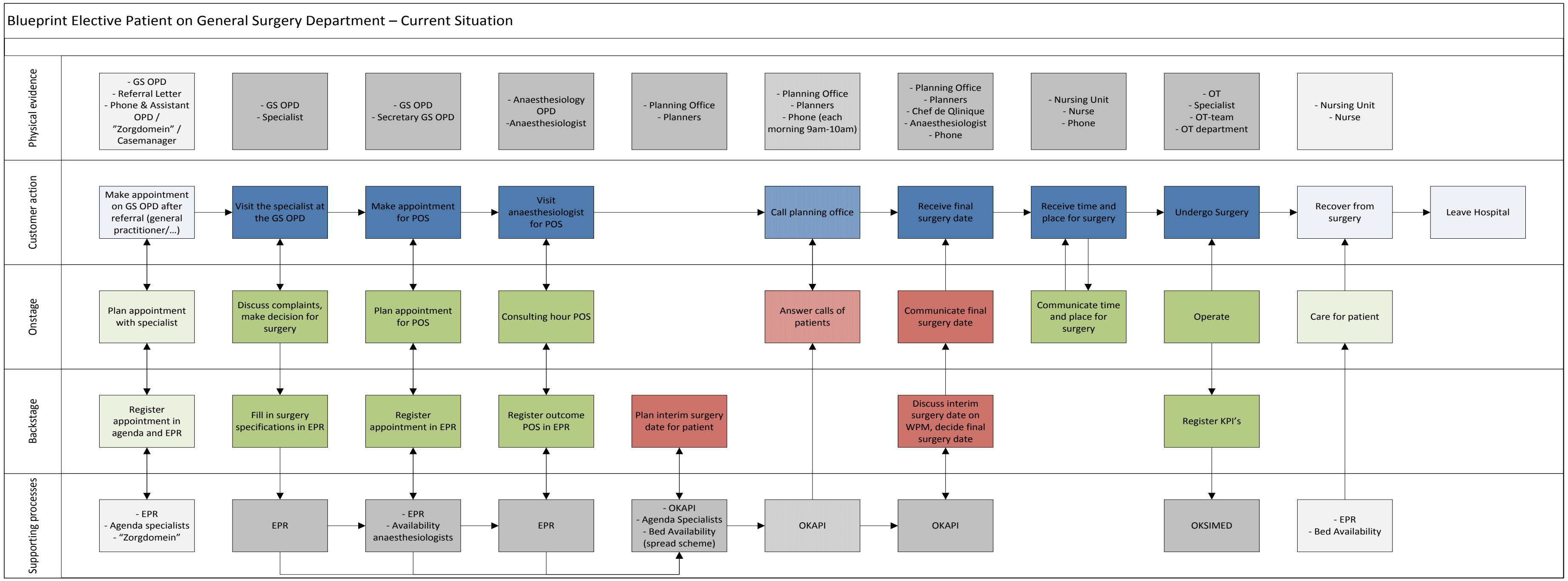


Figure 15: Service blueprint elective patient on GS department

Appendix IV: Extended Data Collection and Analysis

Removal of Urgent and Semi-elective Patients

Emergency and semi-elective patients fell beyond the scope of this research. Therefore, these patients had to be removed from the coupled Excel sheet. Both sheets had a column indicating the patient flow. Oksimed specified whether the operation was planned (elective) or not, while Okapi presented the urgency label (the most common labels were acute, <2 weeks, <6 weeks, <12 weeks, >12 weeks and waiting list). The term semi-elective patients was introduced in July 2013 and therefore no label '<1 week' existed in the databases. For 96.4% of the corresponding surgical cases Oksimed and Okapi agreed upon the patient flow. However, the urgency indicators of the remaining part did not match.

To obtain more insight into the patient flows, the patient waiting time for operation was calculated by subtracting the surgery date by the date of registration. 4 cases showed a negative number, which indicated the surgery date was several days prior to the registration date. The assumption was made these were errors and therefore these were removed from the datasheet. The obtained waiting time made the distinction between patient flows a bit more complex since this indicator still did not correspond to (one of) the indicators of both databases. The doubtful surgical cases are presented in Table 16. As can be seen, Okapi was right more often taking into account the waiting time. Therefore, the assumption was made Okapi was the decisive database with respect to the patient flow in case of doubtful surgical cases. This assumption could also be made from the fact Okapi was the planning tool used on the planning office. Besides, what should be kept in mind is the amount of doubtful cases. 3.6% is not that much to worry about whether it is correctly categorized into the patient flow.

		Waiting Time	
Oksimed	**Okapi**	**<7 days**	**≥7 days**
Urgent	**Elective**	46	303
Elective	**Urgent**	150	67
Urgent	**Urgent**	-	267

Table 16: Number of doubtful surgical cases considered to be eliminated

Further, semi-elective patients had to be identified, since no label for these patients existed in the databases. Only for child surgery, the labels 'semi elective' and 'seven days' existed, but these were not frequently used. Therefore, all operations which took place within one week after registration (and were not removed yet during the removal of urgent patients) were assumed to be semi-elective. There could be argued some elective surgical cases were included to fill empty slots. This would be the case for some cases, but planners usually choose patients who are waiting for a longer period to fill empty slots on the operation program.

The corresponding surgical cases in the coupled datasheet were divided into 4,648 (29.1%) urgent patients, 1,754 (11.0%) semi-elective patients and 9,556 (59.9%) elective patients. After the removal of urgent patients, semi-elective patients and some errors, 9,556 surgical cases were left in the coupled data sheet.

The same removals as stated above were executed for the not corresponding data, to indicate the relevant amount of missing data. As a result, 417 elective surgical cases were present in Okapi, but not in Oksimed. The other way around; 754 elective surgical cases were present in Oksimed, but not in Okapi, of which 367 cases were planned and 378 were not planned. An estimation of the missing data was made by taking the same proportion of doubtful cases presented in Table 16. After the correction for urgent patients, it was estimated 336 elective surgical cases were presented in Oksimed, but not in Okapi

Defining Operation Groups

Before the operation groups could be defined, the surgical interventions had to be discovered on the basis of CTG codes (the Dutch Commission of Health Rates; 'College Tarieven Gezondheidszorg). Each code represents a specific intervention and a corresponding rate, defined by the Dutch Healthcare Authority ('Nederlandse Zorgautoriteit', NZa). On the basis of these CTG codes, healthcare institutions declare the executed interventions to health insurers (Foundation NIVEL, 2013).

To start with, a list of CTG code definitions was obtained so that an extra data row containing the corresponding surgical intervention definition could have been inserted. A lot of surgical cases had more than one CTG code, so in case of a CTG code combination, a combined definition of the codes was placed in the next inserted column. In this way, the 9,556 surgical cases were divided into 2,663 different interventions. The CTG codes were unknown for 483 surgical cases, which were all operations from chs. Only 40 similar interventions (combinations of the same CTG codes) were presented in the datasheet for more than thirty times (≈more than once per month), which means there were a lot of unique interventions presented in the datasheet. On the basis of the definition of the codes, a distinction was made on sub department. In some cases, the sub department could have been deduced from the surgeon. Simultaneously, operation groups were defined together with planners and surgeons for frequently encountered cases on the basis of possible surgeon – operation group combinations, and planning windows. After that, the surgical cases of the datasheet were further distinguished into the defined operation groups. This was not an easy task, since regularly the CTG codes of different operation groups were combined, or the same intervention could have been executed by surgeons of more than one operation group or sub department. So in these cases raised the question which operation group was dominant. Therefore, the sub division in operation groups was accurately discussed, especially for the most common interventions. It seemed that a more exact distinction in operation groups could have been made when the corresponding surgeon and diagnosis were known. After that, the division in operation groups was examined again. Some groups were taken together since the separate groups seemed too small to take into account. For example, a 'TEM' operation is needed to be executed by one surgeon. However, this operation was only performed 46 times according to the combined datasheet. The other characteristics of the operation were similar to the group 'RECTUM AMPUTATIE'. Therefore, these two were combined and for 'TEM' operations, a surgeon requirement was filled in. Other operation groups could also have been combined, but were not taken together taking the number of surgical cases into account and the standard deviation of the surgery duration (keeping in mind the portfolio effect from literature). The remaining operation groups 'AOSOVERIG', 'TRSOVERIG' and 'VTSOVERIG' included all surgical cases which did not belong to one of the other operation groups of its sub department. An overview of the operation groups with the corresponding OR, urgency period and possible surgeon is given in Table 17.

Sub Department	Operation Group	OR	Urgency Period in weeks	Surgeons
AOS				[redacted]
	DARM IBD	Central OR	12	[redacted]
	DARM MALIGNE	Central OR	6	[redacted]
	HIPEC	Central OR	4	[redacted]
	LEVER	Central OR	6	[redacted]
	LITTEKENBREUK	Central OR	6	[redacted]
	MAAG	Central OR	6	[redacted]
	MAMMA	Central OR	2	[redacted]
	MAMMA CDB	DS OR	2	[redacted]
	PANCREAS MALIGNE	Central OR	6	[redacted]
	PANCREAS ONTSTEKING	Central OR	6	[redacted]
	PROCTO	Central OR	6	[redacted]
	PROCTO CDB	DS OR	6	[redacted]
	RECTUM AMPUTATIE	Central OR	6	[redacted]
	SARCOMEN	Central OR	3	[redacted]
	SARCOMEN CDB	DS OR	3	[redacted]
	SCHILDKLIER	Central OR	6	[redacted]
	SLOKDARM	Central OR	2	[redacted]
	AOSOVERIG	Central OR	6	[redacted]
	AOSOVERIG CDB	DS OR	6	[redacted]
	LIESBREUK/LAPCHOL CDB	DS OR	6	[redacted]
TRS				[redacted]
	TRSOVERIG	Central OR	>>	[redacted]
	TRSOVERIG CDB	DS OR	>>	[redacted]
	PROTHESE	Central OR	>>	[redacted]
	PSEUDO-ARTROSE	Central OR	>>	[redacted]
VTS				[redacted]
	(T)EVAR/FEMPOP/SHUNT	Central OR	6	[redacted]
	CEA	Central OR	2	[redacted]
	OAC	Central OR	6	[redacted]
	VTSOVERIG	Central OR	6	[redacted]
	VTSOVERIG CDB	DS OR	6	[redacted]
	VARICES	Central OR	12	[redacted]
	VARICES CDB	DS OR	12	[redacted]
CHS				[redacted]
	KIND	Central OR	6	[redacted]
	KIND CDB	DS OR	6	[redacted]

Table 17: Operation Groups

Surgery Durations

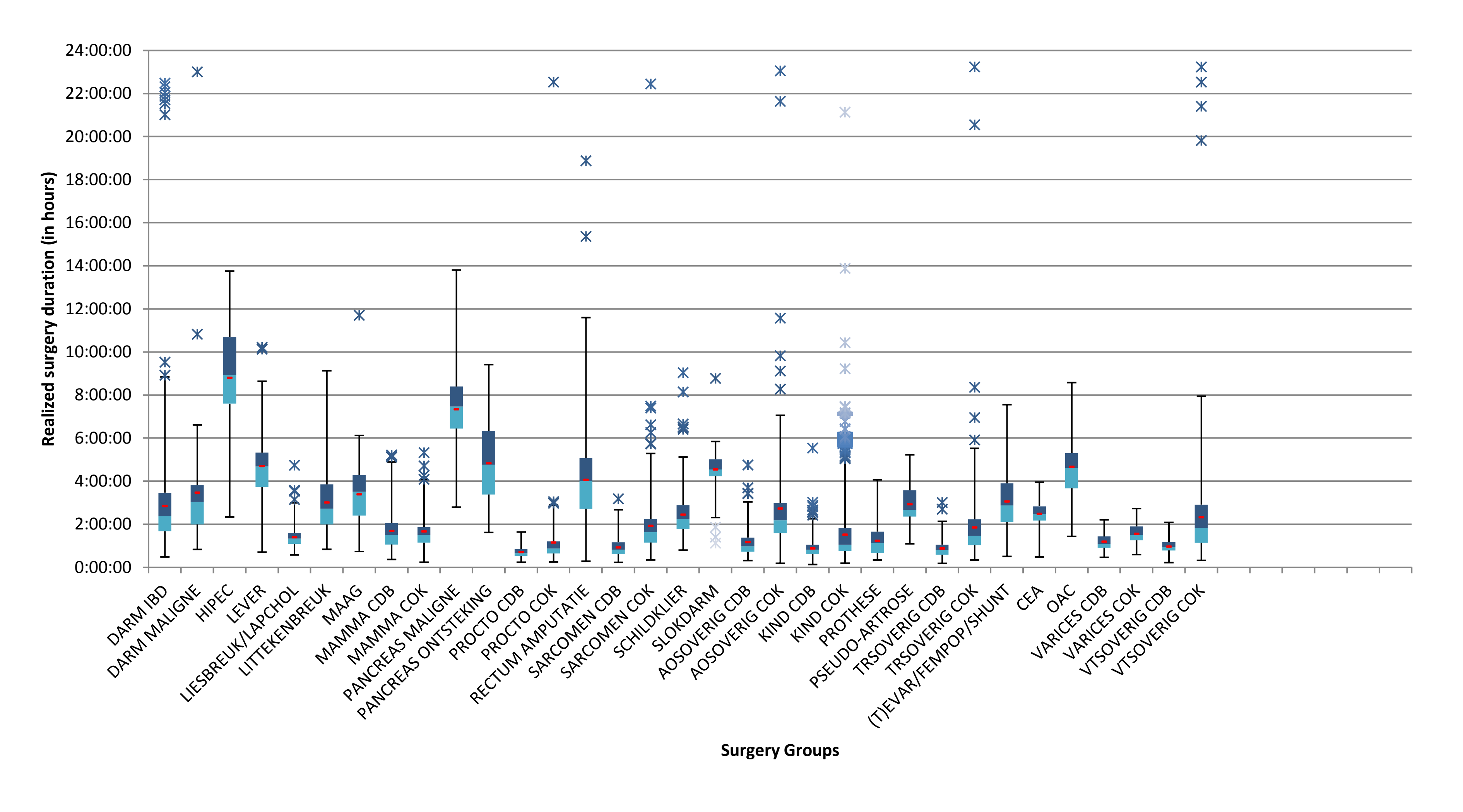


Figure 16: Box plots of realized surgery durations given for each operation group

Surgery Duration Outliers

As can be seen in the box plots presented above, there were some surgery durations exceeding twenty hours. When the outliers would have been loaded into the model, many hours of OR overtime would be registered. Therefore, it was figured out whether these were errors, by comparing the surgery durations with the estimated surgery duration. A scatter plot was made of the estimated and realized surgery durations, presented in the figure below. Scatter plots specified for each operation group were made to determine outliers of doubtful cases. In this way, 21 outliers were detected. An outlier was not deleted, but was replaced by another surgery duration of a random surgical case from the same operation group.

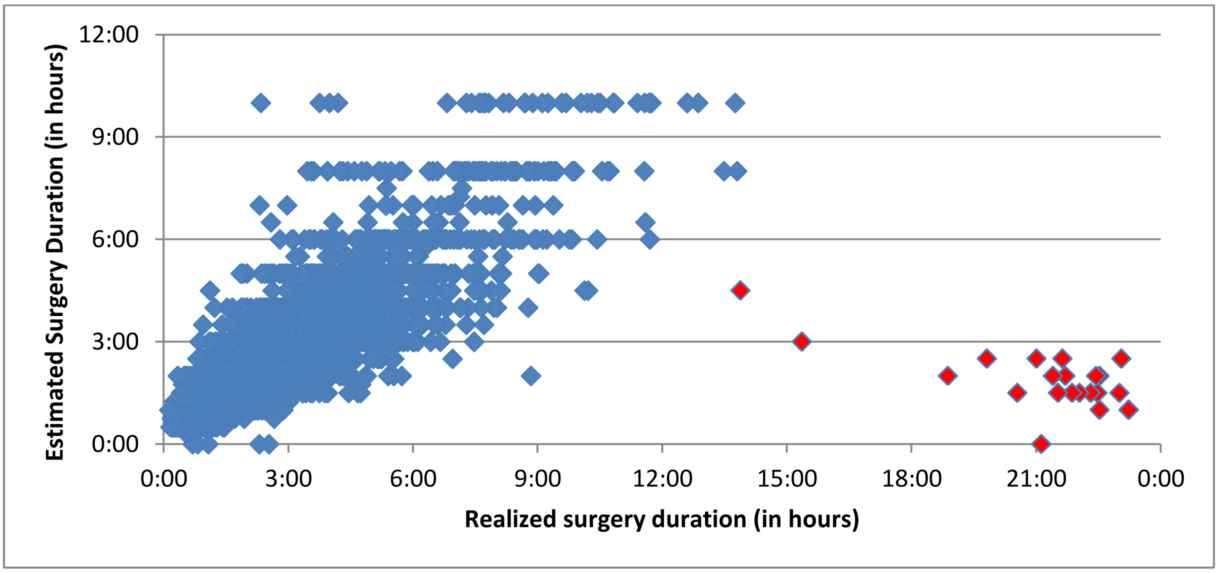


Figure 17: Estimated surgery durations as a function of realized surgery durations

MSS with Block Reservations for Surgery Groups and Surgeons

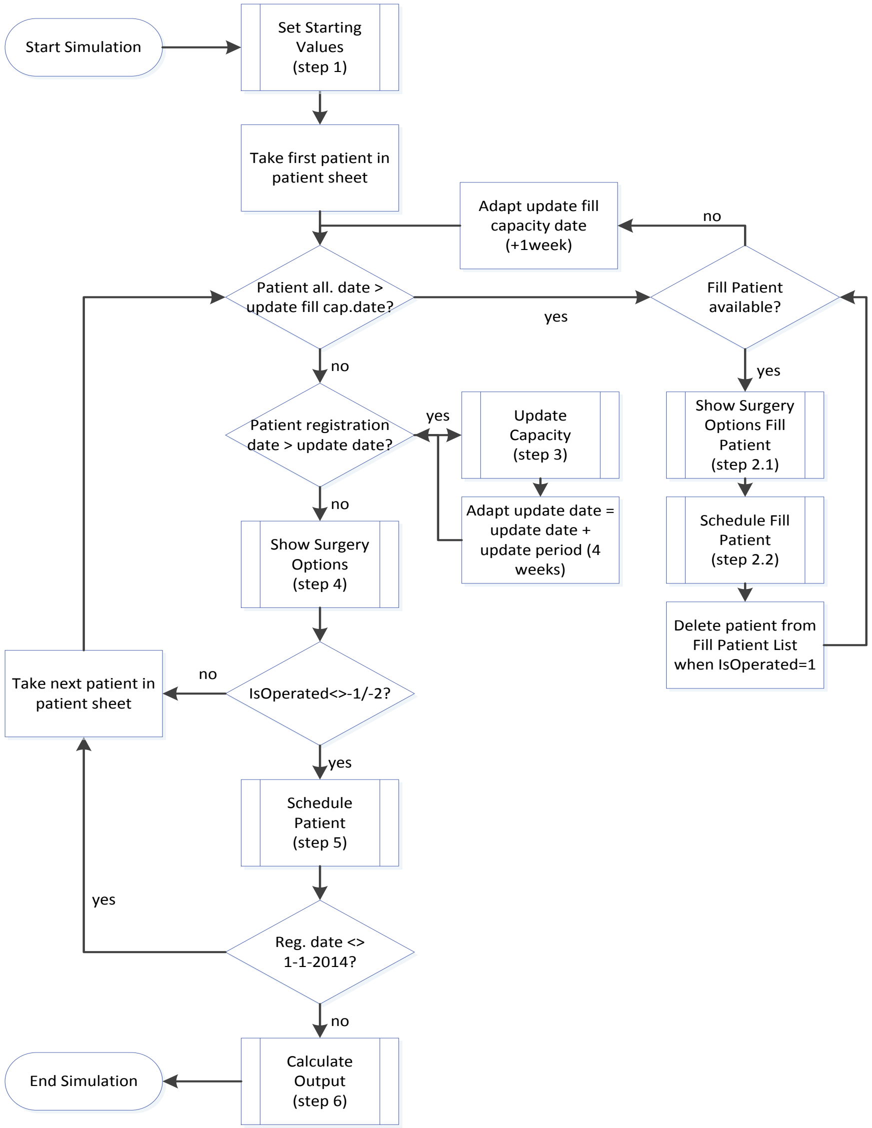
	OR3	OR4	OR5	OR8	OR16	OR34	OR36
	WEEK 2						
Mon		VTSOVERIG	SCHILDKLIER				LIESBREUK/LAPCHOL
Tue		(T)EVAR/…/SHUNT	DARM IBD	PANCREAS ONTSTEKING	KIND		VARICES
Wed		LITTEKENBREUK	RECTUM AMPUTATIE	SLOKDARM	KIND		MAMMA
Thu		VARICES		DARM IBD		KIND	
Fri	PSEUDO-ARTROSE				KIND		
	WEEK 1						
Mon	TRSOVERIG	CEA					TRSOVERIG
Tue		(T)EVAR/…/SHUNT	DARM IBD	AOSOVERIG			MAMMA
Wed		DARM IBD	MAMMA	SARCOMEN	KIND		SARCOMEN
Thu		VTSOVERIG	DARM MALIGNE	DARM IBD		KIND	
Fri	TRSOVERIG				KIND		
	WEEK 4						
Mon	TRSOVERIG	CEA					SARCOMEN
Tue		(T)EVAR/…/SHUNT	DARM IBD	PANCREAS ONTSTEKING	KIND		VTSOVERIG
Wed		LEVER	RECTUM AMPUTATIE	SLOKDARM	KIND		MAMMA
Thu		VTSOVERIG		DARM IBD		KIND	
Fri	TRSOVERIG				KIND		
	WEEK 3						
Mon	TRSOVERIG		LEVER				LIESBREUK/LAPCHOL
Tue		(T)EVAR/…/SHUNT	DARM IBD	AOSOVERIG			PROCTO
Wed		PROCTO	SARCOMEN	MAAG	KIND		MAMMA
Thu		CEA	LITTEKENBREUK	PANCREAS MALIGNE		KIND	
Fri	TRSOVERIG				KIND		
	WEEK 6						
Mon	PROTHESE		LEVER				LIESBREUK/LAPCHOL
Tue		(T)EVAR/…/SHUNT	DARM IBD	AOSOVERIG	KIND		MAMMA
Wed		RECTUM AMPUTATIE	RECTUM AMPUTATIE	SARCOMEN	KIND		MAMMA
Thu		VTSOVERIG		PANCREAS MALIGNE		KIND	
Fri	TRSOVERIG				KIND		
	WEEK 5						
Mon		CEA	LEVER				LIESBREUK/LAPCHOL
Tue		OAC	DARM IBD	MAMMA			AOSOVERIG
Wed		RECTUM AMPUTATIE	SCHILDKLIER	HIPEC	KIND		SARCOMEN
Thu		VTSOVERIG	LITTEKENBREUK	DARM IBD		KIND	
Fri	TRSOVERIG				KIND		

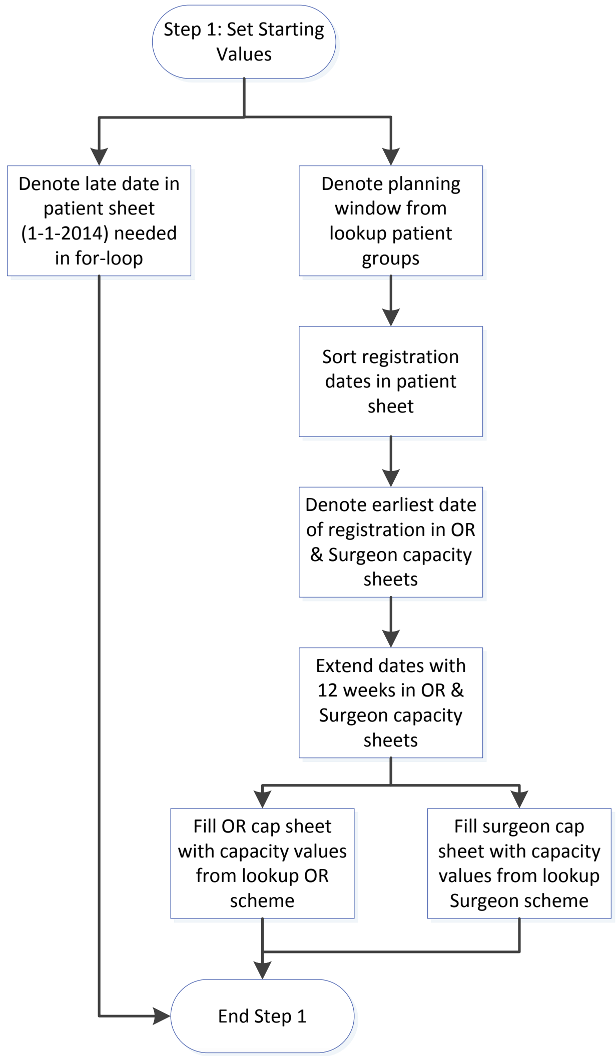
Table 18: MSS with block reservations for operation groups

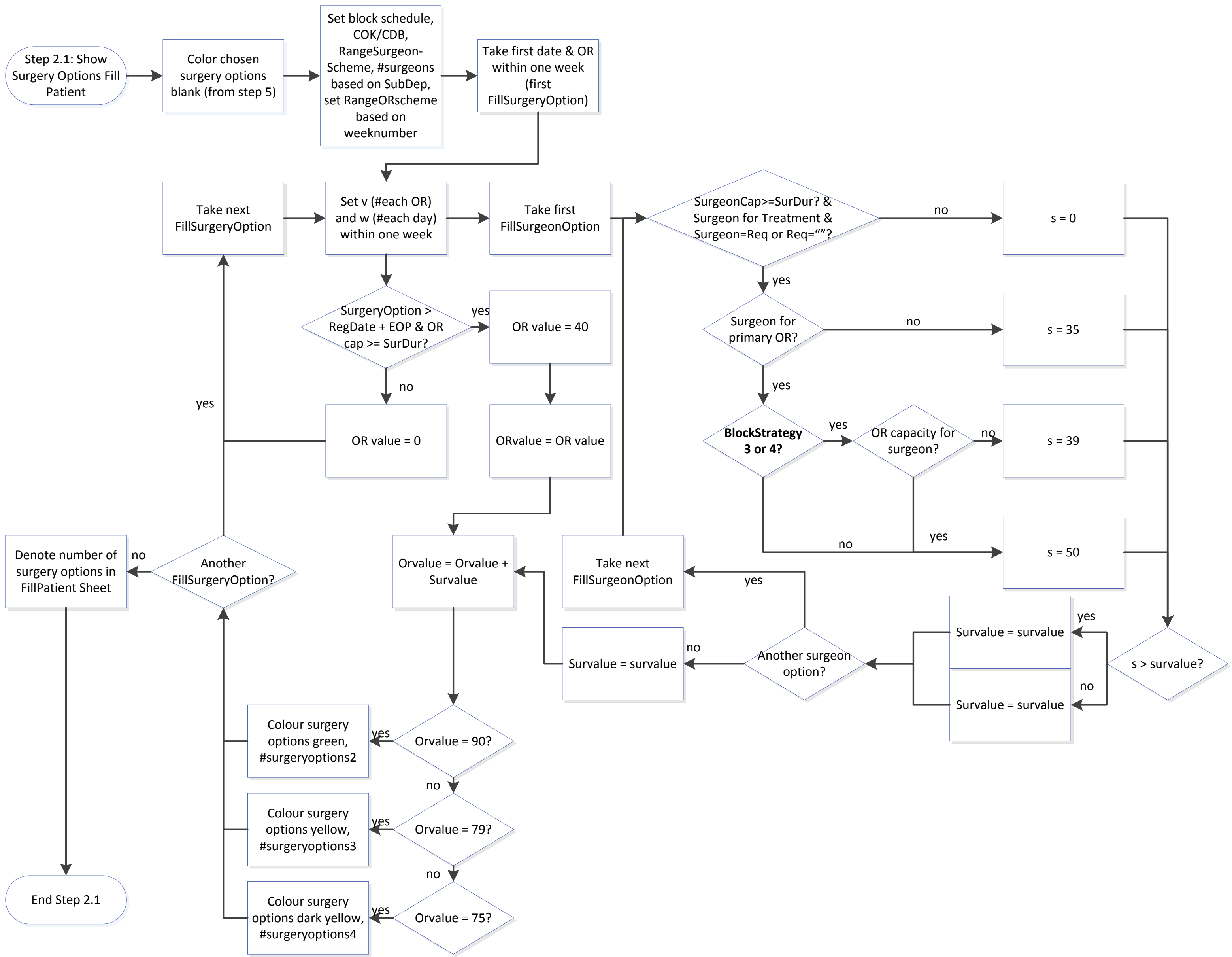
[redacted]

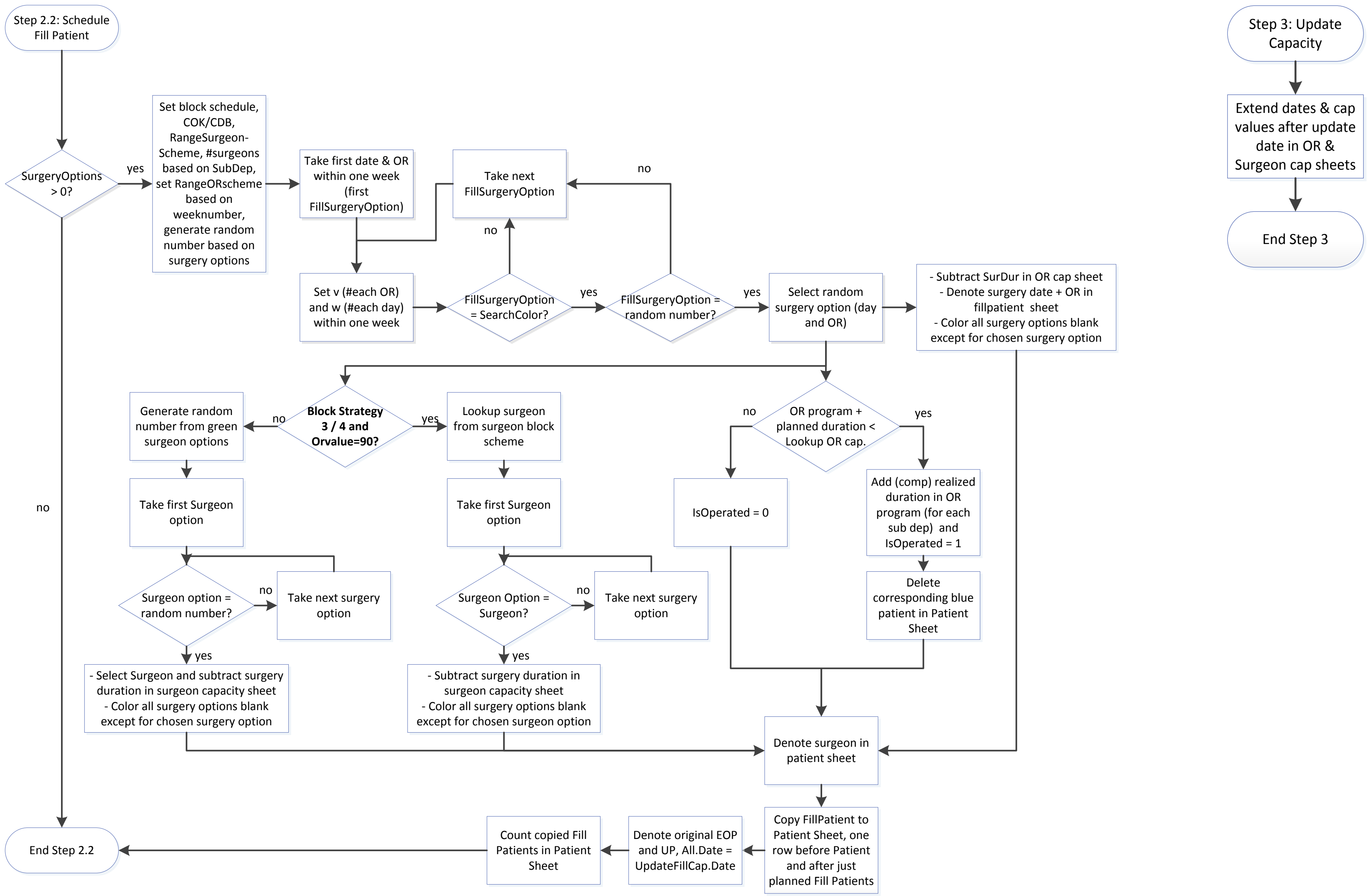
Table 19: MSS with block reservations for surgeons

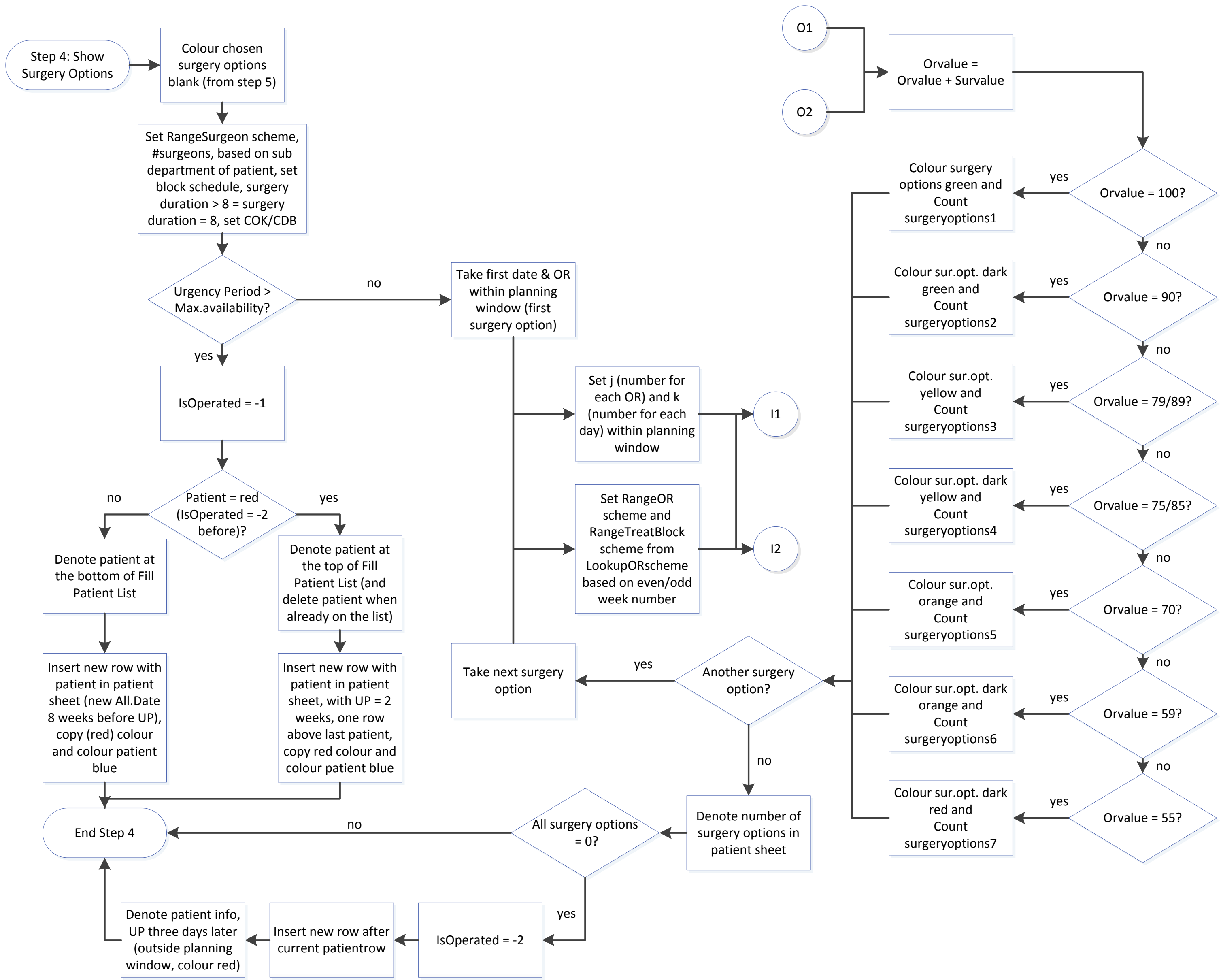
Appendix V: Simulation Model Flow Chart

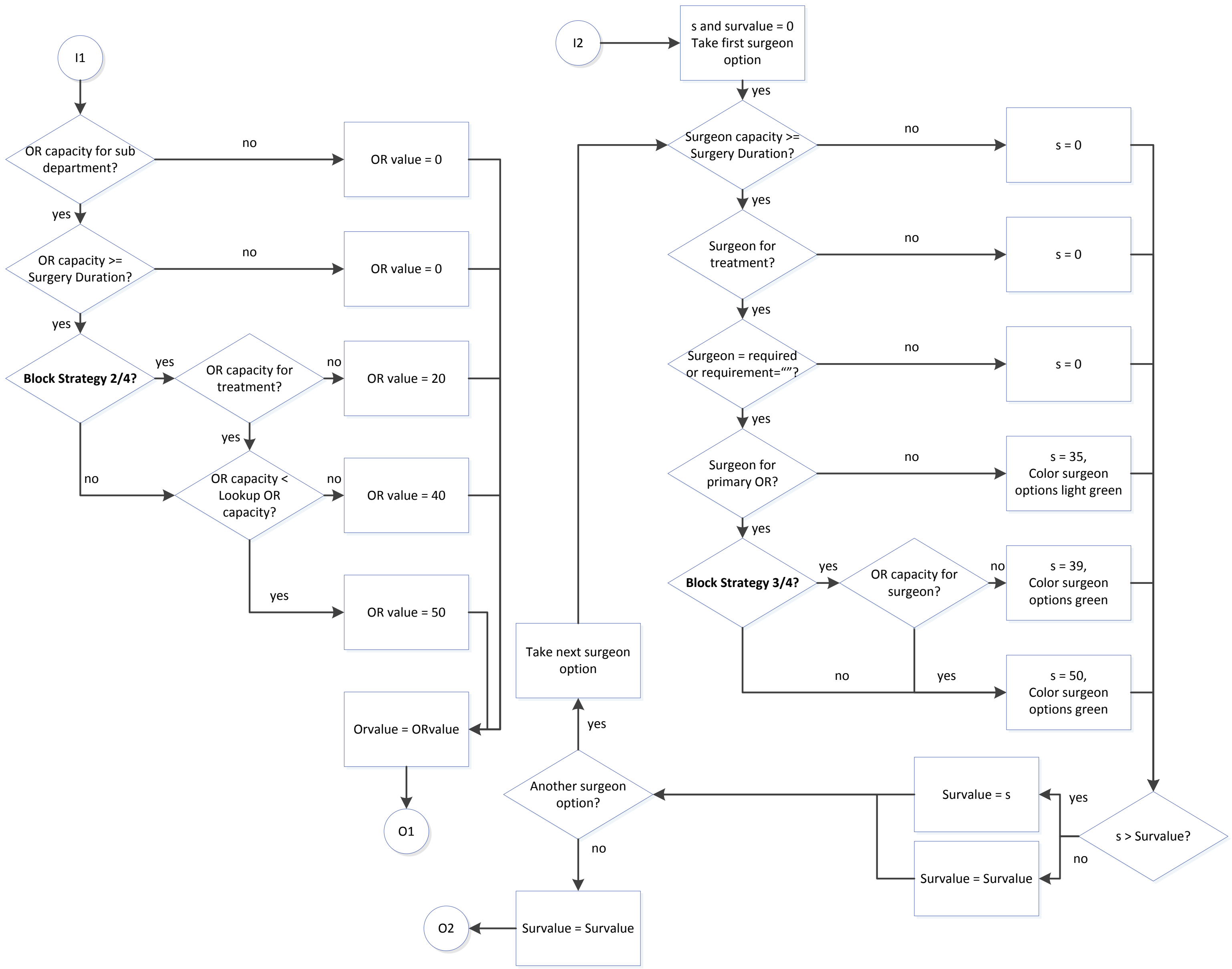


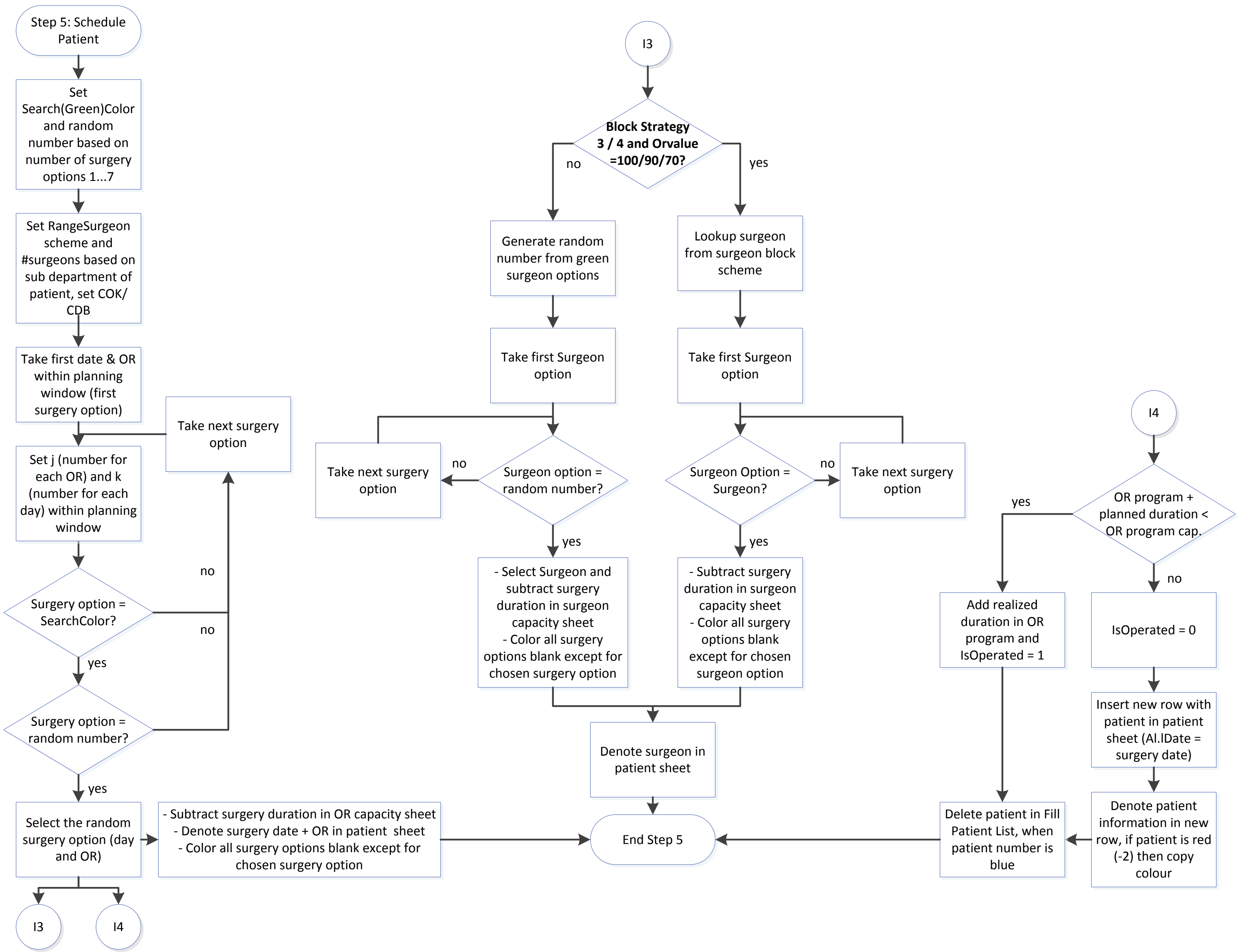


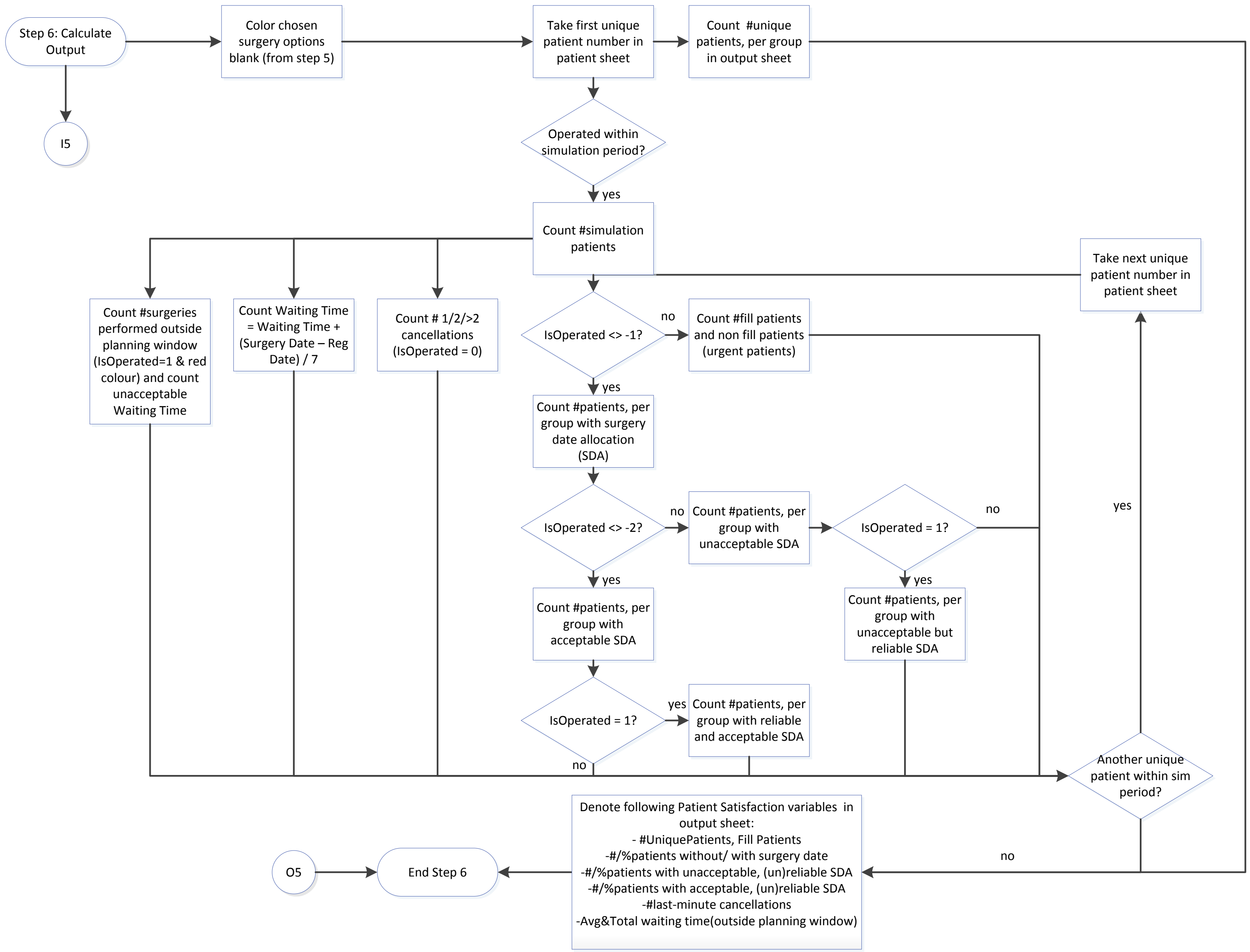

Step 2.1: Show Surgery Options Fill Patient
Color chosen surgery options blank (from step 5)
Set block schedule, COK/CDB, RangeSurgeon-Scheme, #surgeons based on SubDep, set RangeORscheme based on weeknumber
Take first date & OR within one week (first FillSurgeryOption)
Take next FillSurgeryOption
Set v (#each OR) and w (#each day) within one week
Take first FillSurgeonOption
SurgeonCap>=SurDur? & Surgeon for Treatment & Surgeon=Req or Req=“”?
no
s = 0
yes
SurgeryOption > RegDate + EOP & OR cap >= SurDur?
yes
OR value = 40
Surgeon for primary OR?
no
s = 35
yes
no
yes
OR value = 0
ORvalue = OR value
BlockStrategy 3 or 4?
yes
OR capacity for surgeon?
no
s = 39
no
yes
s = 50
Denote number of surgery options in FillPatient Sheet
no
Another FillSurgeryOption?
Orvalue = Orvalue + Survalue
Take next FillSurgeonOption
yes
Survalue = survalue
yes
no
Survalue = survalue
Another surgeon option?
s > survalue?
Survalue = survalue
no
Colour surgery options green, #surgeryoptions2
yes
Orvalue = 90?
no
Colour surgery options yellow, #surgeryoptions3
yes
Orvalue = 79?
no
End Step 2.1
Colour surgery options dark yellow, #surgeryoptions4
yes
Orvalue = 75?

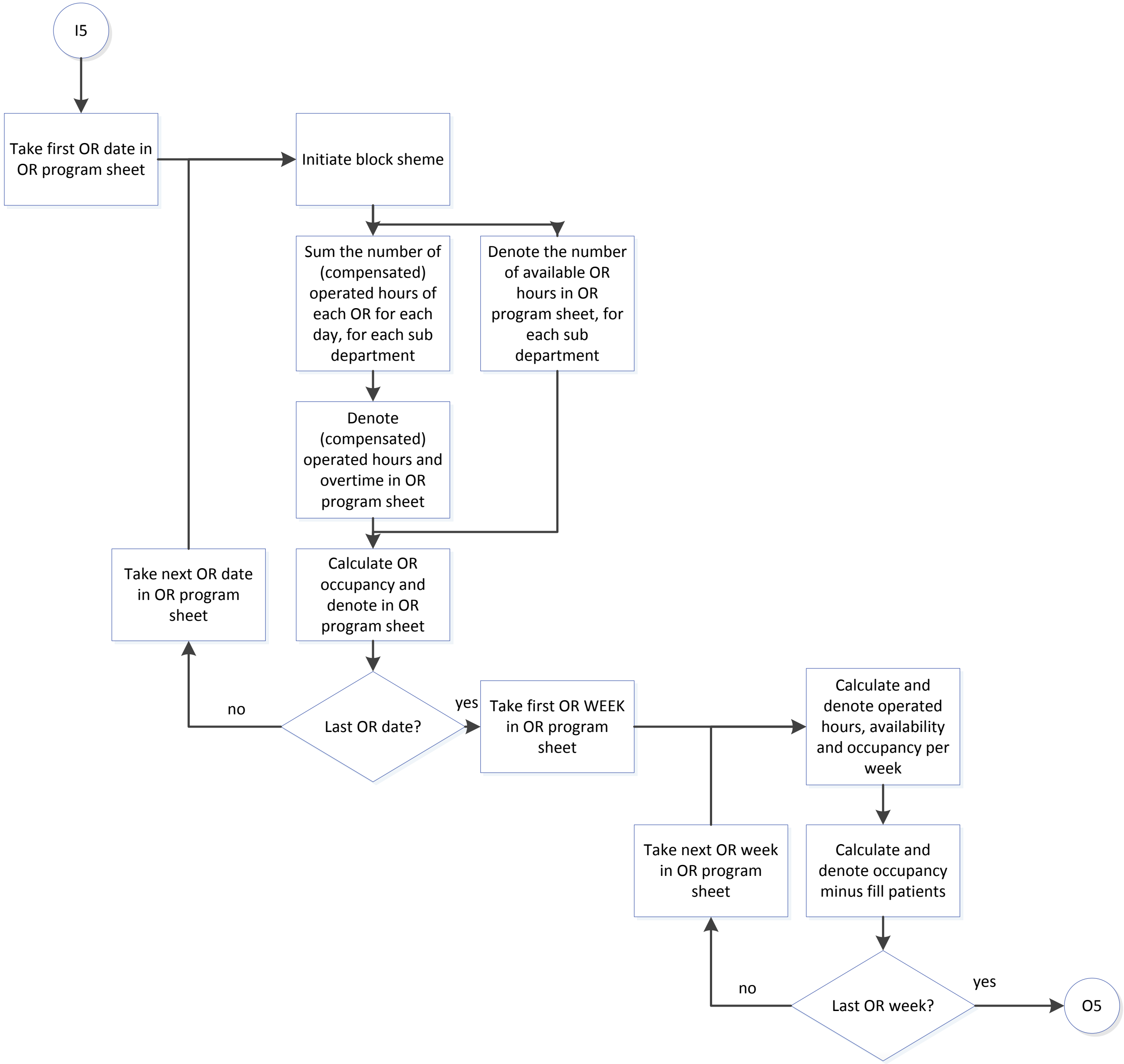

Step 2.2: Schedule Fill Patient
SurgeryOptions > 0?
yes
no
Set block schedule, COK/CDB, RangeSurgeon-Scheme, #surgeons based on SubDep, set RangeORscheme based on weeknumber, generate random number based on surgery options
Take first date & OR within one week (first FillSurgeryOption)
Take next FillSurgeryOption
no
Set v (#each OR) and w (#each day) within one week
FillSurgeryOption = SearchColor?
no
yes
FillSurgeryOption = random number?
yes
Select random surgery option (day and OR)
- Subtract SurDur in OR cap sheet
- Denote surgery date + OR in fillpatient sheet
- Color all surgery options blank except for chosen surgery option
Block Strategy 3 / 4 and Orvalue=90?
no
yes
Generate random number from green surgeon options
Lookup surgeon from surgeon block scheme
Take first Surgeon option
Take first Surgeon option
Surgeon option = random number?
no
Take next surgery option
yes
- Select Surgeon and subtract surgery duration in surgeon capacity sheet
- Color all surgery options blank except for chosen surgery option
Surgeon Option = Surgeon?
no
Take next surgery option
yes
- Subtract surgery duration in surgeon capacity sheet
- Color all surgery options blank except for chosen surgeon option
OR program + planned duration < Lookup OR cap.
no
yes
IsOperated = 0
Add (comp) realized duration in OR program (for each sub dep) and IsOperated = 1
Delete corresponding blue patient in Patient Sheet
Denote surgeon in patient sheet
Copy FillPatient to Patient Sheet, one row before Patient and after just planned Fill Patients
Denote original EOP and UP, All.Date = UpdateFillCap.Date
Count copied Fill Patients in Patient Sheet
End Step 2.2
Step 3: Update Capacity
Extend dates & cap values after update date in OR & Surgeon cap sheets
End Step 3


Step 4: Show Surgery Options
Colour chosen surgery options blank (from step 5)
Set RangeSurgeon scheme, #surgeons, based on sub department of patient, set block schedule, surgery duration > 8 = surgery duration = 8, set COK/CDB
Urgency Period > Max.availability?
no
yes
IsOperated = -1
Patient = red (IsOperated = -2 before)?
no
yes
Denote patient at the bottom of Fill Patient List
Denote patient at the top of Fill Patient List (and delete patient when already on the list)
Insert new row with patient in patient sheet (new All.Date 8 weeks before UP), copy (red) colour and colour patient blue
Insert new row with patient in patient sheet, with UP = 2 weeks, one row above last patient, copy red colour and colour patient blue
End Step 4
Take first date & OR within planning window (first surgery option)
Set j (number for each OR) and k (number for each day) within planning window
Set RangeOR scheme and RangeTreatBlock scheme from LookupORscheme based on even/odd week number
I1
I2
Take next surgery option
yes
Another surgery option?
no
Denote number of surgery options in patient sheet
All surgery options = 0?
no
yes
IsOperated = -2
Insert new row after current patientrow
Denote patient info, UP three days later (outside planning window, colour red)
O1
O2
Orvalue = Orvalue + Survalue
Orvalue = 100?
Colour surgery options green and Count surgeryoptions1
Orvalue = 90?
Colour sur.opt. dark green and Count surgeryoptions2
Orvalue = 79/89?
Colour sur.opt. yellow and Count surgeryoptions3
Orvalue = 75/85?
Colour sur.opt. dark yellow and Count surgeryoptions4
Orvalue = 70?
Colour sur.opt. orange and Count surgeryoptions5
Orvalue = 59?
Colour sur.opt. dark orange and Count surgeryoptions6
Orvalue = 55?
Colour sur.opt. dark red and Count surgeryoptions7
yes
no


I1
OR capacity for sub department?
no
OR value = 0
yes
OR capacity >= Surgery Duration?
no
OR value = 0
yes
Block Strategy 2/4?
yes
OR capacity for treatment?
no
OR value = 20
yes
no
OR capacity < Lookup OR capacity?
no
OR value = 40
yes
OR value = 50
Orvalue = ORvalue
O1
I2
s and survalue = 0 Take first surgeon option
yes
Surgeon capacity >= Surgery Duration?
no
s = 0
yes
Surgeon for treatment?
no
s = 0
yes
Surgeon = required or requirement=""?
no
s = 0
yes
Surgeon for primary OR?
no
s = 35, Color surgeon options light green
yes
Block Strategy 3/4?
yes
OR capacity for surgeon?
no
s = 39, Color surgeon options green
no
yes
s = 50, Color surgeon options green
Take next surgeon option
yes
Another surgeon option?
no
Survalue = Survalue
O2
Survalue = s
yes
s > Survalue?
no
Survalue = Survalue


Step 5: Schedule Patient
Set Search(Green)Color and random number based on number of surgery options 1...7
Set RangeSurgeon scheme and #surgeons based on sub department of patient, set COK/ CDB
Take first date & OR within planning window (first surgery option)
Take next surgery option
Set j (number for each OR) and k (number for each day) within planning window
no
Surgery option = SearchColor?
no
yes
Surgery option = random number?
yes
Select the random surgery option (day and OR)
- Subtract surgery duration in OR capacity sheet
- Denote surgery date + OR in patient sheet
- Color all surgery options blank except for chosen surgery option
I3
I4
I3
Block Strategy 3 / 4 and Orvalue =100/90/70?
no
yes
Generate random number from green surgeon options
Lookup surgeon from surgeon block scheme
Take first Surgeon option
Take first Surgeon option
Take next surgery option
no
Surgeon option = random number?
Surgeon Option = Surgeon?
no
Take next surgery option
yes
yes
- Select Surgeon and subtract surgery duration in surgeon capacity sheet
- Color all surgery options blank except for chosen surgery option
- Subtract surgery duration in surgeon capacity sheet
- Color all surgery options blank except for chosen surgeon option
Denote surgeon in patient sheet
End Step 5
I4
OR program + planned duration < OR program cap.
yes
no
Add realized duration in OR program and IsOperated = 1
IsOperated = 0
Insert new row with patient in patient sheet (Al.IDate = surgery date)
Denote patient information in new row, if patient is red (-2) then copy colour
Delete patient in Fill Patient List, when patient number is blue


Step 6: Calculate Output
I5
Color chosen surgery options blank (from step 5)
Take first unique patient number in patient sheet
Count #unique patients, per group in output sheet
Operated within simulation period?
yes
Count #simulation patients
Take next unique patient number in patient sheet
Count #surgeries performed outside planning window (IsOperated=1 & red colour) and count unacceptable Waiting Time
Count Waiting Time = Waiting Time + (Surgery Date – Reg Date) / 7
Count # 1/2/>2 cancellations (IsOperated = 0)
IsOperated <> -1?
no
Count #fill patients and non fill patients (urgent patients)
yes
Count #patients, per group with surgery date allocation (SDA)
IsOperated <> -2?
no
Count #patients, per group with unacceptable SDA
IsOperated = 1?
no
yes
yes
Count #patients, per group with acceptable SDA
yes
Count #patients, per group with unacceptable but reliable SDA
IsOperated = 1?
yes
Count #patients, per group with reliable and acceptable SDA
no
Another unique patient within sim period?
no
Denote following Patient Satisfaction variables in output sheet:
- #UniquePatients, Fill Patients
-#/%patients without/ with surgery date
-#/%patients with unacceptable, (un)reliable SDA
-#/%patients with acceptable, (un)reliable SDA
-#last-minute cancellations
-Avg&Total waiting time(outside planning window)
O5
End Step 6


I5
Take first OR date in OR program sheet
Initiate block sheme
Sum the number of (compensated) operated hours of each OR for each day, for each sub department
Denote the number of available OR hours in OR program sheet, for each sub department
Denote (compensated) operated hours and overtime in OR program sheet
Take next OR date in OR program sheet
Calculate OR occupancy and denote in OR program sheet
no
Last OR date?
yes
Take first OR WEEK in OR program sheet
Calculate and denote operated hours, availability and occupancy per week
Take next OR week in OR program sheet
Calculate and denote occupancy minus fill patients
no
Last OR week?
yes
O5

Appendix VI: Output Existing System

The realized weekly OR utilization and OR overtime have been obtained from Oksimed for the period equal to the simulation period. The information was specified for chs and all the other sub departments together, and for central and DS OR's. The weekly OR utilization in Oksimed is defined as the weekly used OR hours divided by the weekly available hours. The used OR hours are not compensated for overtime, which results in a higher OR utilization (often even higher than 100%). The OR overtime in Oksimed is defined as the total sum of the number of OR hours which were exceeding the available hours on a surgery date in an OR, divided by the weekly available hours. A weekly OR overtime percentage higher than 5% was not exceptional. In Table 20, the average OR utilization and OR overtime are presented for the complete simulation period. The total average is a weighted average for the number of OR's. Compensated for OR overtime, the average OR utilization would be equal to 86%. What should be kept in mind is that these results also include the semi-elective patients. This would partly explain the high percentage of OR overtime. Therefore, the OR overtime expressed in the number of hours, is carefully computed by taking 5% of 151 available hours. This resulted in 7.55 hours.

	GS central OR	GS DS OR	CHS central OR	CHS DS OR	Total Average
OR utilization	91%	91%	91%	89%	**91%**
OR overtime	5%	2%	9%	2%	**5%**

Table 20: Weekly average OR utilization and OR overtime for week 33 of 2012 until week 32 in 2013 (Oksimed)

In the figure stated below, the realized weekly operated hours are presented, which were obtained from the corresponding data in Okapi and Oksimed for the simulation period. Note that the semi-elective patients are excluded in this source. The blue line represents the operated hours and the red line represents the operated hours compensated operation overtime. The low number of operated hours can be explained from public holidays (carnival, Easter, Kings Day, Whit Monday, summer holidays). For normal weeks, the number of operated hours fluctuated between 120 and 140. With 151 available hours, the utilization would fluctuate between 79% and 93%. Further, the operated hours for patients with a registration date after January 1st, 2013 are specified with the green line. As can be seen, a lot of patients who arrived prior to January 1st have still been operated months later, probably outside the urgency period. As can be concluded from this figure, there is a delay in operating patients because of a high patient waiting list.

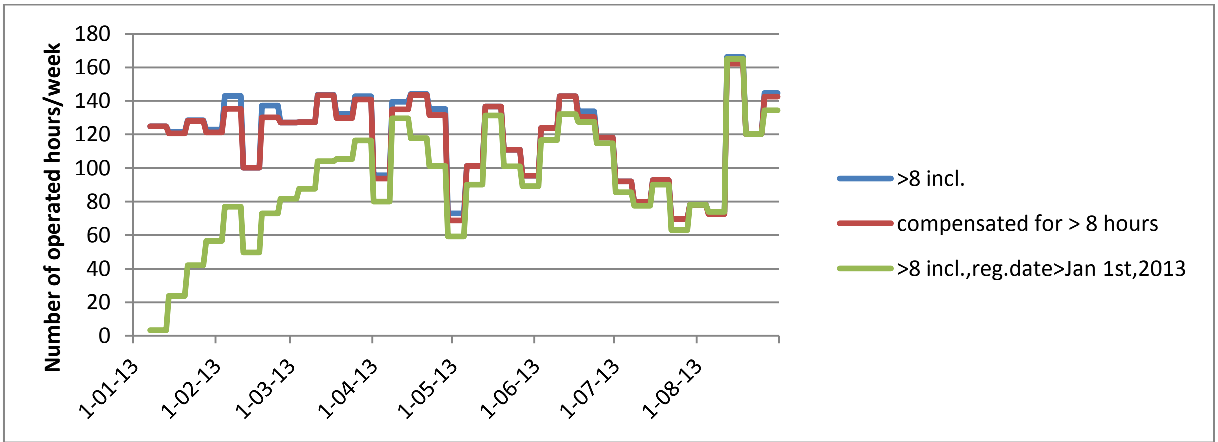


Figure 18: Realized weekly operated hours for week 1 until week 35 in 2013 (Okapi&Oksimed)

As can be seen in the table below, according the corresponding data in Okapi and Oksimed, 1706 patients were operated in the period from February 1st until September 1st. The average waiting time of these patients is high, often higher than the urgency period. As a result, 763 patients (45%) were operated outside the urgency period (assuming the same urgency periods as the input in the simulation model, so the same urgency period within an operation group). This is especially the case for aos patients, which are expressed in blue. Additionally, the overall average waiting time for the patients operated outside the urgency period was equal to 12.4 weeks. The urgency period is given in the last column for comparing these numbers. As can be concluded, there is a critical situation with respect to acceptable surgery dates.

[redacted]

Table 21: Output of existing system, distinguished for each operation group (Okapi&Oksimed)

In Figure 19, the operation status of all registered patients on September 1st, 2013 is given. The operated patients are included in the combined datasheet. The 'waiting for operation' operation status is a sum of all 'planned' and all 'registered' patients. The amount of patients waiting for operation before 2013, were negligible. So at the end of the simulation period, still 460 patients were waiting for operation. 269 patients of this waiting list arrived in July and August.

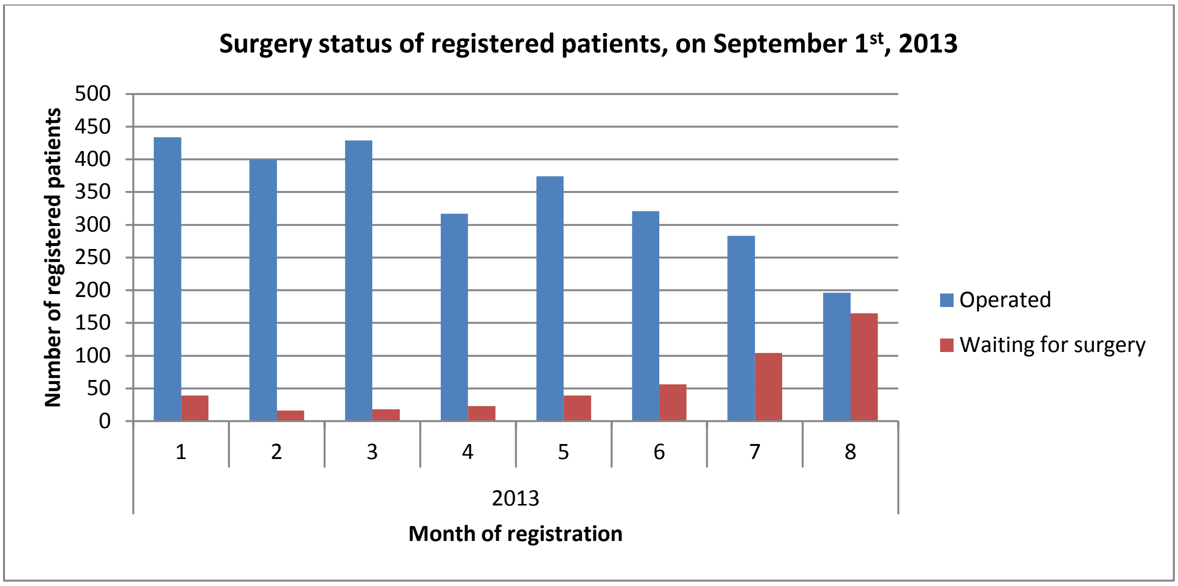


Figure 19: Operation status of registered patients, on September 1st, 2013 (Okapi)

Appendix VII: Extended Simulation Results

Historical Waiting List

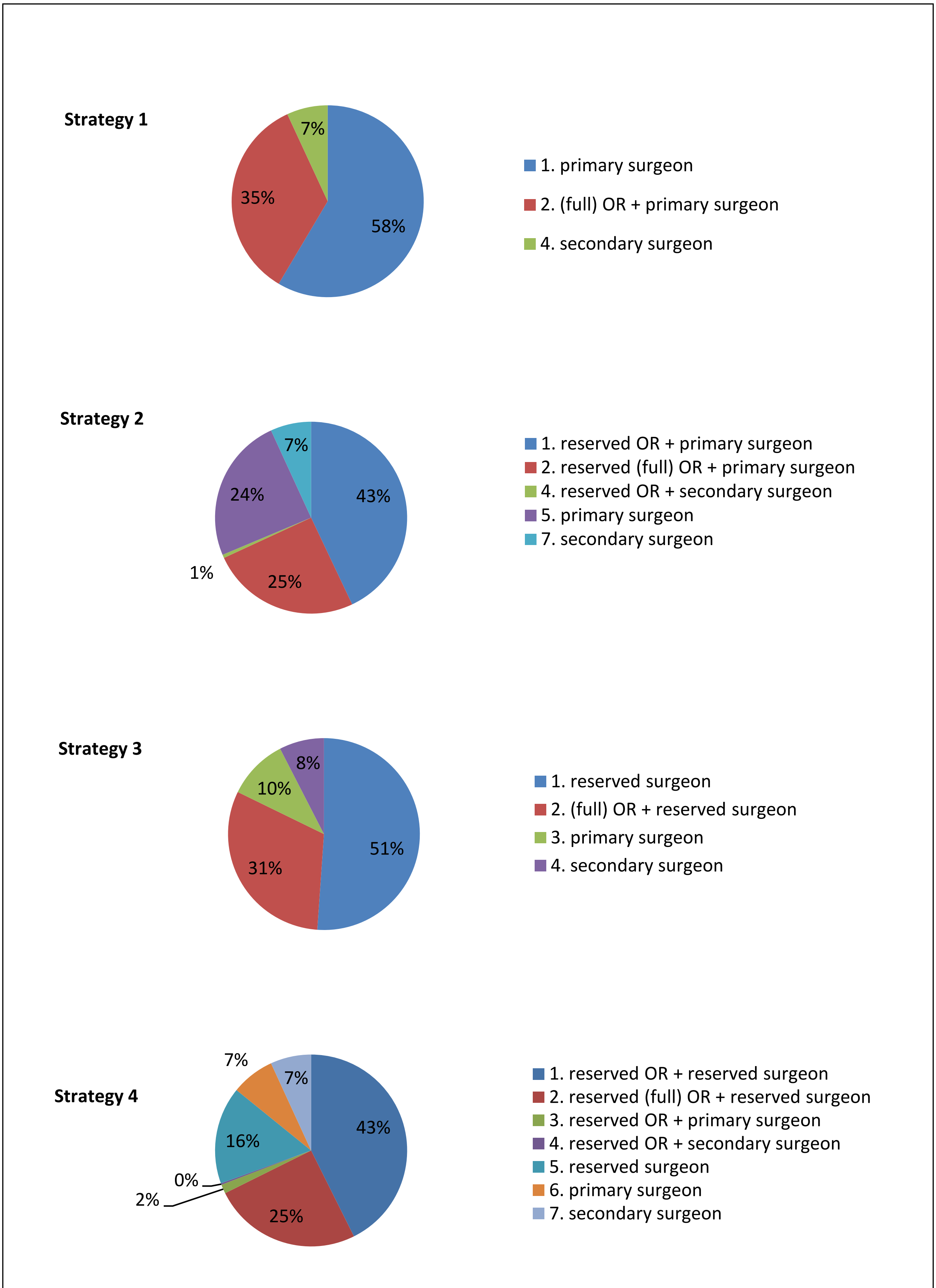


Figure 20: Allocated surgery options to patients under the different strategies under 8-8.5/ … /0/0-actual/historical

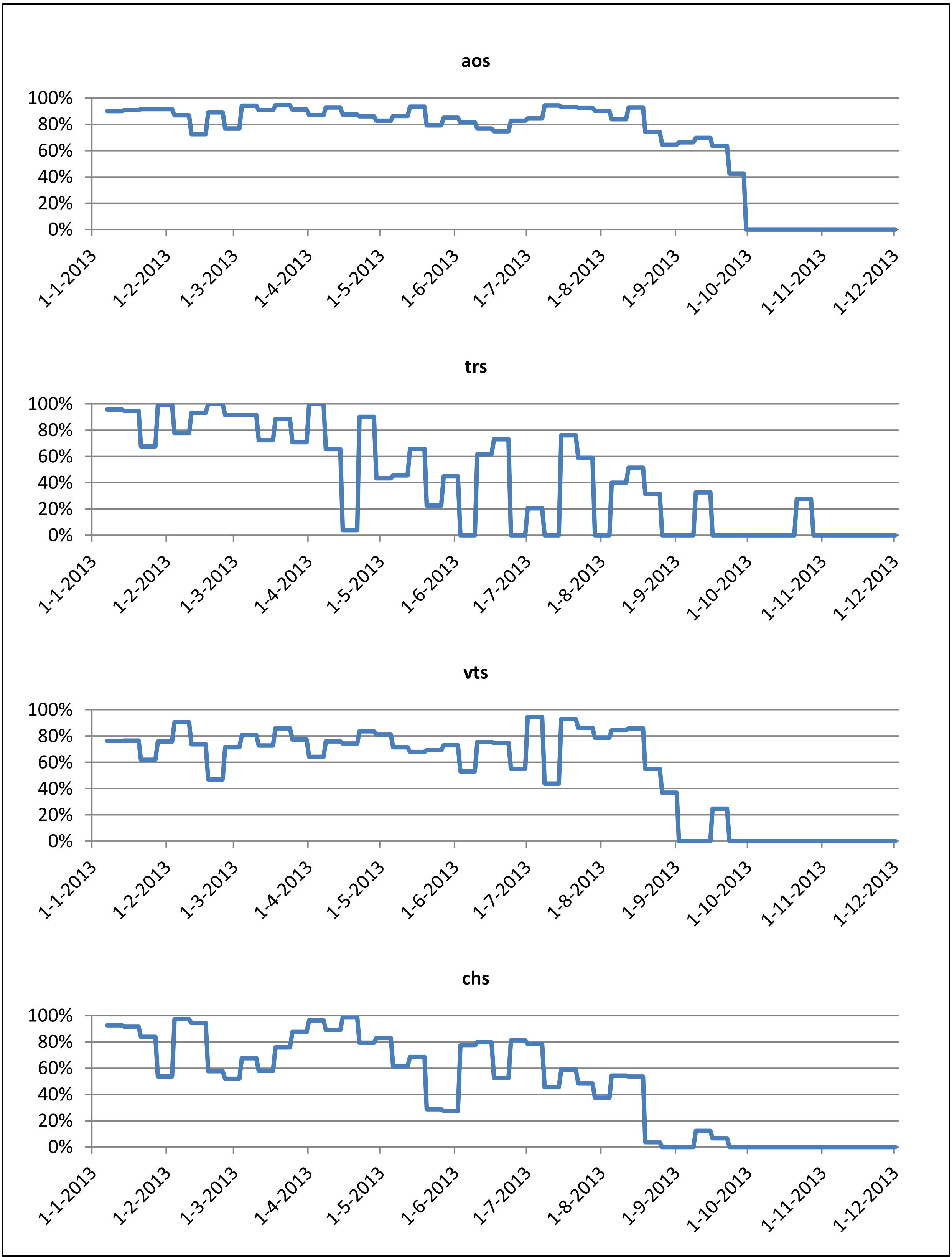


Figure 21: Average weekly OR occupancy specified for each sub department under 8-8.5/4/0/0-actual/historical

	Fill patients flexibility	0	0	1	1
	MSS Adjustments	**Actual**	**Modification**	**Actual**	**Modification**
AOS	# Operated patients during simulation period	880	915	907	914
	# Operated hours during simulation period	2067	2169	2159	2179
	Waiting list on 01-02-2013 (in # patients|hours)	266|637	251|597	254|622	249|600
	Waiting list on 01-09-2013 (in # patients|hours)	69|194	19|51	30|87	18|46
	Reliable and acceptable PSDA (in % of operated patients)	50%	54%	50%	52%
	Unreliability: patient cancellation (in %)	8%	7%	9%	8%
	Unacceptability: outside planning window (in %)	51%	46%	50%	47%
	Average waiting time (in weeks)	7.1	6.3	6.7	6.3
	Unacceptable average waiting time (in weeks)	9.3	8.2	8.6	8.0
	Average weekly occupancy (in %)	85.5%	81.3%	83.5%	82.7%
	Average weekly overtime (in hours)	2.48	2.69	2.44	2.83
TRS	# Operated patients|hours during simulation period	153|251	159|255	162|264	167|272
	Waiting list on 01-02-2013 (in # patients|hours)	40|69	54|91	34|69	39|77
	Waiting list on 01-09-2013 (in # patients|hours)	15|14	23|32	0|0	0|0
	Reliable and acceptable PSDA (in % of operated patients)	83%	75%	83%	75%
	Unreliability: patient cancellation (in %)	2%	4%	4%	8%
	Unacceptability: outside planning window (in %)	3%	6%	3%	8%
	Average waiting time (in weeks)	4.5	9.0	6.1	6.3
	Unacceptable average waiting time (in weeks)	13.0	10.9	13.0	10.9
	Average weekly occupancy (in %)	53.2%	84.0%	64.2%	70.2%
	Average weekly overtime (in hours)	0.04	0.03	0.32	0.05
VTS	# Operated patients|hours during simulation period	205|528	205|524	206|527	203|526
	Waiting list on 01-02-2013 (in # patients|hours)	48|141	51|144	50|143	46|139
	Waiting list on 01-09-2013 (in # patients|hours)	4|9	7|16	5|11	4|9
	Reliable and acceptable PSDA (in % of operated patients)	63%	57%	63%	63%
	Unreliability: patient cancellation (in %)	1%	2%	2%	3%
	Unacceptability: outside planning window (in %)	37%	43%	37%	37%
	Average waiting time (in weeks)	5.4	5.6	5.4	5.3
	Unacceptable average waiting time (in weeks)	6.8	6.5	6.5	6.4
	Average weekly occupancy (in %)	72.6%	71.6%	75.7%	76.2%
	Average weekly overtime (in hours)	0.14	0.12	0.14	0.18
CHS	# Operated patients|hours during simulation period	350|482	357|494	350|481	356|493
	Waiting list on 01-02-2013 (in # patients|hours)	52|69	61|84	52|68	60|84
	Waiting list on 01-09-2013 (in # patient|hours)	7|6	9|10	7|6	9|11
	Reliable and acceptable PSDA (in % of operated patients)	95%	79%	94%	70%
	Unreliability: patient cancellation (in %)	5%	6%	6%	6%
	Unacceptability: outside planning window (in %)	2%	20%	3%	29%
	Average waiting time (in weeks)	3.5	5.0	3.7	5.1
	Unacceptable average waiting time (in weeks)	7.6	7.8	7.5	7.5
	Average weekly occupancy (in %)	63.1%	76.1%	73.3%	76.2%
	Average weekly overtime (in hours)	0.33	0.38	0.42	0.32

Table 22: 8-8.5/4/0/ … - … /historical, specified for each sub department

Reduced Waiting List

	Runs					
	1	2	3	4	5	CV
Run duration (in minutes)	8.6	8.3	8.4	8.4	8.5	0.014
# Operated patients during simulation period	1477	1487	1484	1488	1486	0.003
# Operated hours during simulation period	3082	3081	3094	3108	3082	0.004
Waiting list on 01-02-2013 (in # patients)	257	267	262	259	260	0.015
Waiting list on 01-02-2013 (in expected hours)	552	565	566	569	548	0.017
Waiting list on 01-09-2013 (in # patients)	57	57	55	48	51	0.074
Waiting list on 01-09-2013 (in expected hours)	105	118	106	95	100	0.082
Reliable and acceptable PSDA (in % of operated patients)	77%	77%	78%	77%	79%	0.012
Unreliability: patient cancellation (in %)	7%	7%	7%	6%	7%	0.066
Unacceptability: outside planning window (in %)	12%	12%	11%	11%	10%	0.075
Average waiting time (in weeks)	4.4	4.4	4.4	4.4	4.4	0.000
Unacceptable average waiting time (in weeks)	5.2	5.4	5.2	5.4	5.3	0.019
Average weekly occupancy (in %)	70.9%	70.7%	71.0%	71.5%	71.3%	0.004
Average weekly overtime (in hours)	2.76	2.69	2.93	2.74	2.25	0.095

Table 23: Output of five independent replications of 8-8.5/4/0/0-actual/reduced

	Strategies			
	1	2	3	4
Run duration (in minutes)	8.5	10.3	8.9	8.6
# Operated patients during simulation period	1492	1497	1484	1477
# Operated hours during simulation period	3100	3115	3098	3082
Waiting list on 01-02-2013 (in # patients)	258	271	261	257
Waiting list on 01-02-2013 (in expected hours)	554	582	561	552
Waiting list on 01-09-2013 (in # patients)	43	51	54	57
Waiting list on 01-09-2013 (in expected hours)	87	101	97	105
Reliable and acceptable PSDA (in % of operated patients)	77%	75%	77%	77%
Unreliability: patient cancellation (in %)	6%	6%	7%	7%
Unacceptability: outside planning window (in %)	12%	13%	12%	12%
Average waiting time (in weeks)	4.2	4.5	4.3	4.4
Unacceptable average waiting time (in weeks)	5.2	5.2	5.5	5.2
Average weekly occupancy (in %)	71.6%	71.6%	71.6%	70.9%
Average weekly overtime (in hours)	2.69	2.69	2.51	2.76

Table 24: 8-8.5/ … /0/ 0-actual/reduced

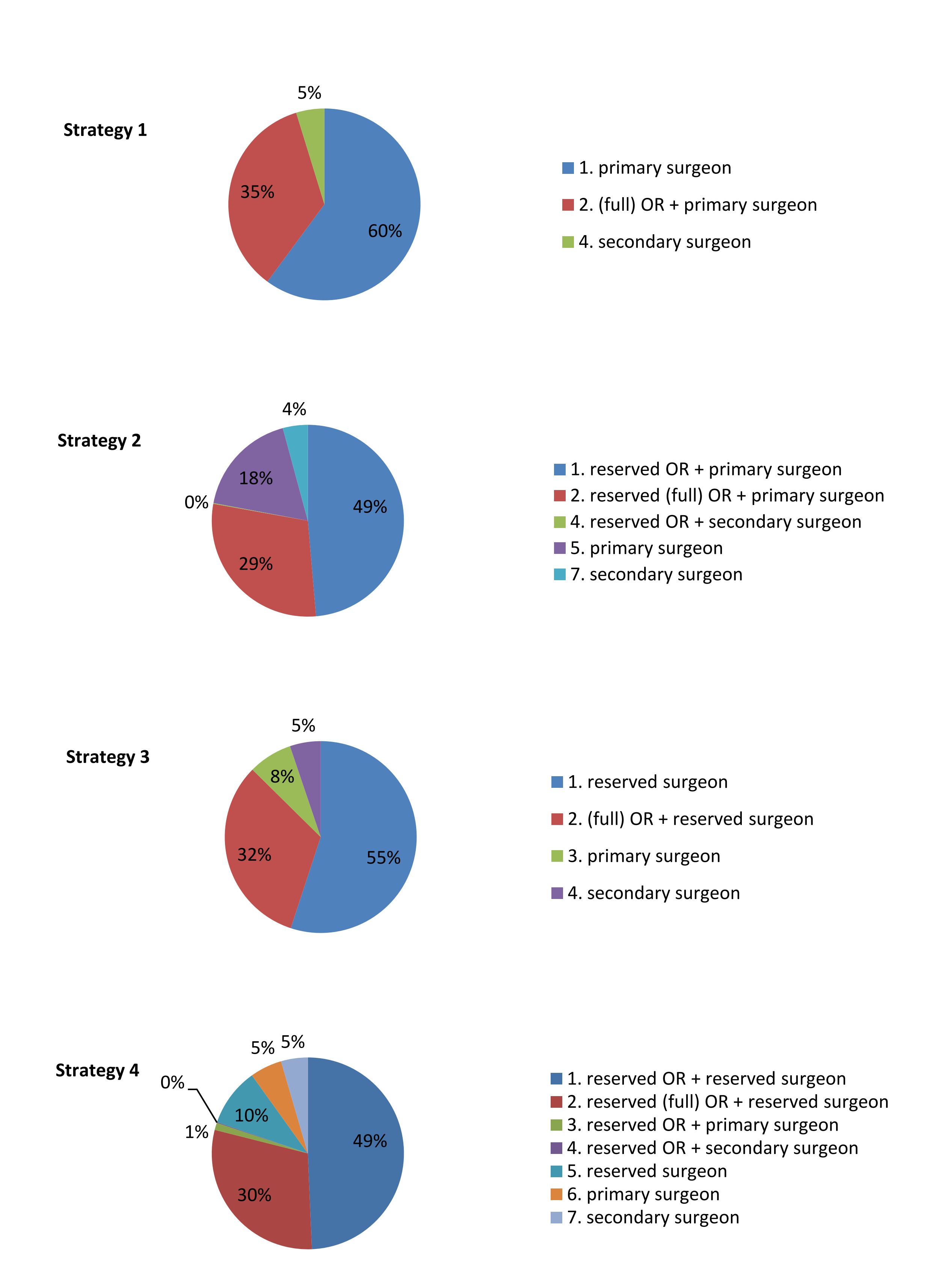


Figure 22: Allocated surgery options to patients under the different strategies under 8-8.5/ … /0/0-actual/historical

Fill patients flexibility	0	0	1	1
MSS Adjustments	**Actual**	**Modification (CI)**	**Actual**	**Modification (CI)**
AOS # Operated patients during simulation period	805	792 (±2)	805	794 (±5)
# Operated hours during simulation period	1895	1864 (±7)	1895	1865 (±4)
Waiting list on 01-02-2013 (in # patients)	145	131 (±1)	142	132 (±3)
Waiting list on 01-02-2013 (in # hours)	336	298 (±7)	334	302 (±6)
Waiting list on 01-09-2013 (in # patients)	23	22 (±2)	20	22 (±5)
Waiting list on 01-09-2013 (in # hours)	64	57 (±5)	63	61 (±8)
Reliable and acceptable PSDA (in % of operated patients)	80%	90% (±0.5%)	83%	90% (±0.8%)
Unreliability: patient cancellation (in %)	7%	5% (±0.6%)	7%	5% (±0.4%)
Unacceptability: outside planning window (in %)	17%	6% (±0.6%)	14%	6% (±0.8%)
Average waiting time (in weeks)	4.6	4.1 (±0.1)	4.5	4.1 (±0.1)
Unacceptable average waiting time (in weeks)	4.9	4.2 (±0.2)	5.2	4.7 (±0.3)
Average weekly occupancy (in %)	78.6%	70.5% (±0.4%)	79.6%	74.4% (±0.2%)
Average weekly overtime (in hours)	2.27	1.97 (±0.08)	2.28	2.06 (±0.23)
TRS # Operated patients during simulation period	152	159 (±2)	158	160 (±4)
# Operated hours during simulation period	248	258 (±2)	255	260 (±8)
Waiting list on 01-02-2013 (in # patients)	39	52 (±0)	30	32 (±4)
Waiting list on 01-02-2013 (in # hours)	67	90 (±0)	60	64 (±8)
Waiting list on 01-09-2013 (in # patients)	15	21 (±2)	0	0 (±0)
Waiting list on 01-09-2013 (in # hours)	14	27 (±3)	0	0 (±0)
Reliable and acceptable PSDA (in % of operated patients)	75%	71% (±0.0%)	71%	70% (±4.4%)
Unreliability: patient cancellation (in %)	3%	4% (±0.1%)	3%	9% (±2.1%)
Unacceptability: outside planning window (in %)	1%	1% (±0.0%)	1%	0.01% (±0.00%)
Average waiting time (in weeks)	4.6	8.9 (±0.2)	2.5	2.6 (±0.2)
Unacceptable average waiting time (in weeks)	16.6	16.6 (±0.0)	16.6	16.6 (±0.0)
Average weekly occupancy (in %)	52.5%	84.7%(±1.0%)	39.6%	39.0% (±0.9%)
Average weekly overtime (in hours)	0.01	0.04 (±0.02)	0.01	0.04 (±0.04)
VTS # Operated patients during simulation period	194	191 (±2)	196	193 (±3)
# Operated hours during simulation period	486	484 (±4)	494	488 (±7)
Waiting list on 01-02-2013 (in # patients)	39	37 (±1)	38	38 (±1)
Waiting list on 01-02-2013 (in # hours)	104	104 (±1)	104	105 (±1)
Waiting list on 01-09-2013 (in # patients)	6	7 (±1)	3	5 (±3)
Waiting list on 01-09-2013 (in # patients)	14	15 (±4)	6	12 (±7)
Reliable and acceptable PSDA (in % of operated patients)	91%	90% (±1.8%)	93%	91% (±2.3%)
Unreliability: patient cancellation (in %)	1%	2% (±1.0%)	2%	2% (±1.4%)
Unacceptability: outside planning window (in %)	9%	9% (±1.8%)	7%	8% (±1.8%)
Average waiting time (in weeks)	4.6	4.5 (±0.2)	4.3	4.5 (±0.2)
Unacceptable average waiting time (in weeks)	4.7	4.8 (±0.6)	4.1	4.6 (±0.5)
Average weekly occupancy (in %)	65.6%	66.4% (±0.6%)	69.6%	69.0% (±0.9%)
Average weekly overtime (in hours)	0.17	0.13 (±0.06)	0.03	0.12 (±0.06)
CHS # Operated patients during simulation period	326	341 (±12)	340	341 (±12)
# Operated hours during simulation period	453	471 (±13)	472	472 (±14)
Waiting list on 01-02-2013 (in # patients)	34	46 (±7)	42	44 (±8)
Waiting list on 01-02-2013 (in # hours)	47	62 (±8)	58	60 (±9)
Waiting list on 01-09-2013 (in # patient)	13	10 (±6)	7	8 (±5)
Waiting list on 01-09-2013 (in # hours)	13	10 (±6)	6	7 (±6)
Reliable and acceptable PSDA (in % of operated patients)	95%	84% (±5.6%)	93%	87% (±3.7%)
Unreliability: patient cancellation (in %)	6%	6% (±1.2%)	6%	5% (±0.9%)
Unacceptability: outside planning window (in %)	4%	15% (±5.9%)	5%	12% (±3.7%)
Average waiting time (in weeks)	3.8	4.6 (±0.4)	4	4.5 (±0.2)
Unacceptable average waiting time (in weeks)	7.2	7.6 (±0.2)	7.1	7.6 (±0.3)
Average weekly occupancy (in %)	57.1%	71.8% (±0.8%)	66.4%	73.6% (±1.2%)
Average weekly overtime (in hours)	0.34	0.33 (±0.06)	0.45	0.27 (±0.07)

Table 25: 8-8.5/4/0/ … - … /reduced, specified for each sub department

Appendix VIII: Extended Recommendations for Further Research

Other recommendations for further research did not arise from the limitations of this research. New perspectives regarding the planning method, or ideas for further research by expanding the scope of this research, are described in this chapter.

Planning Method

Firstly, regarding the planning method, patient shifts on the OR program were not allowed in the redesigned planning method, since the allocated surgery date should be reliable. However, it would be interesting to simulate the influence of patient shifts on the reliability and acceptability of the planning. For example, when a patient cannot be planned within the planning window, a shift of patients can result in acceptable surgery dates for both patients. However, the reliability of the planning decreases. In this way, it would be valuable to distinguish between early operation cancellations and last-minute operation cancellations.

Secondly, cancelled patients are not given priority in the current planning method. They just receive a new surgery date on the cancelled surgery date. It would be interesting to simulate the influence of placing the cancelled patients on the 'fill patient' list. Another way to deal with cancelled patients is to set a more flexible cancellation rule for them. In this way, more OR overtime is allowed when the patient is cancelled (several times) before. It would also be possible to regard other OR's; when another OR is finished earlier than expected, the patient could be operated on that OR, or even on a semi-elective OR.

Scope Expansion

Although the scope of this research is clearly defined, that does not mean the topics which fell beyond the scope are not interesting to include in the model for further research. Firstly, it would be interesting to take into account bed requirements. When a patient needs an ICU or MCU bed, or a bed on the nursing unit, these beds have to be available after the operation. It would be interesting to include the number of hospitalization days as patient attribute. In this way, the number of occupied beds in the simulation model can be monitored, so that the workload on the nursing unit can be observed.

Secondly, it would be interesting to attach more value to surgery durations in this model. To start with, variations of estimated surgery durations can be taken into account, which are needed as patient attribute. It could be investigated how the performance is affected by including the average (or median) surgery duration of each operation group (per surgeon). Furthermore, it would be useful to include standard deviations of surgery durations, to estimate the probability of operation overtime. In this way, variations of the admission and cancellation rules can be included to the simulation model. For example, an admission rule which allows having a maximum probability of OR overtime of a certain percentage. Consequently, a more reliable planning will be obtained.

Thirdly, patient sequencing on the level of online sequencing can be included for further research. When patients are admitted for a certain surgery date in an OR, they are sequenced in the OR for deciding the operation starting time. The way of sequencing will have an influence for the overall planning performance, especially for the cancellations.