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MASTER

Analysis of access times in a gastroenterology department

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Eindhoven University of Technology

Master Thesis

Analysis of Access Times in a Gastroenterology Department

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Abstract

Currently there exists a nation wide shortage of gastroenterologists in the Netherlands, which results in long waiting times for gastroenterological treatments throughout the country. Furthermore, the Dutch National Institute for Public Health and the Environment (RIVM) started the introduction of the Bowel Cancer Screening (BCS) program in 2014 for citizens aged between 55 and 75, which increases the urgency of the shortage.

The Gastroenterology and Hepatology department (GHD) at the Jeroen Bosch hospital (JBZ) in 's-Hertogenbosch, the Netherlands, also faces this problem. Therefore, the JBZ is interested in ways to increase efficiency with which the available staff capacity is used, and the minimum number of necessary gastroenterologists to meet the maximum allowed access time requirements. This report focuses on three aspects of the GHD planning process. First, the determination of the expected yearly appointment demand by modelling the patient treatment paths of each GHD patients with a developed Markov model. Second, the investigation of the current staff capacity, the determination of the minimum staff capacity for different demand scenarios, and a proposal of adjustments to the current staff scheduling to improve efficiency. The final part of this report involves the investigation of the current appointment planning methods and the influence of the proposed staff capacity changes on the access time for first time visitors, and the waiting time for follow-up appointments. Also, the JBZ currently prefers that each patient is treated by the same gastroenterologist as much as possible. This planning method will be compared to a staff pooling method where each qualified gastroenterologist is a potential clinician for every patient, and the influence of both methods on the waiting time will be compared.

All results are obtained from a developed discrete event simulation for the complete GHD planning process at the JBZ, involving the three mentioned aspects.

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Contents

Chapter 1

Introduction

The research for this thesis was conducted at the Gastroenterology and Hepatology department (GHD) at the Jeroen Bosch hospital (JBZ) in 's-Hertogenbosch, The Netherlands. In this chapter, a short introduction to this GHD, and Gastroenterology and Hepatology in general will be given.

1.1 Gastroenterology and Hepatology

Gastroenterology and Hepatology is the medical specialisation focusing on problems concerning the stomach, intestines and liver [21]. Examples of common gastrointestinal diseases are collorectal cancer, Crohn's disease, or irritable bowel syndrome. At the Gastroenterology and Hepatology department (GHD) of the Jeroen Bosch hospital (JBZ) these patients are treated by one of the available gastroenterologists (physicians), or gastroenterologists in training (residents), which are assisted by qualified nurses during specified procedures. Next to the physicians and residents, additional staff members are available to perform specific endoscopic procedures.

The JBZ was founded in 2002 by the merging of two hospitals in 's-Hertogenbosch, the Carolus-Liduina hospital and the Bosch Medicentrum. The merge was finalized in 2011 by the completion of a new main building. In addition to this main building, the JBZ also consists of four locations outside of 's-Hertogenbosch, namely Rosmalen, Boxtel, Zaltbommel and Nieuwkuijk. The first three of them have gastroenterology consultation hours once a week.

The main department at 's-Hertogenbosch consists of two separate subdepartments, namely the outpatient clinic, and endoscopy unit. A patient with an appointment at the outpatient clinic, will get a consultation. An appointment at the endoscopy unit consists of an endoscopic examination. There are several types of consultations, and endoscopies, of which the most important ones are listed in table 1.1. [12, 18]

TABLE 1.1: List of consultations, and endoscopies performed at the GHD.

Endoscopies		
Name	Description	Abbreviation
Colonoscopy	Endoscopy examining the large bowel and first part of the small bowel.	CO
Gastroscopy	Endoscopy examining the esophagus, stomach, and duodenum.	GA
Sigmoidoscopy	Endoscopy examining the last part of the large bowel.	SI
Endoscopic retrograde cholangiopancreatography	Endoscopy examining the bile ducts, and the pancreas duct.	ERCP
Endoscopic ultrasound	Endoscopy examining the stomach, pancreas, and surrounding lymph nodes, and blood vessels, using ultrasound.	EUS
Percutaneous endoscopic gastrostomy	Procedure of applying a PEG feeding tube.	PEG

Consultations		
Name	Description	Abbreviation
First time consultation	Regular consultation - First time visitor	NP
Check-Up consultation	Regular consultation - Check-up	HP
Intake consultation	Introduction consultation for colonoscopies	IP
Call back consultation	Consultation by phone	BE

Both the physicians, and residents are qualified to provide consultations at outpatient clinic, and most of the endoscopies at the endoscopy unit. Some endoscopies, e.g. ERCPs, are only performed by specialised physicians. In chapters 3 and 4, the patients treatment paths will be modelled, and more details about patients and appointments will be discussed.

1.2 Problem Description

At the moment there exists a nation wide shortage of gastroenterologists in the Netherlands, resulting in long waiting times for first time visitors at GHDs all over the country. Also, check-up appointments are delayed due to this capacity shortage. In the 's-Hertogenbosch region, some hospitals have even issued an admission stop for first time visitors, resulting in an even larger admission rate at the JBZ GHD.

One of the events that increased this shortage is the introduction of the Bowel Cancer Screening (BCS) program by the National Institute for Public Health and the Environment (RIVM) commissioned by the Dutch ministry of Health, Welfare and Sport. Since January 2014, men and women over 50 are screened for bowel cancer. If the first screening shows signs of bowel cancer, additional research is needed. This additional research contains an intake consultation and a colonoscopy at the GHD, performed by a qualified gastroenterologist. Due to strict governmental regulations, the BCS patients get priority over 'regular' patients, leaving even less capacity for patients from the second group.

The BCS program is introduced gradually between 2014 and 2019. In 2014, 875.000 invitations were send to all Dutch citizens aged 63, 65, 67, 75, and 76. The goal for the year 2019 and beyond is to send invitations to all citizens aged between 55 and 75, with an odd age, resulting in an expected number of 2.260.000 send out invitations every year and a biennial screening for all members of the target group. [16]

Response figures from the Erasmus MC and the Antoni van Leeuwenhoek hospital in the first half of 2014 show that out of the 190.000 invited people, 68% responded to the invitation. 12% of these participants needed additional research, and out of these group of patients 74% returned for a colonoscopy. These colonoscopies revealed 763 (7%) confirmed cases of bowel cancer, and 3.832 (34%) patients with developed polyps [17].

Beforehand the RIVM estimated the required capacity at 28.000 colonoscopies per year for the additional research nationwide. However, last years figures show that the actual number was 71.400, which is almost a tripling of the expected value. GHDs can not cope with this demand, and therefore, the RIVM decided to increase the threshold used to determine whether additional research is needed or not [20].

However, still the number of required colonoscopies is higher than initially expected, and pressure on Dutch GHDs is rising. Therefore, the JBZ GHD is interested in ways to increase efficient use of their available staff capacity. Also, if the BCS program continues to develop according to last years figures combined with the expected increase in invitations, how much extra capacity is needed to be able to cope with the BCS patients, while still maintaining allowable access times for 'regular' patients with respect to the access time norms?

In 2008 Joustra et al. [13] faced a similar problem at the Academic Medical Center in Amsterdam. In this case a combination of discrete event simulation and integer linear program has been used to address the problem. In this report a combination of discrete event simulation and a Markov model will be used. The current capacity utilization at the JBZ GHD will be described and improvements will be determined.

1.3 Report Outline

First, chapter 2 will contain information about the current planning procedures used at the GHD involving patient treatment paths, staff scheduling, and the planning of appointments. After this each of these parts will be discussed in more detail. Chapters 3 and 4 describe a Markov model which will be used to simulate patient arrival and their treatment paths. Chapter 3 will contain a global patient treatment path model, where each appointment in the patients treatment path will be labeled by their appointment type. The two used appointment types will be endoscopies and outpatient clinic consultations. In chapter 4 this global model will be extended to a detailed model which can be used to predict complete patient treatment paths. A patient treatment path will then contain a list of actual appointments (see table 1.1) instead of appointment types. In chapter 5 the required data will then be analyzed and collected. Together with this data, the Markov model can be used to estimate several demand variables, such as expected number of necessary appointments per year. Chapter 6 will focus on the current staff scheduling procedures and how these can be improved to be able to cope with the demand. Finally, in chapter 7 both the results of the patient treatment path model and the improved staff scheduling will be used to investigate several appointment planning procedures and their influence on patient waiting times. Chapter 8 will contain the conclusions of this report, followed by some point of discussion in chapter 9. An outlook on possible future research can be found in chapter 10.

Chapter 2

Current Capacity Utilization

To be able to improve the capacity utilization, one first has to understand the current situation at the GHD. This involves three parts, namely the patients currently treated at the GHD and their associated treatment paths, the current staff scheduling procedures, and the current appointment planning procedures. In this chapter each of the three parts will be discussed.

2.1 Patient Treatment Paths

There are two main types of patients visiting the GHD: regular patients and patients that participate in the Bowel Cancer Screening (BCS) program. After arrival, regular patients are subdivided into several different patient groups, where each patient group corresponds to a certain disease type, e.g. Crohn disease or colorectal cancer. Although the complaints of patients belonging to the same patient group are comparable, every patient still remains unique, resulting in a unique demand for care.

At the end of their treatment, each patient has completed an almost unique patient treatment path. This patient treatment path will contain a random number of appointments $A_0, A_1, A_2, \ldots$. Each appointment is either a consultation or endoscopy. After each appointment, a GHD physician or resident might advise the patient to return for a consultation, or endoscopy, after a certain number of weeks. This amount of weeks will be called the preferred returning time (PRT). Interviews with planning staff have revealed that it is attempted to plan all appointments within 2 weeks after the PRT. This will be called the maximum allowed access time (MAAT). Let PRT_i be the PRT before appointment A_i and consequently $MAAT_i$ the MAAT before appointment i. So in the current situation

$$MAAT_i \quad \leq \quad PRT_i + 2 \text{ for all } i \geq 1. \tag{2.1}$$

Before starting his treatment path, a patient will first apply for his first appointment A_0. The date on which this application is received at the GHD will be called the application date. There also exists a MAAT between the application date and the first appointment, namely $MAAT_0$. The JBZ has made agreements with general physicians (GPs) and other external physician about the length of $MAAT_0$. These maximum allowed access times depend on urgency, complaint and appointment type. However, the main agreements are a maximum of 6 weeks between application date and first appointment date. if the first appointment is an endoscopy, and a maximum of 8 weeks, if the first appointment is a consultation. Clearly from the patient perspective $PRT_0 = 0$. However, from the GHD perspective it is not desirable to fill up all available time with appointments for new patients right away, leaving no time available for emergency appointments. Therefore, PRT_0 is estimated to be equal to

$$PRT_0 \quad = \quad \max\{MAAT_0 - 2, 0\} \tag{2.2}$$

This results in a relation comparable to the relation between PRT_i and $MAAT_i$ for $i \geq 1$ given in (2.1).

As a result every treatment path contains three lists, namely a list of appointments, PRTs and MAATs, resulting in a patient treatment path looking like

$$\xrightarrow[MAAT_0]{PRT_0} A_0 \xrightarrow[MAAT_1]{PRT_1} A_1 \xrightarrow[MAAT_2]{PRT_2} A_2 \xrightarrow[MAAT_3]{PRT_3} A_3 \ ...$$

As was stated before, there exist two different appointment types, namely consultations or endoscopies. However, if one looks at the appointments in more detail, there exist 19 different possible appointments at the GHD. The most important ones have already been discussed in table 1.1, and list 2.1 includes the abbreviations of all 19 appointments.

Appointments 1 to 12 are endoscopies, and appointments 13 to 16 are consultations. The appointments CO/GA and EUS/GA are combination appointments of the two appointments CO and GA, or EUS and GA. Combination appointments are two appointments that will be performed on the same day by the same staff member. CO/GA and EUS/GA are the two most commonly occurring combination appointments, and they are therefore taken into account separately.

TABLE 2.1: List of the 19 different appointments.

1. CO	6. SI	11. EUS/GA	16. IP
2. CI	7. SD	12. PEG	17. IP BCS
3. GA	8. CO/GA	13. NP	18. CO BCS
4. GI	9. ERCP	14. HP	19. BE BCS
5. GD	10. EUS	15. BE	

Appointments CI and GI are either an intervention colonoscopy or intervention gastroscopy. These specific colonoscopies and gastroscopies take more time than regular colonoscopies and gastroscopies, and can only be performed by physicians.

Also, appointments GD and SD are a gastroscopy or sigmoidoscopy with dilatation, meaning that some part of the intestines needs to be dilated during these procedures. As with the intervention procedures, these two endoscopies also take more time than regular gastroscopies and sigmoidoscopies, and can only be performed by physicians. Also, to perform GD or SD, special facilities are needed. This will be discussed in section 2.2 more thoroughly.

Appointments 17 to 19 are appointments only for BCS patients. IP BCS and BE BCS are consultations, and CO BCS is an endoscopy. All BCS patients have a partially fixed treatment path due to governmental regulations. This treatment path looks like the following treatment path.

$$\xrightarrow[3]{1} \text{IP BCS} \xrightarrow[1]{0} \text{CO BCS} \xrightarrow[1]{0} \text{BE BCS} \ldots$$

As was stated in section 1.2, response figures from the Erasmus MC and the Antoni van Leeuwenhoek hospital show that out of all patients coming in for an IP BCS appointment, 74% comes back for a CO BCS. At the JBZ this continuation percentage is estimated at 67%. If a patient continues his treatment path, the same figures show that approximately 7% of these patient will be diagnosed with colorectal cancer, and consequently follow-up treatment is needed. The actual BCS treatment path will therefore look like

$$\begin{array}{lllll}
\xrightarrow[3]{1} \text{IP BCS} & & & & \text{w.p. } 1-0.67 \\
\xrightarrow[3]{1} \text{IP BCS} & \xrightarrow[1]{0} \text{CO BCS} \xrightarrow[1]{0} \text{BE BCS} & & & \text{w.p. } 0.67 \cdot (1-0.07) \\
\xrightarrow[3]{1} \text{IP BCS} & \xrightarrow[1]{0} \text{CO BCS} \xrightarrow[1]{0} \text{BE BCS} & \xrightarrow[PRT_3]{PRT_3} A_3 \ldots & & \text{w.p. } 0.67 \cdot 0.07
\end{array}$$

If a patient needs follow-up treatment after BE BCS, he will continue his treatment path as if he was a regular patient with colorectal cancer.

Each patient treatment path contains a number of different appointments. The total number of appointments in the treatment path is called the patient demand, which will be calculated specifically for each of the 19 different possible appointments. In this report we are interested in the total patient demand per year for all patients and all appointments.

2.2 Master Schedule

To be able to cope with the yearly patient demand, the GHD should be able to provide enough care to treat all patients. This means enough time should be available in the staff members calendars to perform all demanded appointments. The yearly amount of time available for each appointment listed in list 2.1 will be called the yearly staff supply.

At the GHD, staff members work according to a master schedule, which determines the main task for each staff member during each daypart, and the amount of time a staff member is available per daypart to perform this task.

As was stated in section 1.1 patients are treated at the GHD by one of the available physicians, residents, or extra staff members who are available to perform specific endoscopic procedures. Hospital regulations prescribe that residents can not be taken into account while analyzing staff supply. Therefore, their influence will be omitted in this report.

It is assumed that a week contains 10 dayparts, 5 mornings and 5 afternoons, and a year contains 52 weeks. So in the case of n available physicians and extra staff members a yearly master schedule contains two corresponding $n \times 520$ matrices C and M, where element $C_{i,j}$ contains a value which determines the main task of staff member i on daypart j, and $M_{i,j}$ contains the number of minutes staff member i is available for this task during daypart j.

2.2.1 Tasks per Daypart

Each element of the master schedule matrix C will be equal to one of the following daypart categories.

1. Inpatient Care Clinic
2. Absent
3. Inpatient Care Visitor
4. External Outpatient Clinic

5. Colonoscopy for BCS
6. ERCP
7. EUS
8. Intake for BCS
9. Intake
10. Supervision
11. Colonoscopy
12. Gastroscopy/Sigmoidoscopy
13. Outpatient Clinic (OC)

Each category is connected to a certain task. In almost all categories this task consists of performing certain appointments found in list 2.1. The staff member's time in a daypart categorized by a given category will be mainly used for the appointments associated with this category. Let these appointments be called the category specific appointments. Table 2.2 shows the category specific appointments per category.

TABLE 2.2: Category specific appointments per category.

Category	Category specific appointments
Inpatient Care Clinic	
Absent	
Inpatient Care Visitor	NP, HP, BE
External Outpatient Clinic	NP, HP, BE
Colonoscopy for BCS	CO BCS
ERCP	ERCP, GD, SD
EUS	EUS, EUS/GA
Intake	IP, HP, BE
Intake for BCS	IP BCS, HP, BE
Supervision	
Colonoscopy	CO, CI, CO/GA
Gastroscopy/Sigmoidoscopy	GA, GI, SI, CO/GA
Outpatient Clinic	NP, HP, BE, BE BCS

Note that almost all appointments are logically connected to a category, except for the GD and SD appointments. As was mentioned in the previous section, for these appointments extra facilities are needed. These are the same facilities as needed for the ERCP appointments and therefore these appointments can only be planned during ERCP dayparts.

As can be seen, there are three categories that do not have category specific appointments. These categories are Inpatient Care, Absent, and Supervision. Their associated tasks will be discussed in more detail.

The Inpatient Care Clinic category is assigned to exactly one physician per daypart. During this daypart the assigned physician is responsible for all GHD patients at the

Inpatient Care Clinic (ICC), and he will not be available to perform appointments at the outpatient clinic or endoscopy unit. Throughout the year the ICC responsibility is evenly distributed over all physicians in shifts of two consecutive weeks.

The Absent category speaks for itself and is used to categorize dayparts during which staff members are completely absent. There are three different reasons for a staff member to be absent, namely

1. *Fixed absence per week:* A staff member might have fixed days per week during which he is absent. Each staff member has a bi-weekly fixed schedule for these fixed days off per week.

2. *Vacation days:* Besides fixed absence, staff members are entitled to a predetermined number of vacation days.

3. *Extra days off due to ICC shifts:* Physicians are not allowed to take days off during their ICC shifts. Not even their fixed days off. Since they are entitled to these fixed days off, they get a refund in the form of extra vacation days. Also, during every weekend and public holiday one physician needs to be available for emergencies. These weekend and holiday shifts are spread randomly over the available physicians and they are also rewarded by extra vacation days. These ICC and weekend/holiday refund dayparts can be used as regular vacation days.

It is important to note that vacation requests by physicians are accepted if and only if at least two physicians are available at the hospital during each daypart, namely one physician for the ICC, and one physician for the endoscopy unit, or outpatient clinic.

The last of the three categories is the Supervision category. The task during a daypart categorized by this category is supervising residents or extra staff members that perform endoscopies and need supervision. All residents and some of the current extra staff members need this supervision. As was stated before, residents are not taken into account while analyzing the staff supply. Therefore, only the supervision dayparts for the extra staff members are taken into account.

The elements of master schedule C are categorized per week according to scheduling rules determined by the JBZ. For each daypart category these rules contain requirements on

1. Dayparts per week that are allowed for the specific category, e.g. category ERCP can only be scheduled on predetermined dayparts during the week.

2. Staff members that are qualified to perform the appointments associated with the specific category, e.g. category Colonoscopy for BCS can only be scheduled in the

elements of master schedule C which belong to staff members qualified to perform CO BCS appointments.

3. Desired number of dayparts per week that should be spend on the specific category, e.g. it is desired to schedule category Intake x times per week to be able to cope with the estimated demand for appointment IP.

4. Necessary facilities to be able to perform the tasks associated with the specific category.

The last rule mainly focusses on the roomtype needed for the tasks associated with the specific category. There are two types of rooms, namely consultation rooms and endoscopy rooms. Each category has its own room requirements. However, there exists a maximum number of available consultation rooms and endoscopy rooms for each daypart. It is important that during each daypart in the master schedule these limits are not exceeded.

2.2.2 Minutes per Daypart

The values of the second part of the master schedule, matrix M, are mainly determined by a weekly fixed schedule. This weekly fixed schedule exists for each staff member and determines the exact number of minutes available for appointments during each daypart in a week.

Besides this weekly fixed schedule, the number of minutes per daypart $M_{i,j}$ might also be determined by the dayparts category $C_{i,j}$. For example, if a daypart is categorized by the category Absent, clearly the associated staff member is available for 0 minutes to perform tasks during this daypart, independent of his weekly fixed minutes schedule. Besides the Absent category, more categories influence the number of available minutes per daypart. However, these will not be discussed in detail.

As was stated before, the staff members' time in a daypart, categorized by a given category, will be mainly used for the category specific appointments. However, $M_{i,j}$ defines the available number of minutes, and each appointment has his own duration. Meaning that there might be time left at the end of a daypart. For example, let a given daypart contain 175 minutes available for patient care. There only exists one category specific appointment, and this appointment takes 30 minutes. Clearly, 5 appointment timeslots can be created for this appointment, while 150 minutes are available. This leaves 25 unused minutes during which no extra category specific appointment can be scheduled. To prevent this time from being idle, the category non-specific appointments will be introduced. These appointments can be used to fill up the unused time at the end of dayparts. Table 2.3 shows these non-category specific appointments for each of the daypart categories.

Table 2.3: Non-category specific appointments per category.

Category	Non-category specific appointments
Inpatient Care Clinic	
Absent	
Inpatient Care Visitor	BE BCS
External Outpatient Clinic	BE BCS
Colonoscopy for BCS	PEG, BE, BE BCS, CO, CI, GA, SI, GI, CO/GA
ERCP	PEG, BE, BE BCS, CO, CI, GA, SI, GI, CO/GA
EUS	PEG, BE, BE BCS, CO, CI, GA, SI, GI, CO/GA
Intake	BE BCS
Intake for BCS	BE BCS
Supervision	
Colonoscopy	PEG, BE, BE BCS, GA, SI, GI
Gastroscopy/Sigmoidoscopy	PEG, BE, BE BCS, CO, CI
Outpatient Clinic	

Intuitively it can be seen that the non-category specific appointments of all categories that have access to an endoscopy room include PEG, CO, CI, GA, GI, SI, and CO/GA. For the other remaining time, appointments BE and BE BCS can be used to fill up the unused time.

For appointment durations, there exist three different types, namely

1. Regular duration.
2. Extended duration if performed by physician at an operating room (OR).
3. Extended colonoscopy duration, if performed by extra staff member.

The first one is simply the regular appointment duration which is fixed for each of the appointment in the appointment list. The second one only applies on three specific endoscopies, namely CO, ERCP, and PEG. Each of these endoscopies are performed at an OR with a predetermined probability. If performed at the OR, the regular appointment duration is extended by a predetermined number of minutes. It is important to note that endoscopies at the OR can only be performed by physicians and not by extra staff members. The third duration rule only applies to regular colonoscopies (CO) performed by extra staff members. In this case the regular CO duration is extended by a predetermined number of minutes.

2.3 Appointment Planning

Currently the master schedule is determined at least 3 months in advance. After this the staff calendars are opened for appointment planning. This appointment planning is done by a GHD secretary. As was introduced in section 2.1, each appointment has its associated preferred returning times (PRT). It is assumed that the secretary starts to look for an appointment slot in the master schedule exactly on the preferred returning date. For patients who apply for their first appointment A_0 this preferred returning date is equal to the application date for appointment A_0 plus PRT_0.

This application date also exists for other appointments A_i with $i \geq 1$. It is assumed that a patient applies for follow-up appointments directly after finishing the previous appointment. Therefore the application date for appointment A_i is assumed to be equal to the appointment date of appointment A_{i-1}. As with A_0, the preferred returning date for appointment A_i will be equal to its application date plus PRT_i.

Now a suitable appointment slot satisfies the following three requirements.

- The staff member responsible for the daypart is qualified to carry out the appointment.
- There is enough time left for the appointment during the daypart.
- The appointment is allowed during the daypart according to the daypart category.

The first requirement simply states that an appointment can only be planned into the staff members calendar if and only if this staff member is qualified to carry out this appointment.

The second requirement states that the total duration of all appointments planned during daypart (i, j), can never exceed $M_{i,j}$, the available number of minutes in that daypart.

The third requirement needs a detailed explanation. As was stated in the previous section, each daypart category has his category specific and category non-specific appointments. First it is attempted to fill up all available time in a daypart with its category specific appointments. So if an appointment is one of the category specific appointments of this daypart, then the appointment is allowed during the daypart.

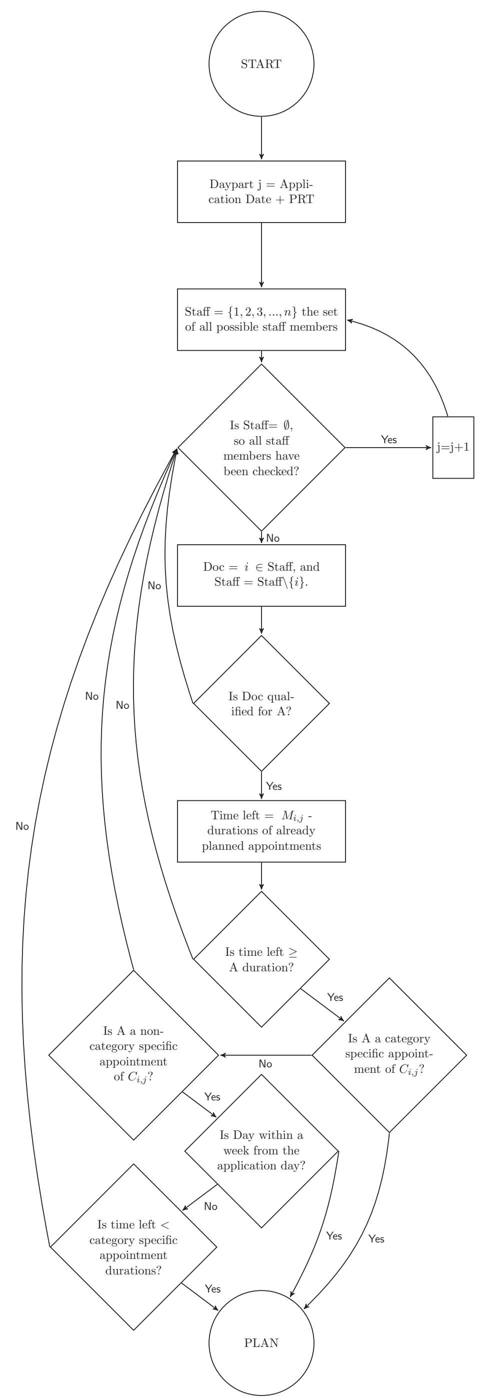
If the appointment is a non-category specific appointment, then the appointment is allowed during the given daypart according to the category if

1. Not enough time is left for any category specific appointment, but enough time is left for the non-category specific appointment under consideration.

2. The daypart is within a week of the current date. In this case there is a large probability that within this last week not enough category specific appointment applications arrive to fill up the still available daypart time.

Figure 2.1 shows the complete appointment planning procedure.

FIGURE 2.1: Appointment Planning Procedure for appointment A.



2.3.1 Main Physician

The previously described appointment planning procedure shows that an appointment can be planned with any available and qualified physician. However, this is not the case for all appointments. The GHD prefers that patients are mainly treated by their 'own' physician, especially during consultations. Let this specific physician be called the patients main physician. It is attempted to schedule all of his appointments with this main physician, which means that the set of possible staff members in the third step of Figure 2.1 only contains the main physician.

There are two exceptions to this rule.

1. The main physician is not qualified to perform the necessary appointment. In this case all qualified staff members are possible staff members.
2. It takes too long before a suitable appointment slot is found in the main physicians calendar. In this case it will be discussed with the patient and/or the main physician what would be preferable; an earlier appointment with another physician, or an appointment with the main physician at a later date.

In both cases the patient might be treated by a different physician. However, the patient will keep his main physician for the rest of his appointments.

2.4 Introduction to the GHD Simulation

The previous three sections show the three elements that influence the appointment planning at the GHD, and consequently the patients access and waiting times. To investigate the influence of each of these factors on the patients access and waiting times, a simulation has been written in JAVA which combines all three factors, and can be used to simulate the total planning process at the GHD.

The simulation starts with the simulation of a master schedule according to the rules mentioned in section 2.2. This master schedule includes two matrices as was stated in section 2.2. One for the daypart categories, and one for the available minutes per daypart. If the simulation covers X years, a master schedule is determined for $X + 1$ years. The reason for this extra year will become clear later on in this section. Figure 2.2 shows a fictional week out of a simulated master schedule with 8 physicians and 4 extra staff members. The first screen shot shows the categories matrix, and the second the minutes matrix.

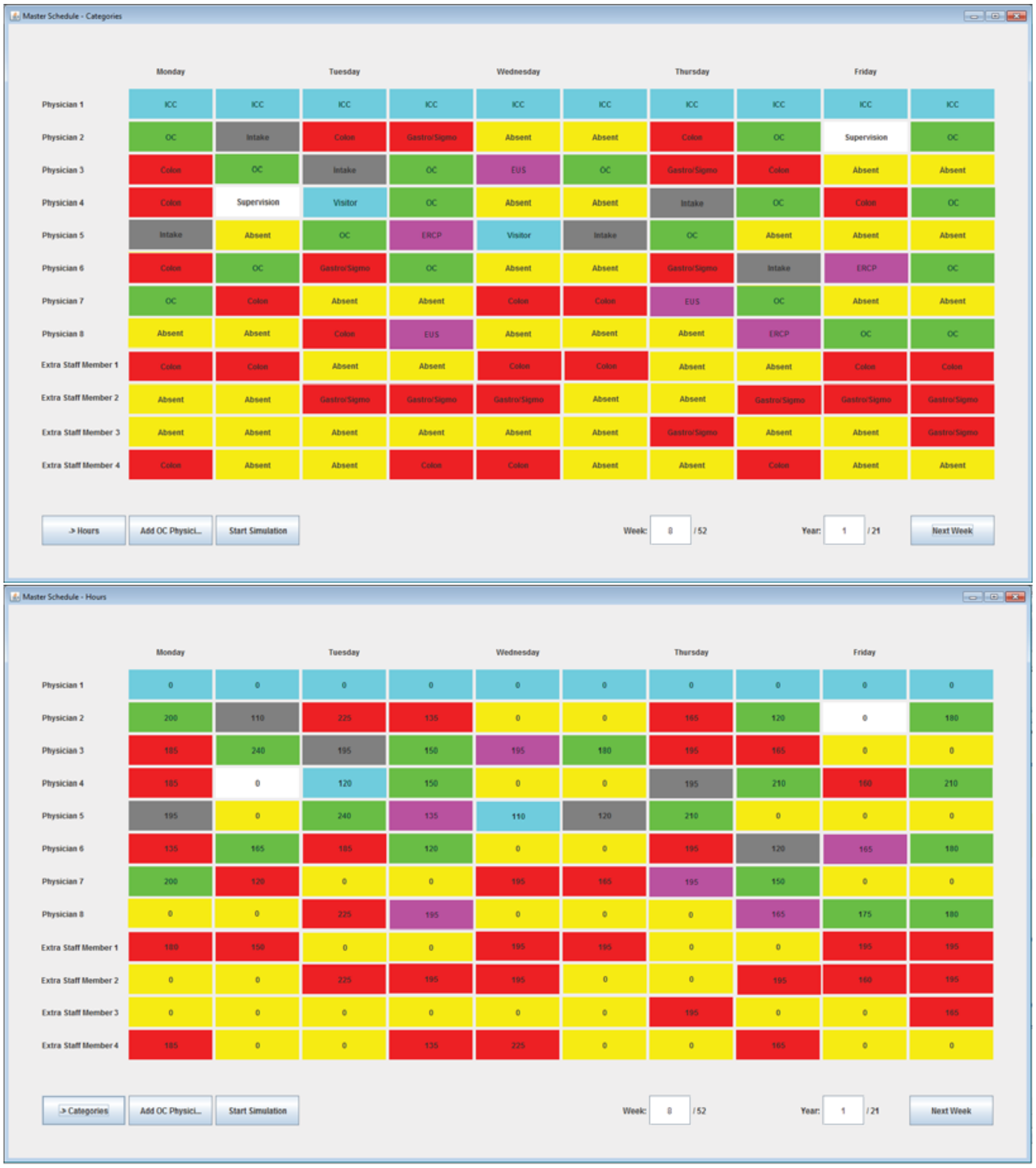


FIGURE 2.2: Simulated fictional example of a master schedule involving 8 physicians and 4 extra staff members.

In chapter 6 several simulated master schedules will be used to determine the estimated yearly staff supply, that results from the master schedule under the currently used master scheduling rules. Also, the influence of several adjustments to these scheduling rules will be investigated. It is attempted to define a set of scheduling rules, such that the estimated yearly staff supply is large enough to be able to cope with the expected yearly patient demand.

After determining the complete master schedule for X years, the simulation continues. It will start on the first daypart of year 1, and will loop through all dayparts until it reaches daypart 520 in year X. During each daypart new patients will arrive and their first appointment will be planned. Also, patients that have entered the GHD during an earlier daypart and have an appointment on the daypart under consideration, will be treated and their next appointment will be scheduled, if this appointment exists. This will be done in the following order.

Patient Arrival Every daypart, patients will arrive according to an arrival distribution which will be determined in chapter 3. Each arriving patient will have a treatment path which will be simulated according to the patient treatment path model, which will be described in chapters 3 and 4. This will result in a list of patients, where each patient is attached to a list of appointments A_i and a list of preferred returning times PRT_i. Each arriving patient will be added to the waiting list for appointment planning, to wait for the planning of its first appointment.

Patient Treatment Patients with an appointment on the given daypart that still have an unplanned appointment in their treatment path will be added to the waiting list to wait for the planning of their next appointment.

Appointment Planning For all patients in the waiting list, their next appointment will be planned in the master schedule according to the rules described in section 2.3. This will be done randomly for all patients in the waiting list.

The simulation output will consist of a list of patients, where each patient has his own treatment path, and for each appointment A_i in this treatment path the application date, appointment date and responsible staff member will be known.

Here the use of this extra master schedule year $X+1$ becomes clear. If a patient arrives on the last day of year X, he wants his first appointment to be planned. However, if no master schedule is known, this planning can not be done. It is therefore assumed that the waiting time for an appointment never exceeds 52 weeks, so this appointment can be planned in year $X+1$. If the waiting time does exceed 52 weeks, this will show in the simulation output, while the last appointments in year 20 can not be planned. However, as will be seen in chapter 7, in general all treated and arriving patients in the first X years can have their appointments planned.

More on this can be found in chapter 7, because in this chapter the simulation result will also be analyzed on waiting times. Furthermore, new planning rules will be introduced, and their influence on the patients waiting time will be investigated.

Chapter 3

Global Patient Treatment Path Model

Every patient treated at the GHD, follows a certain treatment path. As was introduced in section 2.1 each patient treatment path consists of three lists, a list of appointments A_i*, preferred returning times* PRT_i *and maximum allowed access times* $MAAT_i$ *for* $i \geq 0$*. In this chapter the first part of the model will be described, which can be used to model the treatment paths of any patient visiting the Gastroenterology and Hepatology department.*

3.1 Arrival Distributions

As was introduced in the previous chapter, there are two main types of patients visiting the GHD, namely regular patients and patients that participate in the Bowel Cancer Screening (BCS) program. Both groups have their own arrival distribution per daypart. Define N_{REG} as the random variable representing the number of regular patients arriving per dayparts and N_{BCS} the number of BCS patients arriving per daypart.

To determine the distribution of N_{REG}, the JBZ offered arrival data about the number of daily arrivals at the GHD. During the internship that preceded this thesis, this data was used to determine a distribution for $2N_{REG}$, so the number of regular arrivals per day. This was done by using the method in Adan et al. [1] as a guideline (comparing the sample mean and the sample coefficient of variation). The distribution for $2N_{REG}$ turned out to be equal to a negative binomial distribution $NB(r, p)$, so

$$P(2N_{REG} = k) \quad = \quad \binom{k+r-1}{k}(1-p)^r p^k \tag{3.1}$$

The values r and p were determined from the sample mean $\hat{\mu}$ and the sample variance $\hat{\sigma}^2$ by solving the following equations.

$$\frac{pr}{1-p} = \hat{\mu} \tag{3.2}$$

$$\frac{pr}{(1-p)^2} = \hat{\sigma}^2 \tag{3.3}$$

Then the Chi-square goodness-of-fit test was used to determine whether a this $NB(r, p)$ distribution is indeed a good fit to the arrival data [15, p.318-319]. The null hypothesis was set to

H_0 : The data does follow a $NB(r, p)$-distribution,

and consequently

H_1: The data does not follow a $NB(r, p)$-distribution.

Finally, with a significance level of $\alpha = 0.05$, the test resulted in acceptance of H_0. The complete procedure of determination of the $NB(r, p)$-distribution and the use of the Chi-square goodness-of-fit test, including data results, has been discussed in detail in the internship report of the internship that proceeded this research.

It can now be assumed that the distribution of N_{REG} is also a negative binomial distribution, $NB(\bar{r}, \bar{p})$, where the values of $\bar{r}$ and $\bar{p}$ can be determined from the following equations.

$$\begin{aligned} E[N_{REG}] &= \frac{E[2N_{REG}]}{2} \\ \frac{(1-\bar{p})\bar{r}}{\bar{p}} &= \frac{(1-p)r}{2p} \end{aligned} \tag{3.4}$$

$$\begin{aligned} \mathrm{Var}(N_{REG}) &= \frac{\mathrm{Var}(2N_{REG})}{4} \\ \frac{(1-\bar{p})\bar{r}}{\bar{p}^2} &= \frac{(1-p)r}{4p^2} \end{aligned} \tag{3.5}$$

For the BCS patients a different method is used to model the patients treatment path. Every BCS patient that arrives at the GHD, will be registered by the RIVM. The number of registrations per week is a fixed prearranged number. In the simulation of the patient treatment path introduced in section 2.4, it will be assumed that all BCS patients arrive on Monday morning. So $N_{BCS} \neq 0$ on Monday morning and $N_{BCS} = 0$ on all other dayparts, and $10N_{BCS}$ is the fixed number of arriving BCS patients per week. In this chapter the BCS treatment path model will be temporarily omitted. In section 4.2, after finishing the explanation of the regular patient treatment path model, the BCS patient treatment path model will be discussed. This because it will be strongly based upon the regular patient treatment path model, but also contains a completely BCS patient specific part. For now we continue with the explanation of the patient treatment path model for regular patients.

3.2 Global Markov Model State Description

After arrival, regular patients are separated into 12 different patient groups, where each patient group corresponds to a certain disease type. The first 11 subgroups contain the 11 most common gastroenterological diseases, e.g. Crohn disease, and patient group 12 contains all other regular patients. An arriving patient belongs to patient group i with probability p_{G_i}. The model that will be described in the next sections of this chapter can be used to model the patient treatment paths for patients belonging to each of these patient groups. The model methods are the same for each patient group. However, it is important to note that all variables used in the model are patient group specific, unless stated otherwise.

For any regular patient, let the patients treatment path be described by a list of appointments $A_0, A_1, A_2, ...$. As was stated in section 2.1 each A_i is connected to one of the appointments in appointment list 2.1. However, for now it is assumed that only the appointment type of each appointment A_i is known. A_i will be equal to O if the appointment is an outpatient clinic consultation, and S if it is an endoscopy.

To determine the treatment path, a time-homogeneous absorbing Markov process $X_0, X_1, X_2, ...$, with a state space containing 4 states O, S, L, and H, and transition probabilities $p_{A,B}$ for $A, B \in \{O, S, L, H\}$, is introduced. (see fig. 3.1).

States O and S are equal to the two appointments types O and S, and it is assumed that a patients first appointment is equal to an outpatient clinic consultation with probability p_F and to an endoscopy with probability $1-p_F$. Consequently, the Markov process starts in state O with probability p_F, and in state S with probability $1-p_F$.

State H is the absorbing state and will be equal to 'home', or a patient leaves the GHD.

State L is a temporary transition state depending on the preferred returning times between two consecutive appointments. To explain this, assume that $X_i = O$, or S. This state visit represents an actual appointment, meaning that it is linked to an appointment A_j in the treatment path. Note that the Markov chain $X_0, X_1, X_2, ...$, and the treatment path $A_0, A_1, A_2, ...$ are not by definition of equal length. For example,

$$\begin{array}{ccccccccc} X_0 = O & \rightarrow & X_1 = S & \rightarrow & X_2 = L & \rightarrow & X_3 = O & \rightarrow & ... \\ A_0 = O & \rightarrow & A_1 = S & \rightarrow & ... & \rightarrow & A_2 = O & \rightarrow & ... \end{array} \tag{3.6}$$

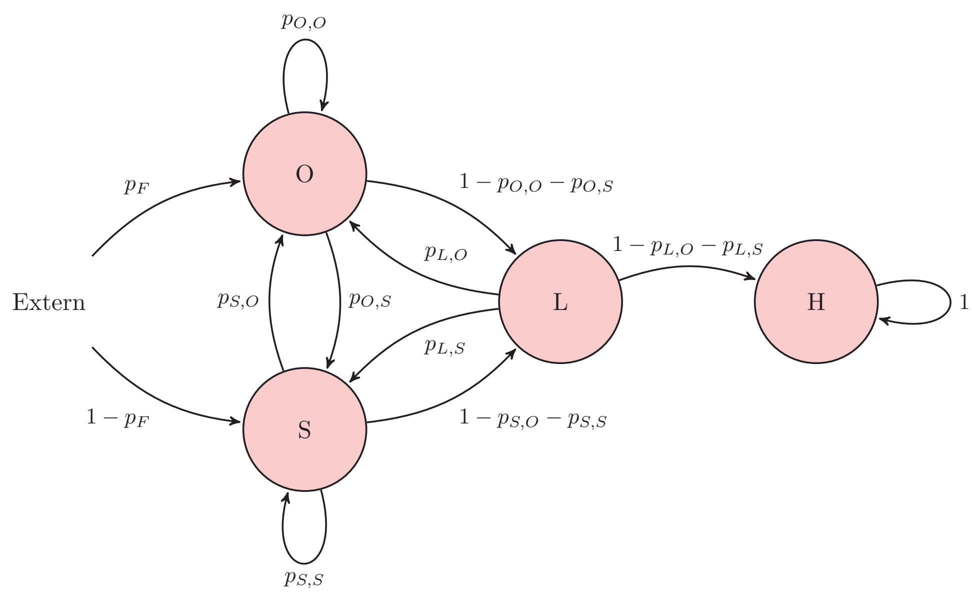


FIGURE 3.1: Markov Process with Transition Probabilities

Therefore, it is not the case that $A_i = X_i$ for all $i \geq 0$.

Now, let PRT_{i+1} be the preferred returning time (PRT, see section 2.1) between appointments A_i, and A_{i+1}. Also, for simplicity assume that A_j is equal to X_j for $j \leq i$. There are now two options for PRT_{i+1}

1. $0 \leq PRT_{i+1} \leq 25$ weeks: Next appointment is required within 6 months, and $A_{i+1} = X_{i+1} = O$, or S. Henceforth, this type of transition will be called a <u>short term</u> transition.

2. $PRT_{i+1} > 25$ weeks: The next appointment is required after 6 months. In this case the patient temporarily visits state L, so $X_{i+1} = L$. In state L there are again two options.

   (a) $26 \leq PRT_{i+1} < 52$ weeks: The next appointment is required after 6 months, but within 1 year. The patient returns to the GHD, so $A_{i+1} = X_{i+2} = O$, or S independent of A_i. Henceforth, this type of transition will be called a <u>long term</u> transition.

   (b) $PRT_{i+1} \geq 52$ weeks: The next appointment is required after 1 year. It is assumed that the patient goes home ($X_{i+2} = H$). If he ever revisits the GHD, he will be treated as a new patient. This assumption follows the policy used at the JBZ GHD, where a patient that has not received a treatment for over one year will receive a full check-up, as a new patient does. Henceforth, this type of transition will be called a <u>home</u> transition.

The addition of this temporary transition state L originates from the fact that only a year of data is available to determine the transition probabilities, and a distribution on the PRTs. Details about this will be explained in section 5.2.2.

However, by adding state L it is automatically assumed that if $PRT_{i+1} > 25$, that A_{i+1} (destination) does not depend on A_i (origin), because of the Markov property. This assumption can be substantiated by the following reasoning. In short term transitions, the next appointment is strongly determined by the previous appointment. For example, there is a relatively small chance a patient needs two endoscopies in row within a short amount of time. Therefore, in general $p_{S,S} < p_{S,O}$. However, it is more common to plan a check-up endoscopy a few months after an endoscopy, which is a long term transition.

In long term transitions the destination appointment is mostly scheduled due to one of the following two reasons.

- Long term predetermined check-up appointment.
- Appointment due to a sudden increase in disease related issues.

Both reasons depend more on the disease type (so patient group) than on the transitions origin appointment. As a result, it can be assumed that the dependence between A_i and A_{i+1} decreases as PRT_{i+1} increases. Following this reasoning it can be assumed that indeed

$$\begin{aligned} P(A_{i+1} = X | A_i = O, PRT_{i+1} > 25) &= P(A_{i+1} = X | A_i = S, PRT_{i+1} > 25) \\ &= p_{L,X} \ \forall \ X \in \{O, S\} \end{aligned} \tag{3.7}$$

3.2.1 Expected Number of Visits

Let the four states in the Markov process be numbered as $\{1, 2, 3, 4\} = \{O, S, L, H\}$. So, for example,

$$P(X_n = O) = P(X_n = 1) \tag{3.8}$$

Now let $E[O]$ be a patients expected number of visits to the outpatient clinic, and $E[S]$ the expected number of visits to the endoscopy unit. Consequently, let $E[L]$ be the expected number of long term transitions. The transition probability matrix P of the

Markov process in Figure 3.1 is given by

$$P = \begin{pmatrix} p_{O,O} & p_{O,S} & 1 - p_{O,O} - p_{O,S} & 0 \\ p_{S,O} & p_{S,S} & 1 - p_{O,O} - p_{S,S} & 0 \\ p_{L,O} & p_{L,S} & 0 & 1 - p_{L,O} - p_{L,S} \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{3.9}$$

where

$$P_{i,j} = P(X_n = j | X_{n-1} = i) \text{ for all } n \geq 1 \tag{3.10}$$

It is known that for all $n \geq 1$, and $k \geq 0$

$$P^n_{i,j} = P(X_{k+n} = j | X_k = i) = P(X_n = j | X_0 = i) \tag{3.11}$$

where $P^n_{i,j}$ is element (i, j) of matrix P^n, and by definition $P^0 = I_4$. [19, Chapter 4].

Matrix P can be written in the canonical form. [9, p. 417]

$$P = \left(\begin{array}{c|c} Q & R \\ \hline \mathbf{0} & I \end{array}\right) \tag{3.12}$$

where Q includes the transient states (O, S and L) and R the absorbing state (H). In case of the Markov process under consideration, Q is a 3×3 matrix and $I = 1$. Now it is easy to see that

$$P^n = \left(\begin{array}{c|c} Q^n & \tilde{R} \\ \hline \mathbf{0} & I \end{array}\right) \tag{3.13}$$

So for $i, j \in \{1, 2, 3\}$ and for all $n \geq 0$, $P^n_{i,j} = Q^n_{i,j}$. The expected number of visits to state $i \in \{1, 2, 3\}$ are equal to

$$\begin{aligned} E[\#\text{ visits to state } i] &= \sum_{n=0}^{\infty} P(X_n = i) \\ &= \sum_{j=1}^{4} \sum_{n=0}^{\infty} P(X_n = i | X_0 = j) \cdot P(X_0 = j) \\ &= p_F \sum_{n=0}^{\infty} Q^n_{1,i} + (1 - p_F) \sum_{n=0}^{\infty} Q^n_{2,i} \end{aligned} \tag{3.14}$$

For matrix Q it is known that

$$\sum_{n=0}^{\infty} Q^n = (I-Q)^{-1} = N \tag{3.15}$$

where the inverse $(I-Q)^{-1}$ exists and N is called the fundamental matrix [9, p. 418-419]. So for all $i, j \in \{1, 2, 3\}$,

$$\sum_{n=0}^{\infty} Q^n_{i,j} = N_{i,j} \tag{3.16}$$

Combining (3.16) with (3.14) results in

$$\begin{aligned} E[O] &= p_F N_{1,1} + (1-p_F)N_{2,1} \\ E[S] &= p_F N_{1,2} + (1-p_F)N_{2,2} \\ E[L] &= p_F N_{1,3} + (1-p_F)N_{2,3} \end{aligned} \tag{3.17}$$

3.3 Transition Times

In section 2.1 two types of transitions times were introduced, namely the preferred returning time (PRT) and maximum allowed access time (MAAT). Both will be discussed in this section.

3.3.1 Preferred Returning Time

As was introduced before, PRT_{i+1} is the preferred returning time before appointment A_{i+1}. In the Markov model under consideration, define $PRT_{X_i,X_{i+1}}$ as the preferred amount of weeks passing between a transition from state X_i to state X_{i+1}.

Assume that in all of the following cases we look at the transition from appointment $X_i = A_i$. As was determined in the section 3.2, there are three types of transitions, namely

1. Short term transitions: $X_i \to X_{i+1}$ with $X_i, X_{i+1} \in \{O, S\}$
2. Long term transitions: $X_i \to X_{i+1} \to X_{i+2}$ with $X_i, X_{i+2} \in \{O, S\}$ and $X_{i+1} = L$
3. Home transitions: $X_i \to X_{i+1} \to X_{i+2}$ with $X_i \in \{O, S\}$, $X_{i+1} = L$ and $X_{i+2} = H$.

If this transition is a short term transition, it is by definition that $0 \leq PRT_{X_i,X_{i+1}} \leq 25$ weeks, and PRT_{i+1} will be equal to the PRT before appointment A_{i+1}. For the rest of this section it is assumed that $X_i = A_i$. Define $T_{A,B}$ as the transition time probability vector of length 26, with

$$T^{(j)}_{A,B} = P(PRT_{X_i,X_{i+1}} = j-1 | X_i = A, X_{i+1} = B) \quad \forall\, A,B \in \{O,S\} \text{ and } 1 \leq j \leq 26 \tag{3.18}$$

The long term transitions contain two consecutive Markov transitions, namely $X_i \to L$, and $L \to X_{i+1}$, each with their own PRT. It is assumed that

$$PRT_{X_i,L} = 26 \;\forall\; X_i \in \{O,S\} \tag{3.19}$$

because all long term transitions have a PRT $\geq$ 26 weeks. For the second transition $L \to X_{i+2}$ a transition time probability vector $T_{L,B}$ of length 26 can be defined, where, equal to the short term transitions

$$T^{(j)}_{L,B} = P(PRT_{L,X_{i+2}} = j-1 | X_{i+2} = B) \;\forall\; B \in \{O,S\} \text{ and } 1 \leq j \leq 26 \tag{3.20}$$

In this case

$$PRT_{i+1} = PRT_{X_i,L} + PRT_{L,X_{i+2}} \tag{3.21}$$

If a patient leaves the system, so $X_{i+2} = H$, the total transition time PRT_{i+1} should be equal to 0. To achieve this, set $PRT_{L,H} = -26$. such that

$$PRT_{i+1} = PRT_{X_i,L} + PRT_{L,H} = 26 - 26 = 0 \tag{3.22}$$

As in section 3.2, the addition of state L implies that the long term transitions are independent of their origin. However, the reasoning behind this can be extended to the assumption that $T_{L,O} = T_{L,S}$, so

$$P(PRT_{L,O} = x) = P(PRT_{L,S} = x) \;\forall\; 0 \leq x \leq 25 \tag{3.23}$$

As mentioned before, there are two reasons to schedule an appointment after a long term transition. However, the transition time in both cases depends more on the patient group, rather than on the transition itself.

If the destination appointment in a long term transition is scheduled due to a check-up appointment, than the transition time is most likely to be 6 or 9 months (independent of appointment type).

The long term transition times before appointments scheduled due to a sudden increase in disease related issues are harder to predict. Depending on the patient group they can for example be uniformly distributed over the time interval $[26, 51]$ weeks. However, they are again independent of the destination appointment. Therefore, T_L can be defined as

$$T_L = T_{L,O} = T_{L,S} \tag{3.24}$$

3.3.2 Maximum Allowed Access Time

$PRT_{X_i,X_{i+1}}$ will be considered a lower bound on the transition time between states X_i and X_{i+1}. On the other hand, $MAAT_{X_i,X_{i+1}}$ is considered to be a desired upper bound.

As was stated in section 2.1, it is assumed that the difference between the PRT and MAAT in appointment transitions is equal to $\delta = 2$ weeks. However, in long term state transitions the appointment transition is split up into two transitions $X_i \rightarrow L$ and $L \rightarrow X_{i+2}$. To avoid adding δ twice in the long term transitions, $MAAT_{X_i,X_{i+1}}$ will be defined in the following way.

$$MAAT_{X_i,X_{i+1}} = PRT_{X_i,X_{i+1}} + \begin{cases} \delta & \text{if } X_i \in \{O,S,L\} \text{ and } X_{i+1} \in \{O,S\} \\ 0 & \text{if } X_i \in \{O,S\} \text{ and } X_{i+1} = L \text{ or} \\ & X_i = L \text{ and } X_{i+1} = H \end{cases} \tag{3.25}$$

3.3.3 Expected Sojourn Time

Define $E[ST]$ as the expected number of weeks a patient will be in the GHD system, before he will be gone for > 1 year. So before he will make a home transition, and visit state H. This will be called a patient's expected sojourn time.

Clearly $E[ST]$ is the sum of the number of weeks between all transitions. However, the number of weeks between each transition consists of two separate parts, namely the PRT and the waiting time W.

In an ideal world $PRT + W \leq MAAT$ for all transitions, so every appointment is scheduled within the maximum allowed access time. However in the current situation many appointments can not be scheduled within the MAAT, leaving $PRT + W > MAAT$. In chapter 7, the waiting time W will be discussed in more detail.

With the current knowledge it is possible with the currently described model to determine a lower bound on $E[ST]$, namely

$$E[ST] \quad \geq \quad \sum_{i=0}^{\infty} PRT_{X_i,X_{i+1}} \tag{3.26}$$

With the same reasoning it is also possible to determine an upper bound on $E[ST]$ in the ideal situation where all appointments are scheduled within their MAAT, which is equal to

$$E[ST] \quad \leq \quad \sum_{i=0}^{\infty} MAAT_{X_i,X_{i+1}} \tag{3.27}$$

Let $E[A, B]$ the expected number of times a patient will make a transition from state A to state B with $A \in \{O, S, L\}$ and $B \in \{O, S, L, H\}$. Then

$$E[A, B] \quad = \quad E[A] \cdot p_{A,B} \tag{3.28}$$

It is also possible to determine for each transition $A \to B$ the expected PRT and expected MAAT, namely

$$E[PRT_{A,B}] \quad = \quad \begin{cases} \sum_{i=1}^{26} (i-1)T_{A,B}^{i} & \text{if} \quad A \in \{O, S, L\} \text{ and } B \in \{O, S\} \\ 26 & \text{if} \quad A \in \{O, S\} \text{ and } B = L \\ -26 & \text{if} \quad A = L \text{ and } B = H \end{cases} \tag{3.29}$$

$$E[MAAT_{A,B}] \quad = \quad \begin{cases} \sum_{i=1}^{26} (i-1+\delta)T_{A,B}^{i} & \text{if} \quad A \in \{O, S, L\} \text{ and } B \in \{O, S\} \\ 26 & \text{if} \quad A \in \{O, S\} \text{ and } B = L \\ -26 & \text{if} \quad A = L \text{ and } B = H \end{cases} \tag{3.30}$$

where δ is assumed to be equal to 2 weeks (see section 3.3.2).

Now the lower bound on $E[ST]$ can be determined by

$$E[ST] \quad \geq \quad \sum_{i=0}^{\infty} E[X_i, X_{i+1}] \cdot E[PRT_{X_i,X_{i+1}}] \tag{3.31}$$

In a comparable way it is possible to determine an ideal upper bound on $E[ST]$, namely

$$E[ST] \quad \leq \quad \sum_{i=0}^{\infty} E[X_i, X_{i+1}] \cdot E[MAAT_{X_i,X_{i+1}}] \tag{3.32}$$

3.3.4 Expected Number of Treated Patients per Year

Define $ST(\delta)$ as

$$ST(\delta) = \sum_{i=0}^{\infty} E[X_i, X_{i+1}] \cdot t_{X_i,X_{i+1}}(\delta) \tag{3.33}$$

with

$$t_{A,B}(\delta) = \begin{cases} \sum_{i=1}^{26}(i-1+\delta)T^i_{A,B} & \text{if} \quad A \in \{O,S,L\} \text{ and } B \in \{O,S\} \\ 26 & \text{if} \quad A \in \{O,S\} \text{ and } B = L \\ -26 & \text{if} \quad A = L \text{ and } B = H \end{cases} \tag{3.34}$$

The patients expected sojourn time is equal to $ST(\delta)$ if and only if all appointments are scheduled δ weeks after the PRT. Clearly the lower bound in section 3.3.3 is equal to $ST(0)$, and the preferred upper bound is equal to $ST(2)$, because it is assumed that the preferred difference between PRT and MAAT is equal to $\delta = 2$ weeks.

Define $ST_i(\delta)$ as the $ST(\delta)$ belonging to patient group i, and $ST_{AV}(\delta)$ as the $ST(\delta)$ belonging to an average arriving patient. Remember that an arriving regular patient belongs to patient group i with probability p_{G_i}, see section 3.2. Therefore,

$$ST_{AV}(\delta) = \sum_{i=1}^{12} p_{G_i} \cdot ST_i(\delta) \tag{3.35}$$

The function $ST_{AV}(\delta)$ is useful to determine the expected number of treated regular patients per year. Each year there are two types of patients that are treated at the GHD, namely

1. Patients that have arrived during the given year.
2. Patients that have arrived during a previous year, and still need treatment during the given year.

The expected number of patient in group 1 per year is equal to the expected number of arrivals per year, so $52 \cdot 10 \cdot E[N_{REG}]$, see section 3.2.

To determine the expected number of patients in group 2, one needs to determine the probability of an average patient needing treatment the year after his arrival. For example, a patient has arrived in week w of the previous year. It is expected that this patient needs treatment in the next year if and only if his expected sojourn time $ST_{AV}(\delta)$ exceeds $52 - w$ weeks.

Define W as the random variable depicting the week of arrival. It is assumed that W is uniformly distributed over all 52 weeks, so

$$P(W = w) = \frac{1}{52} \text{ for all } 1 \leq w \leq 52 \tag{3.36}$$

Define $Y_{+1}(\delta)$ as the random variable equal to 1 if the patient needs treatment in the year after his arrival, and 0 if not, given that all appointments are scheduled δ weeks after the PRT. Now $E[Y_{+1}(\delta)]$ given that the patient has arrived in week w is equal to

$$E[Y_{+1}(\delta)|W = w] = \begin{cases} 1 & \text{if } ST_{AV}(\delta) > 52 - w \\ 0 & \text{otherwise} \end{cases} \tag{3.37}$$

Now the expected value $E[Y_{+1}(\delta)]$ is equal to

$$\begin{aligned} E[Y_{+1}(\delta)] &= P(ST_{AV}(\delta) > 52 - W) \\ &= P(W > 52 - ST_{AV}(\delta)) \\ &= \begin{cases} 1 - \frac{ST_{AV}(\delta)}{52} & \text{if } 52 - ST_{AV}(\delta) \leq 52 \\ 0 & \text{otherwise} \end{cases} \end{aligned} \tag{3.38}$$

Similarly, define $Y_{+x}(\delta)$ as the random variable equal to 1 if the patient needs treatment xth year after his year of arrival, and 0 otherwise, given that all appointments are scheduled δ weeks after the PRT. With the same reasoning as for $E[Y_{+1}(\delta)]$ one can reason that

$$E[Y_{+x}(\delta)|W = w] = \begin{cases} 1 & \text{if } ST_{AV}(\delta) > 52x - w \\ 0 & \text{otherwise} \end{cases} \tag{3.39}$$

So for an average patient

$$\begin{aligned} E[Y_{+x}(\delta)] &= P(ST_{AV}(\delta) > 52x - W) \\ &= P(W > 52x - ST_{AV}(\delta)) \\ &= \begin{cases} 1 & \text{if } 52x - ST_{AV}(\delta) < 0 \\ x - \frac{ST_{AV}(\delta)}{52} & \text{if } 0 \leq 52x - ST_{AV}(\delta) \leq 52 \\ 0 & \text{otherwise} \end{cases} \end{aligned} \tag{3.40}$$

By definition $E[Y_{+0}(\delta)] = 1$ for all $\delta \geq 0$. Now the expected number of patients that need treatment during a given year, is equal to the number of patients that arrive during this year, plus the patients that arrived during the previous year and still need treatment, the patients that arrived 2 years ago and still need treatment etc. This results in

$$\begin{aligned} 520E[N_{REG}] + (520E[N_{REG}]) \cdot E[Y_{+1}(\delta)] + 520E[N_{REG}] \cdot E[Y_{+2}(\delta)] + ... \\ = \sum_{x=0}^{\infty} 520E[N_{REG}] \cdot E[Y_{+x}](\delta) \end{aligned} \quad (3.41)$$

This expectation uses the fact that all appointments are schedule exactly δ weeks after the PRT. Therefore, this expectation can only be used as an estimation of the number of treated patients per year.

Chapter 4

Detailed Patient Treatment Path Model

In the previous chapter 3 a Markov model has been introduced to determine the appointment type O or S for all appointments A_i in the patient treatment path $A_0, A_1, A_2, \ldots$. However, to determine the actual treatment path, one needs to know the actual appointments A_i. In this chapter the Markov model introduced in chapter 3 will therefore be extended to a more detailed model, which makes it possible to thoroughly determine the patient treatment path $A_0, A_1, A_2, \ldots$.

4.1 Detailed Markov Model

The model so far, results in a treatment path with known appointment types O or S for each appointment A_i. Let this be called the global patient treatment path. However, to correctly model the patients treatment path, A_i should be equal to one of the appointments in the appointment list 2.1. This will be called the detailed patient treatment path. In this chapter a procedure will be determined to change all appointment types in the global treatment path into appointments in the detailed treatment path.

First, remember that appointments 1 to 12 on this list are endoscopies (S), and 13 to 15 are outpatient clinic consultations (O). Appointments 17 to 19 are the appointments meant for BCS patients. They can never occur in the patient treatment path of a regular patient and can therefore be omitted for the rest of this section. In section 4.2, the construction of the BCS treatment path will be discussed in which these three appointments will be used. Appointment 16 is also an outpatient clinic consultation, but its occurrence in a patients treatment path depends on special aspects. This will become clear later on in this section.

Let a patient treatment path be depicted by

$$A_0 \rightarrow A_1 \rightarrow A_2 \rightarrow A_3 ... \tag{4.1}$$

If a patient has the following global treatment path

$$O \rightarrow S \rightarrow O \rightarrow O \tag{4.2}$$

then his detailed treatment path might look like

$$NP \rightarrow GA \rightarrow BE \rightarrow HP \tag{4.3}$$

However, there are a few relations and appointment specific properties that need to be clarified.

IP-CO relation A patient whose first appointment is a colonoscopy (CO, or CI), or combination appointment CO/GA, will always get an intake consultation (IP) in advance. The appointment IP is only used in this specific case, so if CO, CI, or CO/GA is the first appointment in a patients treatment path, and can never occur during the rest of a treatment path.

Now to avoid the violation of the Markov property, the following assumption is made. Let a patient's global treatment path look like this.

$$S \rightarrow ... \rightarrow ... \tag{4.4}$$

Then his detailed treatment path can be

$$CO \rightarrow ... \rightarrow ... \tag{4.5}$$

So his first appointment is CO, therefore his final detailed treatment path will look like

$$IP \rightarrow CO \rightarrow ... \rightarrow ... \tag{4.6}$$

However, if his global treatment path looks like

$$O \to S \to ... \to ... \tag{4.7}$$

His final detailed treatment path might for example look like

$$NP \to CO \to ... \to ... \tag{4.8}$$

So no IP is included. If the global treatment path is changed into a detailed treatment path and A_0 turns out to be CO,CI, or CO/GA, than IP is added to the beginning of the treatment path as an extra appointment A_{-1}.

NP-HP-BE relation This relation can be split up into two relations. First, as the name suggests, a call-back consultation BE never occurs as a patients first appointment.

Secondly, a check-up appointment HP never occurs before a first time visitor consultation NP. Also, an NP only occurs once in a patients treatment path. The only exception on this rule is if a patients first appointment is CO, CI, or CO/GA, and therefore this appointment is preceded by an IP. In this case no NP will occur during the patients treatment path, and the next outpatient clinic appointment can be a HP appointment.

To clarify these relations, a few examples will be given.

Example 1: A patients global treatment path looks like this

$$O \to O \to O \to O \tag{4.9}$$

Now the first appointment A_0 can only be an NP appointment, because BE is not allowed, and HP can only occur after the occurrence of NP. The other appointments A_i, $i \geq 1$ can both be HP or BE. Not NP, because NP can only occur once in a patients treatment path. A possible detailed patient route is therefore

$$NP \to BE \to HP \to HP \tag{4.10}$$

Example 2: A patient global treatment path looks like this, and it is known that the $A_0 \neq CO$.

$$S \to O \to O \to O \tag{4.11}$$

Then A_1 either be BE or NP. Not HP, because HP can only occur after the occurrence of NP. If $A_1 = BE$, then A_2 can again be BE or NP, with the same reasoning as before. However, if $A_1 = NP$, then A_2 can only be BE or HP, because NP can never occur twice in a treatment path. This continues until the end of the treatment path. Therefore, the detailed treatment path might look like

$$GA \rightarrow BE \rightarrow NP \rightarrow HP \tag{4.12}$$

Example 3: A patient global treatment path looks like this, and it is known that $A_0 = A_2 = CO$.

$$S \rightarrow O \rightarrow S \rightarrow O \tag{4.13}$$

So the semi-detailed treatment path looks like this

$$IP \rightarrow CO \rightarrow O \rightarrow CO \rightarrow O \tag{4.14}$$

Note, that only the first A_0 =CO is preceded by A_{-1} =IP. Now A_1 can only be BE or HP, because NP is not allowed in a treatment path with first appointment IP. Therefore, the detailed treatment path might look like this

$$IP \rightarrow CO \rightarrow HP \rightarrow CO \rightarrow HP \tag{4.15}$$

To include all these rules, the treatment path will be separated into 3 phases, namely

1. First appointment: only contains the patients first appointment. The only allowed outpatient clinic consultation is NP.
2. Follow-Up appointments before NP: contains all appointments after the first appointment, but before the occurrence of NP or IP. If NP occurs, then this appointment is also included in phase 2. Therefore, the only allowed outpatient clinic appointments are BE and NP.
3. Follow-Up appointments after NP: contains all appointments after the first appointment, and after the occurrence of NP or IP. The only allowed outpatient clinic appointments are BE and HP.

This turns the Markov chain in Figure 3.1 into a Markov chain with three phases, see Figure 4.1.

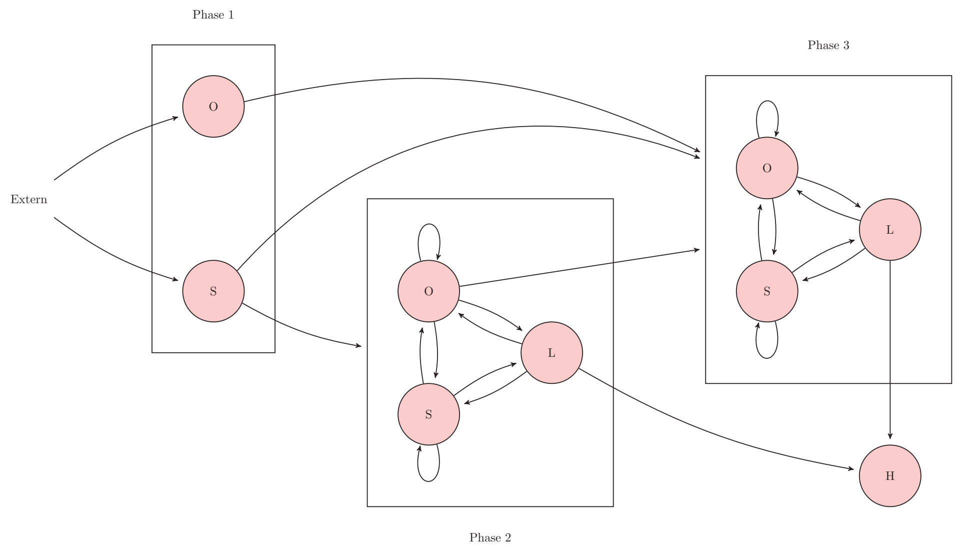


FIGURE 4.1: Detailed Markov Process

Now for each of these three phases $k = 1, 2, 3$ and for the two appointments types $B \in \{O, S\}$ define a probability vector D_B^k, where the jth element is equal to

$$\begin{aligned}(D_B^k)^{(j)} \quad = \quad P(A_i = APP_j| \quad & A_i = \text{ is a type } B \text{ appointment,} \\ & A_i = \text{ in phase } k \text{ of the treatment path)}\end{aligned} \tag{4.16}$$

So for the first appointment A_0 the detailed appointment is equal to APP_j with probability $(D_B^1)^{(j)}$, if A_0 is equal to $B \in \{O, S\}$ in the global treatment path. And the follow-up appointment A_i for $i \geq 1$ is equal to APP_j with probability

$$P(A_i = APP_j|A_i = B) \quad = \quad \begin{cases} (D_B^3)^{(j)} & \text{if } A_k = NP \text{ for a } 0 \leq k < i \\ & \text{or } A_0 = CO, CI \text{ or } CO/GA \\ (D_B^2)^{(j)} & \text{otherwise} \end{cases} \tag{4.17}$$

With these six probability vectors, the global treatment path can completely be changed into a detailed treatment path.

4.1.1 Expected Number of Appointments

In section 3.2.1, the expected number of visits $E[O]$ and $E[S]$ have been determined. In this section the expected values $E[APP_j]$ will be determined, where $E[APP_j]$ is the expected number of times a patient needs appointment APP_j during his treatment path for $j = 1, 2, 3, ..., 19$. So, for example, $E[CO]$ is the expected number of regular colonoscopies (CO) a patient needs during his treatment path.

It is known that the regular patient treatment paths do not contain BCS appointments, and therefore

$$E[IPBCS] = E[COBCS] \quad = \quad E[BEBCS] = 0, \tag{4.18}$$

because these appointments are only available for BCS patients.

Define $E[APP_{j,k}]$ as the expected number of appointments APP_j in phase $k = 1, 2, 3$ in the treatment path. Clearly $E[APP_j]$ depends on $E[APP_{j,k}]$. Remember that appointment IP is only planned before $A_0 =$ CO, CI, or CO/GA. Therefore, $E[IP]$ only depends on the first phase of the treatment path, and it can be seen that

$$E[IP] \quad = \quad E[CO_1] + E[CI_1] + E[CO/GA_1] \tag{4.19}$$

To define $E[APP_j]$ for the other appointments APP_j with $j = 1, 2, 3, ..., 15$, define $E[O_k]$ as the expected number of visits to the outpatient clinic in phase $k = 1, 2, 3$, $E[S_k]$ the expected number of endoscopies in phase k, and $E[APP_{j,k}]$ as the expected number of appointment APP_j in phase k. It can be seen that

$$E[APP_{j,k}] \quad = \quad E[O_k] \cdot (D_O^1)^{(j)} + E[S_k] \cdot (D_S^2)^{(j)} \tag{4.20}$$

In the next part of this section these expected values will be determined for each phase $k = 1, 2, 3$.

Phase 1 Every patient visits phase 1, because every patient at least has one appointment in his treatment path. Now $E[O_1]$ is simply the expectation that a patients first appointment will be an outpatient clinic consultation. This is equal to p_F. With the same reasoning $E[S_1]$ can be determined, resulting in

$$\begin{aligned} E[O_1] &= p_F \\ E[S_1] &= 1 - p_F \end{aligned} \tag{4.21}$$

Phase 2 To determine $E[O_2]$ and $E[S_2]$ it is necessary to zoom in on the phase 2 detail of the Markov process in Figure 4.1. This zoomed in Markov process looks exactly like the Markov process in Figure 3.1, except one extra state is added, namely Phase 3 (see Figure 4.2)

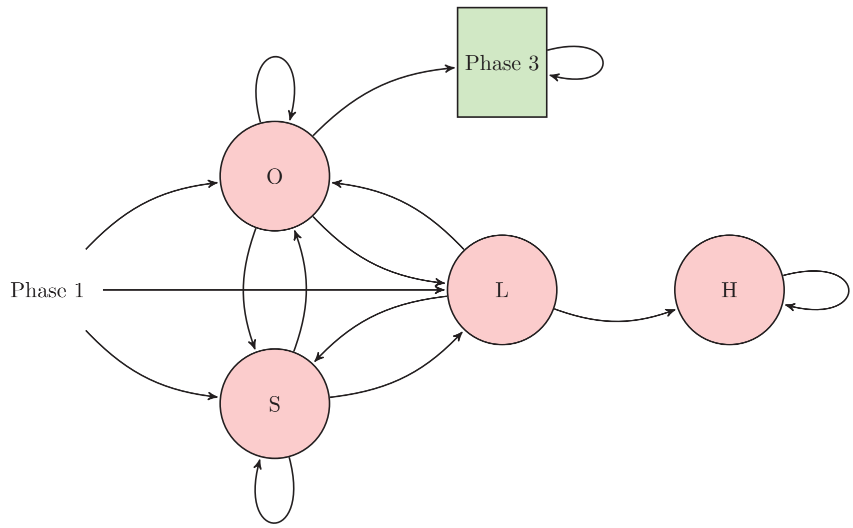


FIGURE 4.2: Phase 2 part of the Detailed Markov Process

Define P_2 as the transition matrix of this detailed Markov chain, where the states are ordered in the following way: $\Omega = \{O, S, L, H, \text{Phase 3}\}$. Then

$$P_2 = \begin{pmatrix} (D_O^2)^{(15)} p_{O,O} & (D_O^2)^{(15)} p_{O,S} & (D_O^2)^{(15)}(1 - p_{O,O} - p_{O,S}) & 0 & (D_O^2)^{(13)} \\ p_{S,O} & P_{S,S} & 1 - p_{S,O} - p_{S,S} & 0 & 0 \\ p_{L,O} & P_{L,S} & 0 & 1 - p_{L,O} - p_{L,S} & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \tag{4.22}$$

Define N_2 as the fundamental matrix belonging to this detailed Markov chain, and define $p_F^{(2)}$ as the starting probabilities vector. Finally, define $\tilde{X}_i$ as the i^{th} state of this detailed Markov chain.

It is known that a patient entering phase 2 always comes from state S in phase 1. Therefore, the probability of $\tilde{X}_0 = O$ is equal to $p_{S,O}$. With the same reasoning one can determine that

$$p_F^{(2)} = \begin{pmatrix} p_{S,O} & P_{S,S} & 1 - p_{S,O} - p_{S,S} & 0 & 0 \end{pmatrix}^T, \tag{4.23}$$

where $[p_F^{(2)}]_i = P(\tilde{X}_0 = \Omega_i)$.

Now with the same reasoning as in (3.17), it can be determined that

$$\begin{aligned} E[O_2] &= \sum_{i=1}^{3} [p_F^{(2)}]_i N_{i,1}^{(2)} \\ E[S_2] &= \sum_{i=1}^{3} [p_F^{(2)}]_i N_{i,2}^{(2)} \\ E[L_2] &= \sum_{i=1}^{3} [p_F^{(2)}]_i N_{i,3}^{(2)} \end{aligned} \tag{4.24}$$

Phase 3 As with phase 2, one can zoom in on the phase 3 part of the Markov process in Figure 4.1. This results in a Markov process equal to the global Markov process in Figure 3.1, only with different starting probabilities. Define $\bar{X}_i$ as the i^{th} state the patient visits in phase 3 of his treatment path.

A patient can enter phase 3 in three different ways, namely

1. From phase 1 with last appointment in phase 1 equal to NP, so of type O.
2. From phase 1 with last appointment in phase 1 equal to CO, CI, or CO/GA, so of type S.
3. From phase 2 with last appointment in phase 2 equal to NP, so of type O.

Define $\bar{X}_{-1}$ as the last appointment in the previous state and define $p^{(3)}_{F,\bar{X}_{-1}}$ as the starting probabilities vector for phase 3, given $\bar{X}_{-1}$. This gives

$$p^{(3)}_{F,\bar{X}_{-1}} = \{p_{\bar{X}_{-1},O}, p_{\bar{X}_{-1},S}, 1 - p_{\bar{X}_{-1},O} - p_{\bar{X}_{-1},S}, 0\} \text{ for } \bar{X}_{-1} \in \{O, S\} \tag{4.25}$$

Now with the same reasoning as in (3.17), it can be determined that

$$\begin{aligned} E[O_3|\bar{X}_{-1}] &= \sum_{i=1}^{3} [p^{(3)}_{F,\bar{X}_{-1}}]_i N_{i,1} \\ E[S_3|\bar{X}_{-1}] &= \sum_{i=1}^{3} [p^{(3)}_{F,\bar{X}_{-1}}]_i N_{i,2} \end{aligned} \tag{4.26}$$

Phase Transitions Define $p_{i\to j}$ as the probability of going from phase i to phase j. There are three different possible phase transitions, namely $p_{1\to 2}$, $p_{1\to 3}$, and $p_{2\to 3}$. A patient leaving phase 1 either goes to phase 2 or phase 3. So

$$p_{1\to 2} = 1 - p_{1\to 3} \tag{4.27}$$

Also a patient goes to directly to phase 3 if an only if A_0 = NP, CO, CI, or CO/GA. So

$$p_{1\to 3} = p_F (D^1_O)^{(13)} + (1 - p_F) \cdot ((D^1_S)^{(1)} + (D^1_S)^{(2)} + (D^1_S)^{(8)}) \tag{4.28}$$

Now only $p_{2\to 3}$ is unknown. A patient enters phase 3 out of phase 2 if and only if he visits state Phase 3 in the phase-2 Markov process in Figure 4.2. If one only looks at this phase-2 Markov process, than it can be seen that this process has two absorbing states

H and Phase 3. A patient continues to phase 3, if and only if his chain is absorbed in state Phase 3.

Recall that P_2 is the transition probability matrix of this process and N_2 the fundamental matrix. Also, recall that a transition probability matrix can be written in canonical form (see (3.12), which looks like

$$P_2 = \left(\begin{array}{c|c} Q_2 & R_2 \\ \hline \mathbf{0} & I \end{array}\right) \tag{4.29}$$

Now define matrix B as the matrix

$$B = N_2 R_2 \tag{4.30}$$

It is known that $B_{i,j-3}$ is the probability of a chain will be absorbed in state j if the chain starts in state i [9, p. 420]. Remember that $p_F^{(2)}$ is the vector with the starting probabilities in this phase-2 Markov process. Therefore the probability of being absorbed in state Phase 3 (or state 5), so the probability of going from phase 2 to phase 3, is equal to

$$p_{2\to3} = \sum_{i=1}^{5} (p_F^{(2)})_i \cdot B_{i,5} \tag{4.31}$$

Now all the above can be combined in determining $E[APP_j]$, namely

$$\begin{aligned} E[APP_j] = \; & E[APP_{j,1}] + p_{1\to2}(E[APP_{j,2}] + p_{2\to3}E[APP_{j,3}|\bar{X}_{-1} = O])+ \\ & p_{1\to3}(P(A_0 = NP)E[APP_{j,3}|\bar{X}_{-1} = O]+ \\ & P(A_0 = CO, CI, \text{ or } CO/GA)E[APP_{j,3}|\bar{X}_{-1} = S]) \end{aligned} \tag{4.32}$$

Every patient enters phase 1 of the treatment path, hence, $E[APP_{j,1}]$. After this a patient continues to phase 2 with probability $p_{1\to2}$. If he continues to phase 2, he continues to phase 3 with probability $p_{2\to3}$ and his last appointment in phase 2 will be NP. Therefore, in this case $\bar{X}_{-1} = O$. If the patient does not continue to phase 2 after phase 1, than he immediately continues to phase 3. This happens with probability $p_{1\to3}$. If he continues to phase 3, this either happens after appointment A_0, so $\bar{X}_{-1} = O$, or after appointments $A_0 =$ CO, CI, or CO/GA, so $\bar{X}_{-1} = S$.

As was stated at the beginning of section 3.2, the total patient treatment path model can be used to determine the patient treatment paths for patients in all different patient groups $i = 1, 2, 3, ..., 12$. However, it is interesting to determine the expected number of times an average patient needs a appointment APP_j during his treatment path, $E[APP_j]_{AV}$. Therefore, define $E[APP_j]_i$ as the expected number of times a patient in patient group i needs appointment APP_j during his treatment path. This expected value can now be determined by equation (4.32) with the use of patient group i model variables. In section 3.2 it has been introduced that p_{G_i} is the probability of an arriving patient belong to patient group i. This results in

$$E[APP_j]_{AV} = \sum_{i=1}^{12} p_{G_i} E[APP_j]_i \tag{4.33}$$

Remember that $E[N_{REG}]$ is the expected number of regular patients arriving at the GHD per daypart. It is assumed that a week has 10 dayparts available for patient care, and 52 weeks, resulting in $52 \cdot 10 \cdot E[N_{REG}]$ expected arrivals per year. And it is expected that these patients together need appointment APP_j

$$E[APP_j]_{TOT} = 52 \cdot 10 \cdot E[N_{REG}] \cdot E[APP_j]_{AV} \tag{4.34}$$

times during their treatment paths.

It is important to note that a patient arriving during year 1, might need appointments during year 2. However, the probability of needing x appointments during year 2, is equal to the probability of a patient that arrived during the same time in year 2, needing x appointments in year 3. Due to this reasoning it can be stated that $E[APP_j]_{TOT}$ is the expected number of times appointment APP_j needs to be performed at the GHD per year.

4.2 Modelling the BCS Treatment Path

As was stated in section 3.1, the patient treatment path model so far can be used to determine the treatment path for regular patients. The treatment path of the BCS patients is determined in a different way, because these patients have a partially fixed treatment path due to governmental regulations. This treatment path looks like the path in (4.35).

$$\xrightarrow[3]{1} \text{IP BCS} \xrightarrow[1]{0} \text{CO BCS} \xrightarrow[1]{0} \text{BE BCS} \tag{4.35}$$

where the value above (resp. below) the arrows indicates the PRT (resp. MAAT). However, last year's figures show that out of all patients that apply for the IP BCS appointment, only $\frac{2}{3}$ continues the treatment path to CO BCS. If the patient continues to CO BCS, he will always receive appointment BE BCS. So the expected number of times a BCS patient needs appointments IP BCS, CO BCS, and BE BCS are equal to

$$\begin{aligned} E[IPBCS] &= 1 \\ E[COBCS] = E[BEBCS] &= \tfrac{2}{3} \end{aligned} \tag{4.36}$$

After BE BCS, a patient continues his treatment path if the patient is diagnosed with bowel cancer. This is the disease associated with one of the first 11 patient groups. Let this be patient group x.

Last years figures show that 7% of the treated BCS patients were diagnosed with bowel cancer. [17]. Therefore, a BCS patient continues his treatment process with probability $\frac{2}{3} \cdot 0.07$. Otherwise, the patient leaves the system after BE BCS.

If a BCS patients continues his treatment path, he already had an IP BCS appointment. As with the IP appointments, this means that the patient continues his treatment path as a patient belonging to patient group x in phase 3 of his treatment path.

For the rest of this subsection, let $p_{A,B}$ be the transition probabilities associated with patient group x. If the patient continues his treatment process, his last known appointment in the treatment path is BE BCS. So following the reasoning in section 4.1.1 to determine the phase 3 expectations, $\bar{X}_{-1} = O$. The next state will be completely determined by the transition probabilities of patient group x, so state O with prob. $p_{O,O}$ etc. However, it is known that the patient under consideration is not going home after BE BCS, and also that he will be treated fairly soon (PRT $\leq$ 25 weeks), because he is diagnosed with bowel cancer. Therefore, his next appointment will be of type $B \in \{O, S\}$ with probability

$$P(\bar{X}_0 = B | \bar{X}_{-1} = O, PRT_{\bar{X}_{-1},\bar{X}_0} <= 25) = \frac{p_{O,B}}{p_{O,O} + p_{O,S}} \tag{4.37}$$

As was stated before, $E[APP_j]_i$ is defined the expected number of times a patient belonging to patient group i needs appointment APP_j during his treatment path. With the same reasoning define N as the fundamental matrix of the global Markov process belonging to patient group x. Define $E[O]_{BCS}$, and $E[S]_{BCS}$ as the expected number of O, and S appointments a BCS patient will need, given that he continues his treatment path after BE BCS. Giving the starting probabilities in (4.37), this results in

$$\begin{aligned} E[O]_{BCS} &= \tfrac{p_{O,O}}{p_{O,O}+p_{O,S}} N_{1,1} + \tfrac{p_{O,S}}{p_{O,O}+p_{O,S}} N_{2,1} \\ E[S]_{BCS} &= \tfrac{p_{O,O}}{p_{O,O}+p_{O,S}} N_{1,2} + \tfrac{p_{O,S}}{p_{O,O}+p_{O,S}} N_{2,2} \end{aligned} \tag{4.38}$$

And this results in

$$E[APP_j]_{BCS} = \begin{cases} 1 & \text{if } APP_j = IPBCS \\ \frac{2}{3} & \text{if } APP_j = COBCS \\ & \text{or } BEBCS \\ \frac{2}{3} \cdot 0.07 \cdot (E[O]_{BCS} \cdot (D_O^3)^{(j)} + & \\ E[S]_{BCS} \cdot (D_S^3)^{(j)}) & \text{otherwise} \end{cases} \tag{4.39}$$

Remember that $10N_{BCS}$ is the predetermined number of weekly arriving BCS patients per year (section 3.1), then the total number of times all BCS patients combined need appointment APP_j per year is equal to

$$E[APP_j]_{BCS,TOT} = 10N_{BCS} \cdot E[APP_j]_{BCS} \tag{4.40}$$

Chapter 5

Data Analysis

To use the patient treatment path model given in chapters 3 and 4, several patient group dependent variables should be known, e.g. the transition probabilities in the global Markov chain. In this section, the methods used to determine these variables out of the available data, will be described.

5.1 Main Variable Determination

For each patient group i the following variables are needed in the patient treatment path model

- Starting probability p_F.
- Transition probability matrix P for the global Markov chain (see (3.9))
- Short term transition time probability vectors $T_{A,B}$ for $A, B \in \{O, S\}$ (see (3.18))
- Long term transition time probability vector T_L (see (3.24))
- Detailed appointment vectors D_B^k for $k = 1, 2, 3$ and $B \in \{O, S\}$ (see (4.16))

Also, the probability of belonging to patient group i, p_{G_i} should be determined. For all 12 patient groups, the above mentioned variables are different. However, the methods to determine the variables out of the data are identical for all patient groups. Therefore, no differentiation will be made between patient groups in this section (unless mentioned otherwise). Also, due to confidentiality restrictions, no detailed numbers will be given.

The determinations of the transition probability matrix P and of the long term transition time distribution vectors T_L need a more detailed explanation. Therefore, this determination will be described in more detail. The determination of the other variables will be summarized. The main data that was used to determine the necessary variables was a set containing the calendar data of the GHD physicians and residents between July 1, 2013, and June 30, 2014. Let this data set be called Set Total. Each data point in Set Total is an appointment performed between the two given dates. One data point might look like

Patient Number	Patient Group	Patient Name	Appointment	Date Date	Staff Member	Appointment Code
123456	5	Jansen	NP	1-8-2013	Dr. Peters	X

Table 5.1: Example of a data point in Set Total.

By combining all data points belonging to patient Jansen, one can construct the treatment path of this patient between July 1, 2013 and June 30, 2014. The JBZ uses a specific system to label all appointments with an appointment code. This appointment code reveals several things about the appointment, for example whether the appointment is the patients first appointment at the GHD, or a follow-up appointment. Using this appointment code one can split-up the Set Total into 2 subsets, Set 1 and Set 2. Set 1 contains all known first appointments, and Set 2 all follow-up appointments. Now p_{G_i} is determined to be the fraction of people belonging to patient group i in Set 1.

After that all 3 sets, Set Total, and Set 1, and Set 2 have been split up into 12 subsets, Set Total.i, Set 1.i, and Set 2.i, belonging to patient group i. Now for each patient group i p_F is equal to the fraction of outpatient clinic consultations in Set 1.i.

Remember that $(D_O^k)^{(j)} = 0$ for all $j = 1, 2, 3..., 12$ and $j = 16, 17, 18, 19$ for all $k = 1, 2, 3$, because in these cases APP_j is not a regular consultation. With the same reasoning $(D_S^k)^{(j)} = 0$ for all $j = 13, 14, 15, ..., 19$, and $k = 1, 2, 3$. Now the other elements of the vectors D_B^k can be determined by

- D_A^1: if $A = O$, the fraction of outpatient clinic consultations being of type NP, HP, and BE in Set 1.i. If $A = S$ the same holds, only this time for the fraction of detailed endoscopies. (see page 7)
- $D_S^2 = D_S^3$: the fraction of each detailed endoscopy clinic consultation in Set 2.i.

Vectors D_O^2, and D_O^3 are determined together. It is known that in phase 2 only BE and NP are allowed consultations, and in phase 3 only BE and HP. So

$$(D_O^2)^{(14)} = (D_O^3)^{(13)} = 0 \qquad (5.1)$$

Also,

$$\begin{aligned} (D_O^2)^{(13)} &= 1-(D_O^2)^{(15)} \\ (D_O^3)^{(14)} &= 1-(D_O^3)^{(15)} \end{aligned} \tag{5.2}$$

From Set 2.i one can determine the fraction of BE appointments in the follow-up consultations. Let this fraction be called p_{BE}. It is assumed that this fraction is independent of the phase of treatment path, and therefore

$$(D_O^2)^{(15)} = (D_O^3)^{(15)} = p_{BE} \tag{5.3}$$

Now only $D^2_{O,NP}$ and $D^3_{O,HP}$ are left, resulting in

$$(D_O^2)^{(13)} = (D_O^3)^{(14)} = 1-p_{BE} \tag{5.4}$$

The distribution vectors $T_{A,B}$ with $A,B \in \{O,S\}$ were determined from Set Total.i in the following way. Between every two consecutive appointments X and Y in Set Total.i, a certain amount of days passes. After finishing appointment X, the patient under consideration, asks for the planning of appointment Y after x weeks, where x is the PRT. Interviews with the planning staff revealed that, during the given year, appointment Y was almost always scheduled within x and $x+1$ weeks after appointment X. In the case that no appointment slot was available for appointment Y, it was attempted to squeeze in the appointment, or one of the staff members would work overtime.

Therefore, it is assumed that the PRTs can be estimated from the transition times in days by using the following relation.

$$PRT = \left\lfloor \frac{\text{transition time in days}}{7} \right\rfloor \tag{5.5}$$

Henceforth, the term 'transition time' refers to this rounded estimated PRT. Now $T_{A,B}$ with $A,B \in \{O,S\}$ is a vector of length 26 where the i^{th} element is equal to

$$P(PRT_{A,B} = i-1) = \frac{\#\text{ transitions } A \to B \text{ with } PRT_{A,B}=i-1}{\#\text{ transitions } A \to B \text{ with } PRT_{A,B} \leq 25} \tag{5.6}$$

The determination of the transition probabilities $p_{A,B}$, and the long term transition time distribution vector T_L will be described in more detail.

5.2 Determination of Transition Probabilities, and Long Term Transition Time Distribution

To determine the transition probabilities and long term transition time distribution, one first has to know whether a transition in the data set is a long or short term transition. However, the given data set only offers information about appointments made between July 1, 2013, and June 30, 2014. Therefore, it is unknown whether a patient with an appointment on June 29, 2014, returns within 6 months, between 6 months and a year or after a year. A method based on the Kaplan-Meier survival estimator is used to determine the probability of a transition being a short term, long term, or home transitions [14].

Let the survival function $S(t) = P(PRT > t)$ be the probability of any transition 'surviving' t weeks, so no appointment is planned between $(0, t]$ weeks after the last appointment. Here PRT is the random variable depicting the PRT independent of the origin or destination appointment of the transition.

Now $P(PRT > t|PRT \geq t)$ can be estimated from data set Total.i for $0 \leq t \leq 51$ by the following relation.

$$P(PRT > t|PRT \geq t) \quad = \quad \frac{\#\text{ transitions with } PRT > t}{\#\text{ transitions with } PRT \geq t} \tag{5.7}$$

Since PRT is known to be a discrete value in weeks, it is known that for all $t = 0, 1, 2, ..., 51$, $P(t < PRT < t+1) = 0$. Therefore, one can state that $P(PRT \geq t+1) = P(PRT > t)$, resulting in the following relation between $S(t)$, and $S(t+1)$.

$$\begin{aligned} S(t+1) &= P(PRT > t+1) \\ &= P(PRT > t+1|PRT \geq t+1) \cdot P(PRT \geq t+1) \\ &= P(PRT > t+1|PRT \geq t+1) \cdot P(PRT > t) \\ &= P(PRT > t+1|PRT \geq t+1) \cdot S(t) \end{aligned} \tag{5.8}$$

Since by definition $S(0) = 1$, taking the product from 0 to $j - 1$ now gives

$$S(t) \quad = \quad \prod_{k=0}^{t} P(PRT > k|PRT \geq k) \;\forall t \geq 0 \tag{5.9}$$

Let $S_A(t)$ be defined as $S_A(t) = P(PRT_{A,} > t)$ for any $A \in \{O, S\}$. With the same reasoning as in (5.7), and (5.9), one can determine $S_A(t)$ from Set Total.i for all $A \in \{O, S\}$.

Now, an estimation of $P(PRT = t)$ can be determined by

$$\begin{aligned} P(PRT = t) &= P(PRT > t) - P(PRT > t + 1) \\ &= S(t) - S(t + 1) \end{aligned} \tag{5.10}$$

With the same reasoning an estimation of $P(PRT_{A,} = t)$ can be determined with $S_A(t)$ and $S_A(t + 1)$

Let p_{ST}^A be the probability that any transition starting in state $A \in \{O, S\}$, ends up to be a short term transition. Then p_{ST}^A can be determined by

$$\begin{aligned} p_{ST}^A &= P(PRT_{A,} \leq 25) \\ &= 1 - S_A(25) \end{aligned} \tag{5.11}$$

Let p_{LT} be the probability that any transition (independent of the involved appointments) ends up to be a long term transition, given that it is not a short term transition. Then by definition

$$\begin{aligned} p_{LT} &= P(PRT \leq 51 | PRT \geq 26) \\ &= \tfrac{P(26 \leq PRT \leq 51)}{P(PRT \geq 26)} \\ &= \tfrac{S(25) - S(51)}{S(25)} \\ &= 1 - \tfrac{S(51)}{S(25)} \end{aligned} \tag{5.12}$$

5.2.1 Transition Probabilities

Now p_{ST}^A and p_{LT} are available to estimate whether a transition is a short term, long term, or home transition. They are both independent of the destination appointment. The arguments used in section 3.2 substantiate that this is allowed in long term transition analysis. It is also important to note that p_{LT} is independent of the origin appointment. The use of p_{LT} in further long term transition analysis can also be validated by the arguments in section 3.2.

Now these two values can be used to determine the transition probabilities $p_{A,B}$ with $A \in \{O, S, L\}$ and $B \in \{O, S\}$.

For the short term transitions, so for $A \in \{O, S\}$ and $B \in \{O, S\}$, $p_{A,B}$ can be estimated from set Total.i by

$$\begin{aligned} p_{A,B} &= P(A \to B, \text{ transition is short term transition }) \\ &= P(A \to B, PRT_{A,} \leq 25) \\ &= P(A \to B | PRT_{A,} \leq 25) \cdot P(PRT_{A,} \leq 25) \\ &= \frac{\#\text{ transitions } A\to B \text{ with } PRT_{A,B} \leq 25}{\#\text{ transitions originating from } A \text{ with } PRT_{A,} \leq 25} \cdot p_{ST}^{A} \end{aligned} \tag{5.13}$$

The long term transition probabilities $p_{L,B}$ with $B \in \{O, S\}$ can be estimated in a comparable way by

$$\begin{aligned} p_{L,B} &= P(L \to B, \text{ transition is long term transition }) \\ &= P(A \to B\ \forall A \in \{O, S\}, PRT \leq 51 | PRT \geq 26) \\ &= P(A \to B\ \forall A \in \{O, S\} | 26 \leq PRT \leq 51) \cdot P(PRT \leq 51 | PRT \geq 26) \\ &= \frac{\#\text{ transitions with destination appointment } B \text{ with } PRT_{,B} \geq 26}{\#\text{ transitions with } PRT \geq 26} \cdot p_{LT} \end{aligned} \tag{5.14}$$

5.2.2 Long Term Transition Time Distributions

As was stated in section 5.1, the elements of the short term transition time distribution vector $T_{A,B}$ are determined by (5.6).

For the long term transition time distributions T_L the i^{th} element will be equal to $P(PRT_{L,} = i - 1)$. This value can be estimated for set Total.i by

$$\begin{aligned} P(PRT_{L,} = i - 1) &= P(PRT = i + 25 | 25 < PRT \leq 51) \\ &= \frac{P(PRT = i+25)}{P(25 < PRT \leq 51)} \end{aligned} \tag{5.15}$$

which can be estimated by the definition of $P(PRT = t)$ found in (5.10).

Now the point of introducing state L becomes clear. Two different ways were used to determine the transition time distributions $T_{A,B}$, and T_L, namely (5.6) for the short term transitions, and (5.15) for the long term transitions.

If (5.15) would have been used to determine the short term transition times as well, no differentiation could have been made between the origin and destination appointments in the transitions.

On the other hand, using (5.6) to determine the long term transition times, would not be possible, due to the unavailability of enough data points to get a trustworthy distribution over all possible $0 \leq PRT \leq 51$.

Furthermore, every patient in the data set Total.i has a last appointment in the data set. It is unknown whether this last appointment actually is the patients last appointment in the treatment path, or if a new appointment is scheduled after June 29, 2014. And if a new appointment is scheduled outside of the data set scope, it is unknown whether this transition is short, or long term. This influences the transitions probabilities $p_{A,B}$, and a survival analysis is necessary to determine a trustworthy estimate of the transition probabilities $p_{A,B}$, and of the $PRT_{L,}$.

5.3 Comparing Model Results to Original Data

In this section the results of the Markov model described in chapters 3 and 4 will be compared to 2014 year figures offered by the Jeroen Bosch Hospital. As was stated before, the Markov model has been simulated by a simulation program written in JAVA. The results of this simulation program will also be compared to both the original data, and model results.

The simulation is done over a predetermined number of years, were each year contains 52 weeks, and each week contains 10 dayparts. During each daypart patients arrive according to a $NB(r, p)$-distribution (see section 3.1). After arrival they will be assigned to a patient group, and patient treatment path which will be constructed according to the Markov model.

The comparison of the original data, and model and simulation results will be done for the following two values, namely

1. Number of treated patients per year
2. Number of appointments per year per appointment

It is important to note that in the simulation all dayparts are labeled by a number. For example simulation daypart 100, is daypart 100 in year 1. Also, simulation daypart 550 is daypart 30 in year 2 etc. From now on all mentioned dates related to the simulation will be expressed in simulation dayparts, and can easily be transformed to simulation years by (5.16)

$$\text{Simulation year} = \left\lfloor \frac{\text{Simulation daypart} - 1}{520} \right\rfloor + 1 \qquad (5.16)$$

For confidentiality reasons, no absolute values will be given, and all results will be given relative to the original data unless stated otherwise.

5.3.1 Number of Treated Patients per Year

The number of treated patients in a given year is the number of patients that need an appointment during this year. In section 3.3.4 the expected number of treated patients per year has been determined according to the model, given that each appointment is planned exactly δ weeks after the PRT.

To obtain a comparable value from the simulation, 20 years of arriving patients have been simulated. As was stated before, every patient arrives during a given daypart, and he is attached to a simulated patient treatment path. Each appointment in this treatment path has a PRT after the last appointment. Remember that A_i is the $i$the appointment in the treatment path of a simulated patient, and PRT_i the associated PRT. Define T_i as the appointment date of appointment A_i. If each appointment A_i is planned exactly $PRT_i + \delta$ weeks after the the previous appointment, and T_0 is the appointment date (in dayparts) of the first appointment, then

$$T_i = T_0 + 10 \cdot \sum_{i=1}^{i} (PRT_i + \delta) \tag{5.17}$$

.

is the appointment date for appointment A_i. The appointment year Y_i can now be determined with (5.18) by

$$Y_i = \left\lfloor \frac{T_i - 1}{520} \right\rfloor + 1 \tag{5.18}$$

After this is done for all simulated patients and their appointments, the number of treated patients in year i can be determined by counting all patients that need an appointment during year y, for $1 \leq y \leq 20$. Figure 5.1 shows both the model and simulation results relative to the original data for $0 \leq \delta \leq 3$ weeks.

If all appointments are planned exactly 3 weeks after the PRT, then both the modelled, as well as the simulated expected number of treated patients per year, are approximately equal to the original number of treated patients in 2014.

Also, the warm-up period of the simulation is clearly visible. It can be seen that from year 6 onwards, the simulated number of treated patients, given $\delta = 3$, stabilizes. This value will be useful in the next section.

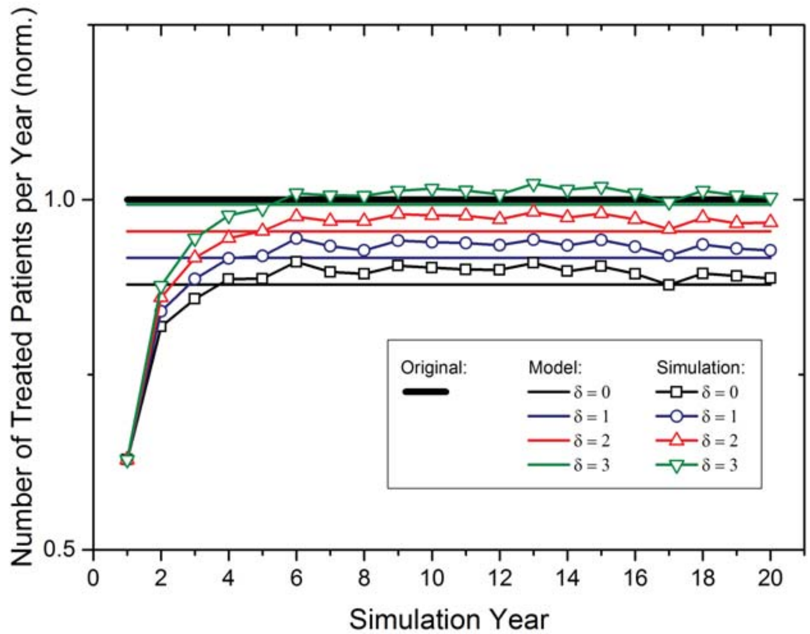


FIGURE 5.1: Comparing Results for Number of Treated Patients

5.3.2 Number of Appointments per Year per Appointment APP_j

As was described in section 4.1.1, $E[APP_j]_{TOT}$ is the expected number of times appointment APP_j needs to be performed at the GHD per year for regular patients.

The same simulation results as in the previous section can be used to determine the number of appointments per year per appointment APP_j in the 20 simulated years, given that each appointment is scheduled exactly $PRT + \delta$ weeks after the last appointment. The result of the previous simulation suggest the usage of $\delta = 3$. As was described in (5.17), each appointment in the simulation has an appointment date given δ. Define $X_{APP_j,y}$ as the number of times an appointment of type APP_j has an appointment date in year y.

The results in the previous section suggests that, given $\delta = 3$, during simulation years $y \geq 6$, the expected number of treated patients has stabilized. Consequently, it is expected that $X_{APP_j,y}$ during these years gives a good estimate of the number of appointments of type APP_j needed during an average year. Now Figure 5.2 shows the comparison of the original data, model results, and average of $X_{APP_j,y}$ over the years $6 \leq y \leq 20$. Some appointments are combined into one main appointment, for example, CO, CI, and CO/GA. This because the hospital administration does not make a difference between these appointments. Also, the two combination appointments CO/GA and EUS/GA are taken into account in both CO and GA (resp. EUS and GA).

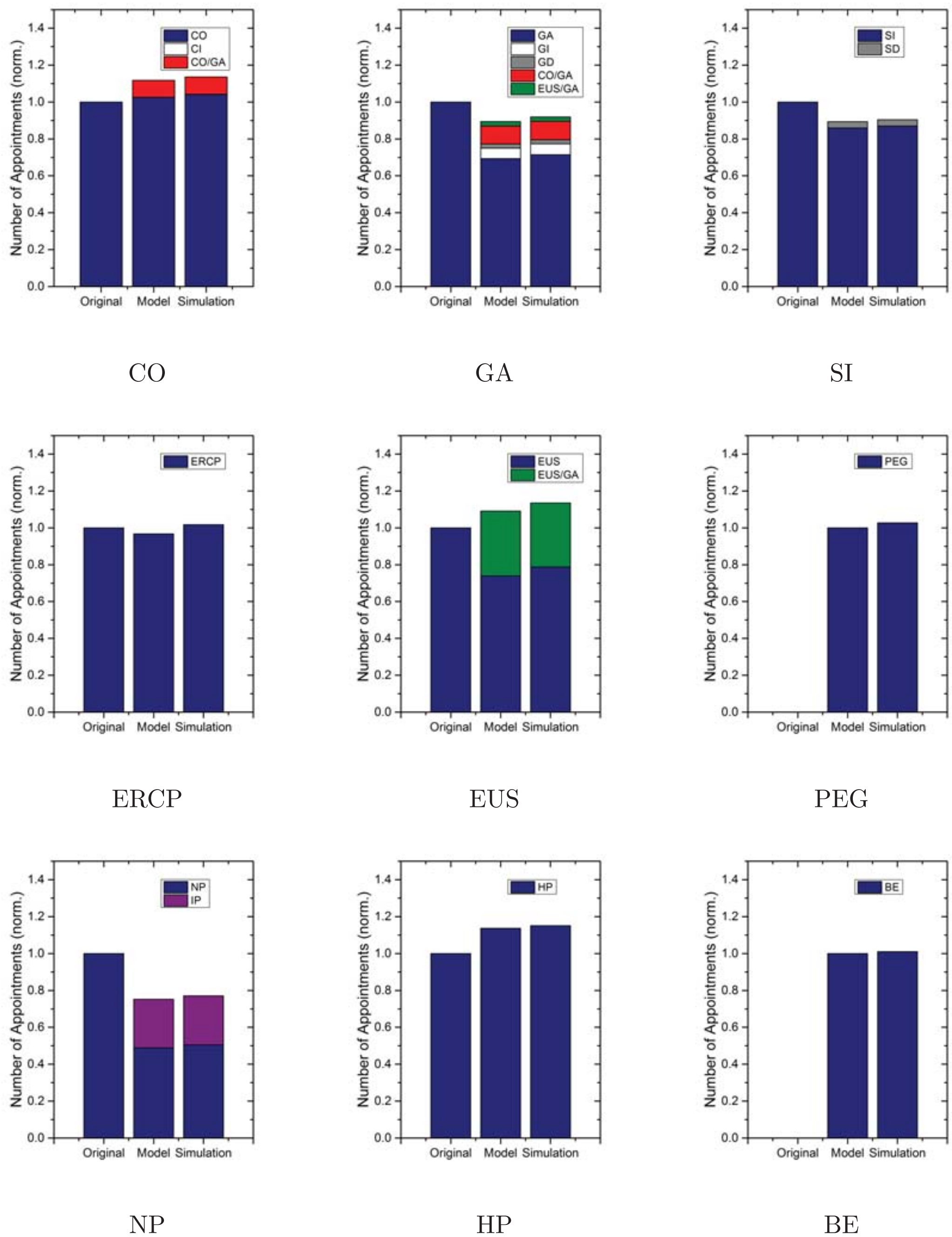


FIGURE 5.2: Number of appointments - Original data compared with model and simulation results.

All numbers are relative to the original data. However, as can be seen, not for all appointments the original data has been known, for example in the case of PEG. In these cases all numbers are relative to model result, $E[APP_j]_{TOT}$. The appointments IP BCS, CO BCS and BE BCS, are not taken into account, because the patients currently under consideration are only regular patients. Therefore $E[APP_j]_{TOT} = 0$ for all three appointments.

In most cases the original, model and simulation results are roughly equivalent. However, as can be seen, a large gap exists between the number of NPs in the original data, and the number of NPs in the model and simulation. This can be explained due to administrative reasons, which will not be discussed in detail. Combining these reasons with the model and simulation result, turns this gap into a gap comparable to the other differences.

5.3.2.1 Including BCS Patients

The model results $E[APP_j]_{TOT}$ for each appointment APP_j is only the expected number of appointments APP_j needed per year for regular patients. In section 4.2 also this expected value for BCS patients has been determined, namely $E[APP_j]_{BCS,TOT}$. Clearly this expectation depends on the number of BCS patients that arrive at the GHD per year $520N_{BCS}$. For the remainder of this thesis, four scenarios will be taken into account, namely the value of N_{BCS} on Monday mornings will be

- Scenario 1: $N_{BCS} = 0$, so 0 BCS patients per week
- Scenario 2: $N_{BCS} = 26$, so 26 BCS patients per week
- Scenario 3: $N_{BCS} = 30$, so 30 BCS patients per week
- Scenario 4: $N_{BCS} = 48$, so 48 BCS patients per week

Figure 5.3 shows the expected increase per scenario relative to $E[APP_j]_{TOT}$, so the model result without BCS patients. For the simulation result without BCS patients, the simulation result from the previous section is used. For the other three simulation results, three new 20-year-simulations were executed. Again the average of $X_{APP_j,y}$ for $6 \leq y \leq 20$ was taken to obtain the simulation average. For all four simulations also the standard deviation of $X_{APP_j,y}$ for $6 \leq y \leq 20$ has been determined, which are also shown in Figure 5.3.

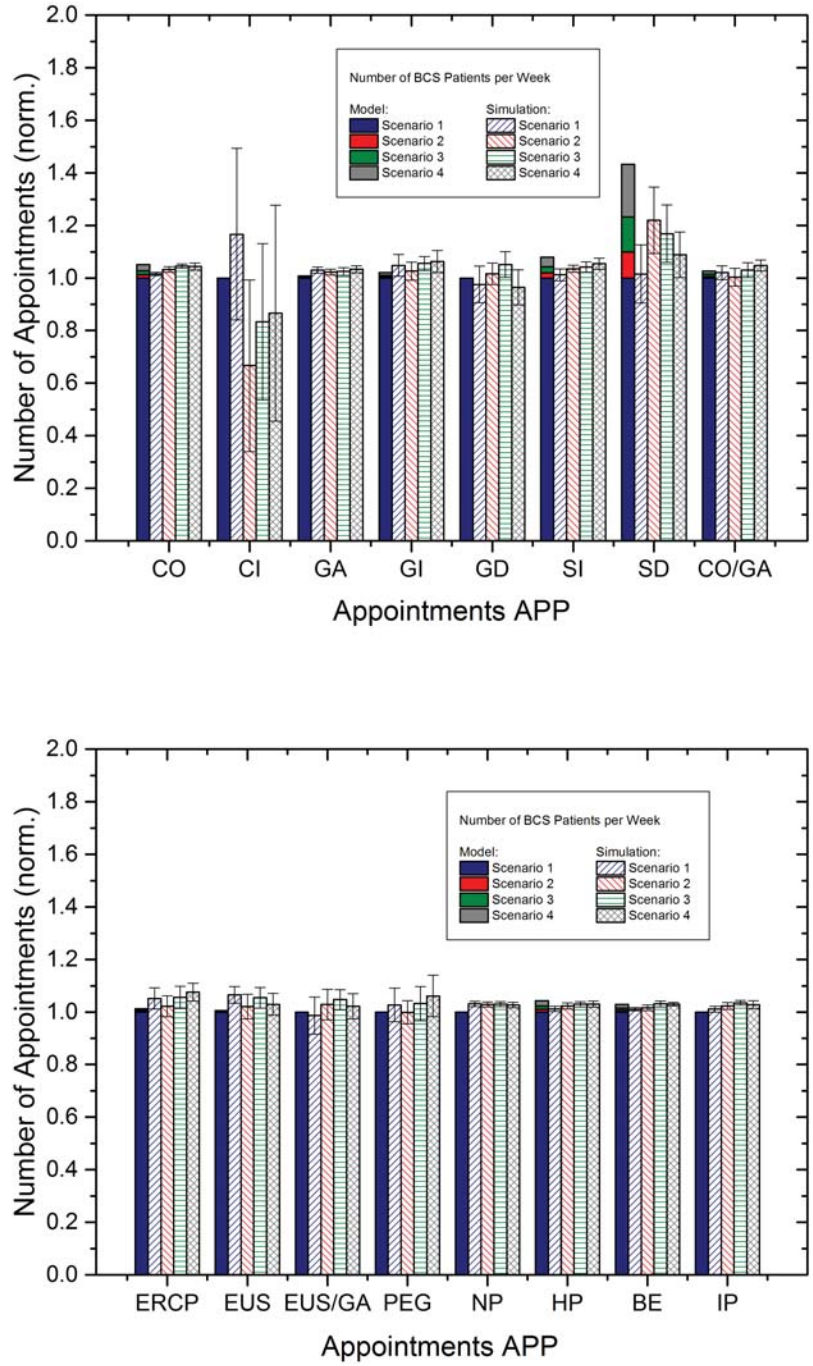


FIGURE 5.3: The expected number of appointments in the 4 BCS model scenario's compared relative to scenario 1 (Only regular patients, 0 BCS).

For appointments IP BCS, CO BCS and BE BCS, $E[APP_j]_{TOT} = 0$, because these appointments are reserved for BCS patients. Therefore these values are presented relative to the values in scenario 2, in Figure 5.4.

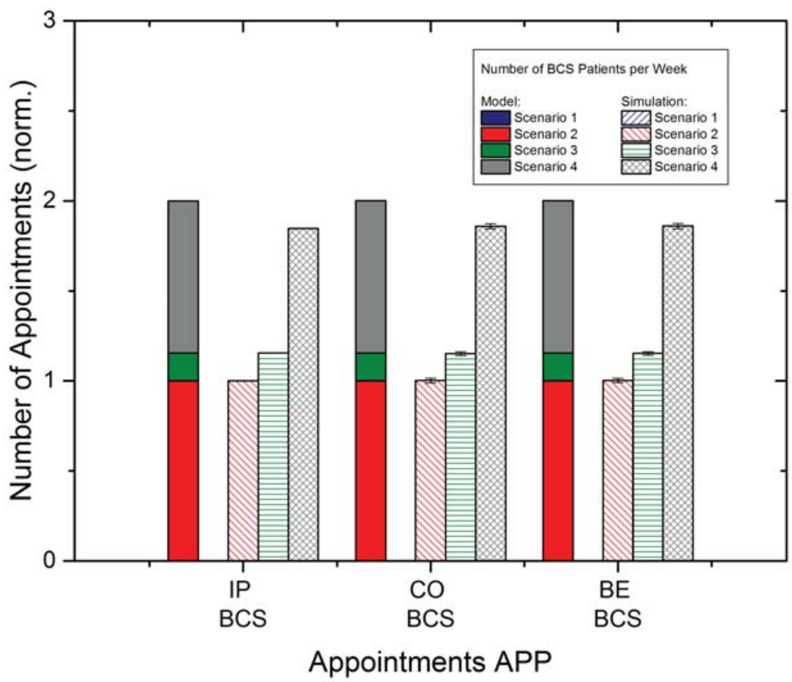


Figure 5.4: The expected number of appointments in the 4 BCS model scenario's compared relative to scenario 2.

The simulation results in all three presented figures are comparable to the expected model results, which results in a trustworthy simulation for the patient treatment paths. This can be concluded for all appointments except for the results for appointment CI. The difference between model results and simulation results for this appointment is due to the fact that the CI appointment is a very rarely occurring appointment. Because of this rare occurrence, and because all values are represented relative to the modelled results in scenario 1, a small deviation in the simulation results, leads to a large deviation in the relative simulation results. It is important to note that the absolute model and simulation results are also comparable for this appointment CI.

Chapter 6

Master Schedule Simulation

The patient treatment path model described in the previous chapters can be used to determine the expected yearly demand. In order to meet this demand, the expected number of yearly available appointment slots should be sufficient. This will be called the staff supply. In this chapter the current staff supply will be determined, compared to the patient demand, and adjusted such that the expected staff supply will meet the expected patient demand.

6.1 Master Schedule Determination

In section 2.2 the reader has been introduced to the master schedule. Remember each master schedule consists of two different matrices C and M, where each element $M_{a,b}$ and $C_{a,b}$ corresponds to daypart b in the calendar of staff member a. In matrix C each daypart is categorized by one of the following categories

1. Inpatient Care Clinic
2. Absent
3. Inpatient Care Visitor
4. External Outpatient Clinic
5. Colonoscopy for BCS
6. ERCP
7. EUS
8. Intake for BCS
9. Intake
10. Supervision
11. Colonoscopy
12. Gastroscopy/Sigmoidoscopy
13. Outpatient Clinic (OC)

and $M_{a,b}$ contains the number of minutes available for appointments in each corresponding daypart.

To determine the expected number of available appointment slots for appointment APP_j per year out of C and M, remember that each daypart category is associated with predetermined category specific, and non-category specific appointments (see tables 2.2 and 2.3). During daypart (a, b), $M_{a,b}$ minutes are available and it is attempted to spend as much of this time as possible on the category specific appointments of category $C_{a,b}$. The residual time will be spend on non-category specific appointments.

Now to determine the available supply a simple 'fill-the-box' method is used. This method will be based on the assumption that it is harder to find an appointment slot for appointments with a longer duration. Therefore it is attempted to find appointment slots for the category specific appointments in decreasing order of duration. All residual time will be used for non-category specific appointments, also in decreasing order of duration. The next example will explain this method in more detail.

Step 1 *Example:* Let $M_{a,b}$ be 175 minutes, and let $C_{a,b}$ be a category with one category specific appointment A with a regular duration of 30 minutes. Clearly, 5 appointment slots can be created for this appointment, while 150 minutes are available. This leaves 25 unused minutes during which no extra appointment can be scheduled. These minutes can be spend on the non-category specific appointments B, C, and D respectively with durations of 20, 10, and 5 minutes. While appointment slots are created in order of decreasing duration, this will result in 1 appointment slot for appointment B and 1 appointment slot for appointment D.

All simulation results presented in this chapter will be determined from the simulation output of a master schedule simulation over 20 years. So this simulation output will contain two matrices C and M of size $n \times 520 \cdot 20$, where n is the number of available staff members. If the described procedure is applied on dayparts (a, b) for $a = 1, 2, 3, ..., n$ and $b = 1, 2, 3, ..., 520$ in each simulation year $Y = 1, 2, 3, ..., 20$, one can determine $S_{APP_j,Y}$, the number of available appointment slots for appointment APP_j in simulation year Y. The average over these 20 years will be S_{APP_j}, or the expected yearly number of available appointment slots for appointment APP_j.

After this first step the supply determination is not yet finished. The following example explains the second step.

Step 2 *Example:* Assume that the example daypart in the previous daypart occurs on average once a week, this will result in $S_A = 260$ appointment slots for appointment

A, $S_B = 52$ appointment slots, $S_C = 0$ appointment slots and $S_D = 52$ appointment slots per year. Now assume that the yearly expected demand for appointment B is equal to 40 appointments. This will result in a residual of 12 appointment slots. These appointment slots can be converted to 24 appointment slots for appointment C, so the final expected yearly supply will be $S_B = 40$ and $S_C = 24$.

This method can be used for all appointments. Appointment slots are converted to other appointment slots in order of importance. So first the category specific appointments in order of decreasing duration. If no category specific demand is left, then appointment slots are changed into non-category specific appointment slots, again in order of decreasing duration.

So the final estimated supply depends on the expected yearly demand. Remember that the total yearly expected demand for appointment APP_j is equal to $E[APP_j]_{TOT} + E[APP_j]_{BCS,TOT}$. The first part is equal to the demand from the regular patients, and the second part from the BCS patients. In section 5.3.2.1 four different demand scenarios have been introduced, namely

- Scenario 1: $N_{BCS} = 0$, so 0 BCS patients per week
- Scenario 2: $N_{BCS} = 2.6$, so 26 BCS patients per week
- Scenario 3: $N_{BCS} = 3.0$, so 30 BCS patients per week
- Scenario 4: $N_{BCS} = 4.8$, so 48 BCS patients per week

So, $E[APP_j]_{TOT}$ is equal for all four scenarios, and $E[APP_j]_{BCS,TOT}$ depends on the N_{BCS}. This will result in an expected yearly demand for each scenario and consequently in a different yearly supply for each scenario. Therefore, the analysis in this chapter will be done for all four scenarios.

As will be shown during the remainder of this chapter, the current expected yearly supply will not be sufficient to cope with the demand in all four scenarios. Therefore, the goal of this chapter is to make adjustments to the current staff supply such that it meets the requirements. This will eventually result in four different supply scenarios corresponding to the four demand scenarios.

From section 2.2 remember that the values in M are first determined by the predetermined weekly fixed schedule. Next the values in matrix C will be determined according to category specific scheduling rules. Remember that these scheduling rules contain rules on

1. Dayparts per week that are allowed for the specific category, e.g. category ERCP can only be scheduled on predetermined dayparts during the week.

2. Staff members that are qualified to perform the appointments associated with the specific category, e.g. category Colonoscopy for BCS can only be scheduled in the elements of master schedule C which belong to staff members qualified to perform CO BCS appointments.

3. Desired number of dayparts per week that should be spend on the specific category, e.g. it is desired to schedule category Intake x times per week to be able to cope with the estimated demand for appointment IP.

4. Necessary facilities to be able to perform the tasks associated with the specific category.

After determination of matrix C, matrix M is adjusted to matrix C, because some daypart categories influence the number of minutes available for appointments.

The values used to determine matrix M are fixed and no changes can be made to that. Therefore, to adjust the supply, one has to adjust either

1. The master schedule planning rules for matrix C

2. The number of available staff members.

Clearly the first adjustment is a cheaper and therefore a more preferable adjustment. However, there might be cases in which these adjustments are not sufficient and extra staff members need to be added to the currently available staff to be able to cope with the demand. At the end of this chapter the four different supply scenarios will all contain a set of master schedule adjustments, which can be used to change that master schedule, such that the resulting expected yearly staff supply is sufficient to cope with the expected yearly patient demand of the associated demand scenario.

To determine which changes should be made to the master schedule without loosing the overview, the categories will be added to the master schedule in the following six different steps.

1. Inpatient Care Clinic, Absent, Inpatient Care Visitor, and External Outpatient Clinic

2. Colonoscopy for BCS, ERCP, and EUS

3. Intake for BCS, and Intake

4. Supervision, and Colonoscopy, and Gastroscopy/Sigmoidoscpy for the extra endoscopic staff members

5. Colonoscopy, Gastroscopy/Sigmoidoscopy and Outpatient Clinic for physicians.

These sets of categories are based on their similarities in scheduling rules. The set order is due to the category importance, such that categories of higher importance are scheduled first and therefore are not influenced by the categories of lower importance. In this chapter each of these scheduling steps will be discussed separately. First the categories will be added to the simulated master schedule. The simulation output will be compared to the desired scheduling rules of the categories under consideration. Next the supply resulting from the categories under consideration will be compared to the patient demand of each of the four demand scenarios. Next if necessary, adjustments to the master schedule will be made, such that the supply is sufficient to cope with the demand.

6.2 Inpatient Care Clinic Categories, Absence, and External Outpatient Clinic

The first set of categories contains Inpatient Care Clinic, Absent, Inpatient Care Visitor, and External Outpatient Clinic. As was stated in section 2.2 the Inpatient Care Clinic category is assigned to exactly one physician per daypart. It is planned in shifts of two weeks after which the next physician takes over. During the Inpatient Care Clinic shifts the physician is not allowed to take days off. Therefore, this category is scheduled before the Absent category.

Secondly the Absent category is scheduled. Again remember from section 2.2 that there are three different types of absence, namely

1. Fixed absence per week

2. Vacation days

3. Extra days off due to ICC shifts

The first type of absence is scheduled in the master schedule according to a fixed weekly schedule known for each staff member, and the other two types of absence are scheduled randomly by picking a random week and completely filling it with Absent days for the given staff member until all allowed absence days are gone.

The thing these two categories have in common is the fact that during these dayparts staff members are not available for appointments. The only thing they do is reduce the number of available minutes for appointments per year.

The third and fourth category, Inpatient Care Visitor and External Outpatient Clinic have two things in common. They each occur on fixed dayparts during the week, and they both reduce the associated values in the matrix M. Their big difference is that the Inpatient Care Visitor category can be scheduled with any physician, while for the External Outpatient Clinic category specific physicians are appointed.

Now to check whether the simulated master schedule obeys the scheduling rules concerning the preferred number of dayparts per week, Figure 6.1 shows the average number of dayparts per week spend on the four mentioned categories relative to the desired number of dayparts. For example, it is desired that the Inpatient Care category occurs during every daypart, and therefore occurs 10 dayparts per week. The simulation output shows that this also happens almost all the time. The average per week is calculated over all 1040 weeks in the simulation by counting the number of dayparts spend on the given category.

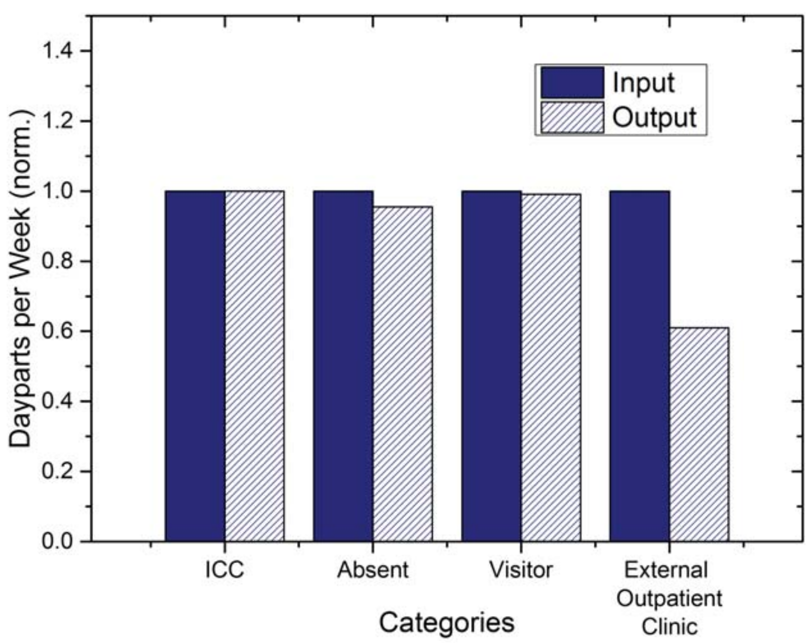


Figure 6.1: Average simulated number of dayparts per week spend on categories ICC, Absent, Visitor, and External Outpatient Clinic per category relative to the desired simulation input.

For the external outpatient clinic category this value is less satisfying. It can be seen that the external outpatient clinic consultations are only scheduled approximately half of the time. This is a result which is also observed in reality. A possible explanation of this low scheduling rate can be that for these external outpatient clinic only one physician and only one daypart per week is allowed. There is a reasonable probability that this physician is, for example, on vacation on this specific daypart, or he might be scheduled for his ICC shift. If this is the case then the external outpatient clinic is simply cancelled, resulting in an unplanned external outpatient clinic during that specific week. The probability of an unplanned daypart due to physicians absence increases if the number of allowed physicians, and/or the number of allowed dayparts per week decreases.

6.2.1 Available Minutes per Year

As was stated in the previous section, all four categories up until now, negatively influence the values in matrix M. Remember that each appointment has its own duration. Therefore, the expected number of necessary minutes per year can be determined from the expected yearly demand for all four demand scenarios.

To be able to cope with this demand the first requirement is that enough minutes are available in M per year. Figure 6.2 shows the expected demand in minutes for each of the four scenarios, and the expected supply in minutes given the fixed weekly values of the matrix M, and the expected influence of the previous four categories on this matrix.

It can be seen that even without categorizing the dayparts, so putting restrictions on the supply, there are not enough minutes available to cover the demand in any of the four scenarios. The only way to add extra minutes to the master schedule, is by adding extra staff members. Therefore, Figure 6.3 shows the simulated supply in minutes, with 1 up to 6 extra physicians.

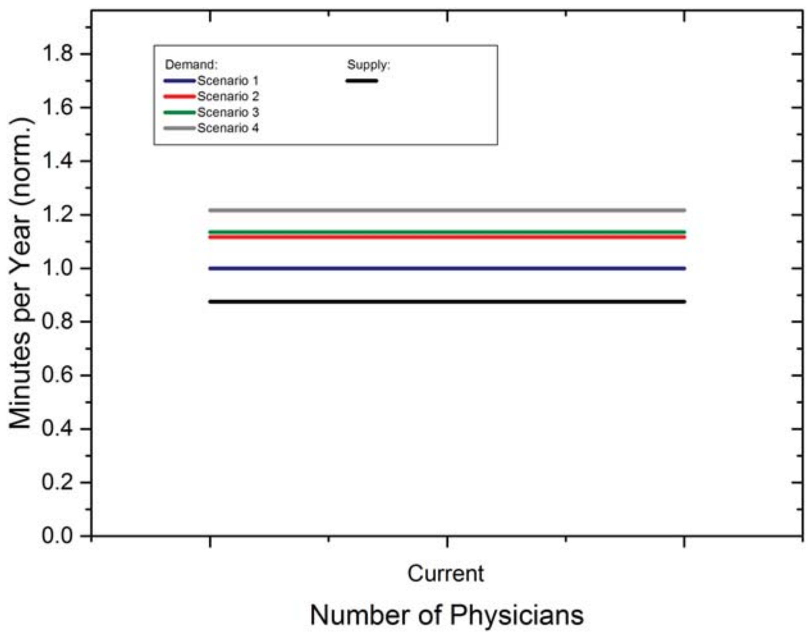


FIGURE 6.2: Simulated master schedule supply compared to modelled demand in minutes (rel. to demand scenario 1).

From this figure the following can be concluded.

Master Schedule Adjustments

- At least 1 extra physician is needed to be able to cope with the regular demand in scenario 1.
- At least 2 extra physicians are needed to be able to cope with the regular demand in scenario 2.
- At least 3 extra physicians are needed to be able to cope with the regular demand in scenarios 3 and 4.

Throughout the rest of this chapter all suggested master schedule adjustments will be represented as 'Master Schedule Adjustments', similar to the master schedule adjustment above. These adjustments will immediately be implemented to the simulation for the remainder of the chapter, and will be added to the associated supply scenario. So for example, from now on all simulations done for demand scenario 1, will contain the current number of physicians + 1 extra physician. This extra physician is an average

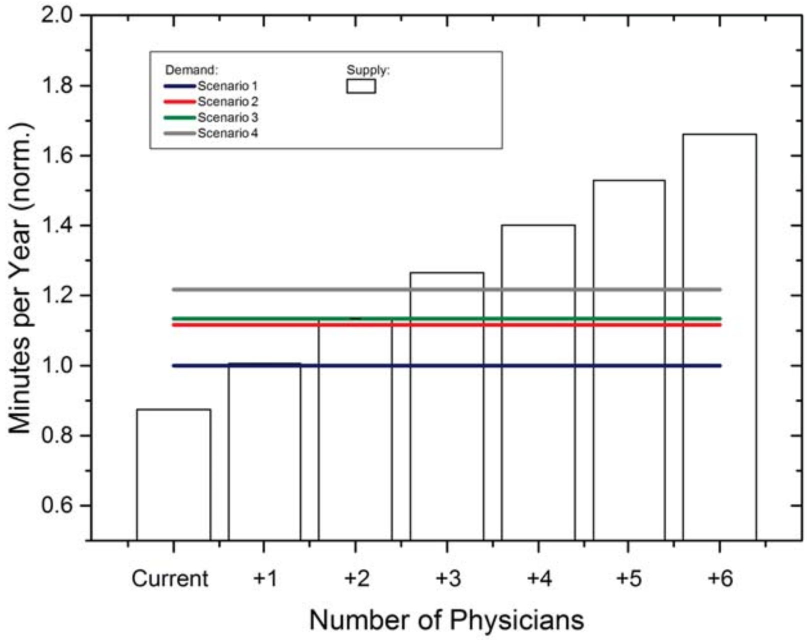


FIGURE 6.3: Simulated master schedule supply with increased number of available physicians compared to the modelled demand in minutes (rel. to demand scenario 1).

physician as it comes to available dayparts per week and vacation days, and he will not have extra special qualifications.

6.2.2 Available Appointment Slots per Year

As was stated before, it is not interesting to only look at the expected number of minutes per year, but the interesting value is the expected number of appointment slots per year per appointment APP_j. During dayparts categorized by Inpatient Care Clinic and Absent, no appointments can be scheduled. During the Inpatient Care Visitor and External Outpatient Clinic dayparts the category specific appointments are NP, HP, and BE. Figure 6.4 shows the expected number of NP, HP, and BE appointments that can already be planned during these categories relative to the demand in each scenario. In this figure and upcoming similar figures the small bars show the 95% confidence interval for the represented sample mean [15, p. 250]. Due to the fact that these confidence intervals are relatively small, they might not be visible properly in the figures.

This figure shows that expectedly almost 50% of the yearly NP demand can be scheduled during the Visitor and External Outpatient Clinic categorized dayparts. No changes can be made to the master schedule to increase the number of available appointment slots

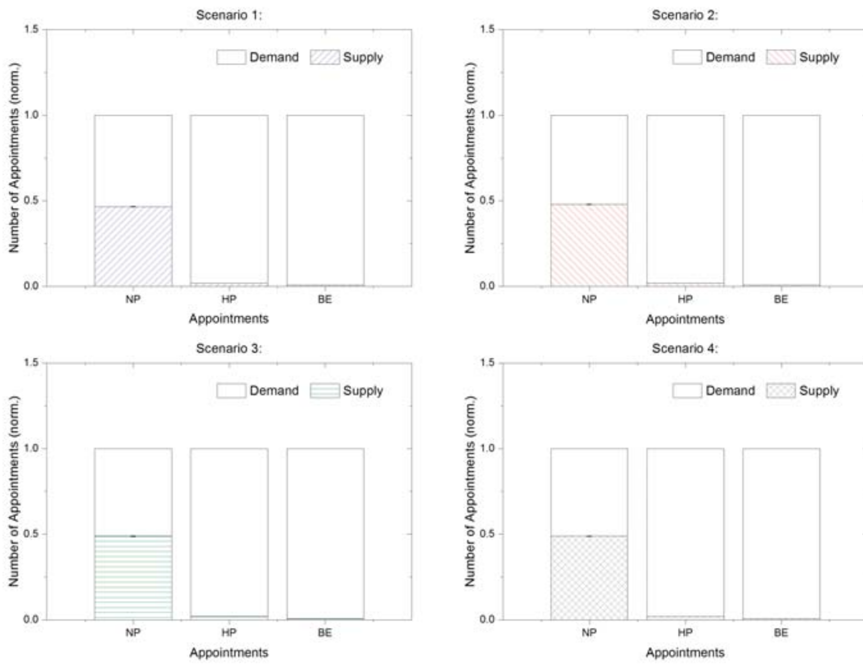


Figure 6.4: Percentage of planned appointments in Visitor and External Outpatient Clinic categories per scenario relative to the modelled demand.

in dayparts categorized by these four categories. So the rest of the demand should be scheduled during dayparts categorized by one of the other categories.

6.3 Colonoscopy for BCS, ERCP, and EUS

The next three categories that will be added to the master schedule are Colonoscopy for BCS, ERCP and EUS. What they have in common is that these three categories can only be scheduled with physicians that are qualified to perform the associated endoscopies resp. CO BCS for Colonoscopy for BCS, ERCP, SD and GD for ERCP, and EUS and EUS/GA for EUS.

Furthermore, the categories ERCP and EUS need extra facilities besides endoscopy rooms. These facilities are available to the GHD on predetermined dayparts each week. Therefore, these categories can only be scheduled during these dayparts. Also, they are desired to be scheduled on each of these dayparts.

The Colonoscopy for BCS category can be scheduled during any daypart. There only exists a desired number of dayparts per week spend on Colonoscopy for BCS.

Figure 6.5 shows the simulated number of dayparts per week, relative to the desired number of dayparts per week.

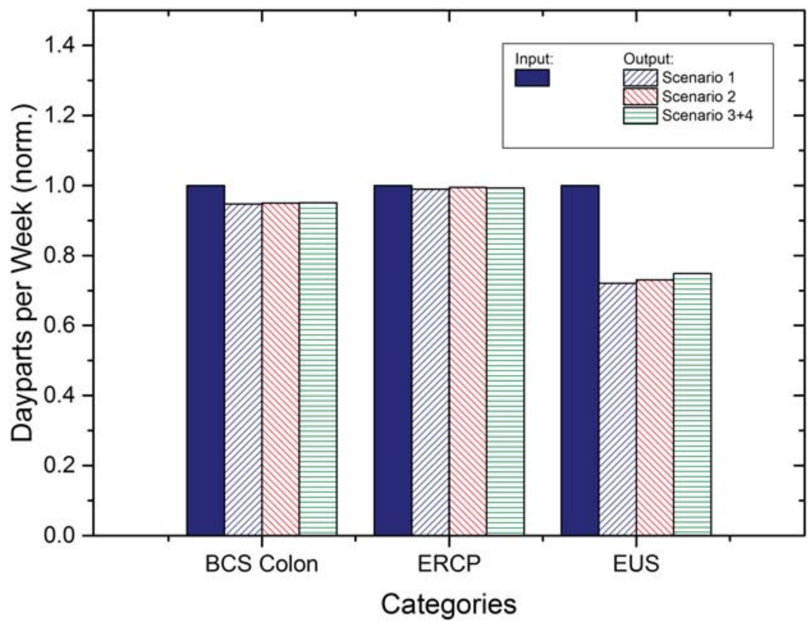


FIGURE 6.5: Average simulated number of dayparts per week spend on categories Colonoscopy for BCS, ERCP, and EUS per category relative to the desired simulation input.

Especially the EUS dayparts are not all planned as desired. As with the External Outpatient Clinic dayparts this is due to the fact that only a few physicians are qualified to perform EUS endoscopies. Therefore, the probability of absence of all allowed physicians during an allowed daypart increases.

The problem of unplanned dayparts is less significant for the Colonoscopy for BCS, and ERCP dayparts, while there are more qualified physicians, and/or more allowed dayparts per week.

It is interesting to see that slightly more EUS dayparts are scheduled if the number of available physicians increases (+1 in scenario 1, +2 in scenario 2, and +3 in scenario 3 and 4). This corresponds to the expectation, while for example the ICC shift responsibility is divided over more physicians. This ICC shift is one of the reasons why the physicians qualified for EUS might be unavailable for EUS during the allowed dayparts, which results in unscheduled dayparts. Therefore, this increase in physicians will cause a decrease in the probability of all EUS qualified physicians being absent during a daypart allowed for EUS. This will subsequently result in an increase in the number of scheduled EUS dayparts per week.

The category specific appointments for the three categories under consideration can only be planned during the daypart categories under consideration. Therefore, it is important that the appointment slot supply during these dayparts for these specific appointments is sufficient for the demand. For each of the four scenarios, the simulated results can be found in Figure 6.6.

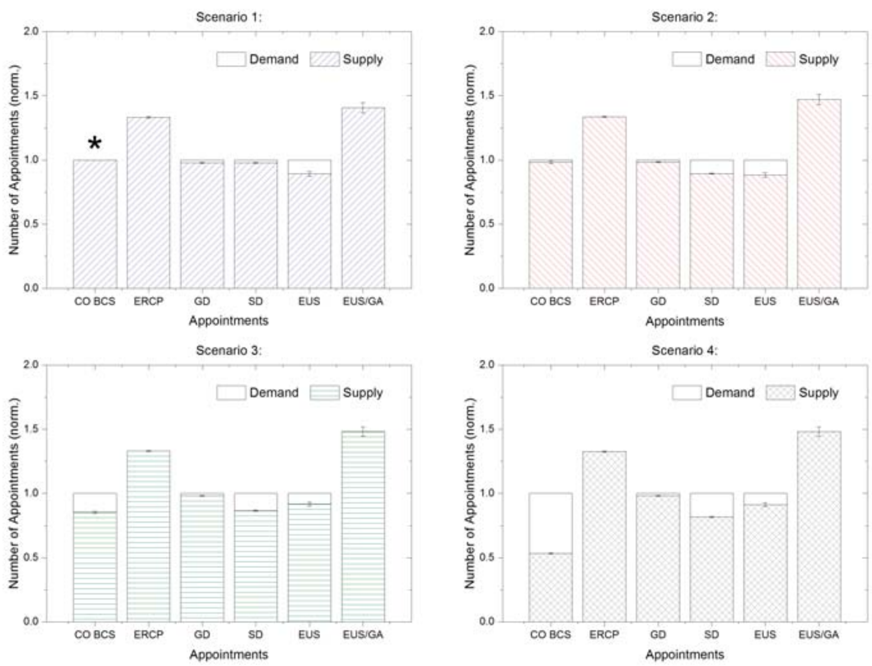


Figure 6.6: Average number of available appointment slots per year for the category specific appointments relative to demand per scenario. (*: CO BCS demand in scenario 1 is 0, and supply is > 0, causing the relative supply to be infinite.)

It is important to note that in demand scenario 1 the demand for CO BCS appointments is 0. However, the supply in appointment slots is larger then 0, while the Colonoscopy for BCS appointments are scheduled according the desired number of dayparts per week. Therefore it can be concluded that for scenario 1, 0 dayparts per week should be spend on Colonoscopy for BCS.

In all four scenarios not enough time seems to be available for GD, SD and EUS appointments. However, there are too many appointment slots reserved for ERCP, and EUS/GA. The excess ERCP appointment slots can be used to create GD and SD appointment slots, see step 2 of the staff supply determination in section 6.1. With the same reasoning, excess EUS/GA appointment slots can be used for EUS appointment slots. This results in enough appointment slots available for each of these appointments.

There only exists a shortage in CO BCS appointment slots for scenarios 2,3, and 4. There are two methods to increase the number of available time slots for CO BCS.

1. Increase the number of qualified physicians for the Colonoscopy for BCS category. This way the probability of scheduling all desired dayparts per week increases.
2. Increase the desired number of dayparts per week.

It is expected that the first method will not result in a large improvement, while Figure 6.5 shows that already, on average, almost all of the desired Colonoscopy for BCS dayparts per week are scheduled. Therefore, the only options seems to be adding extra dayparts per week for Colonoscopy for BCS. Doing this results in Figure 6.7.

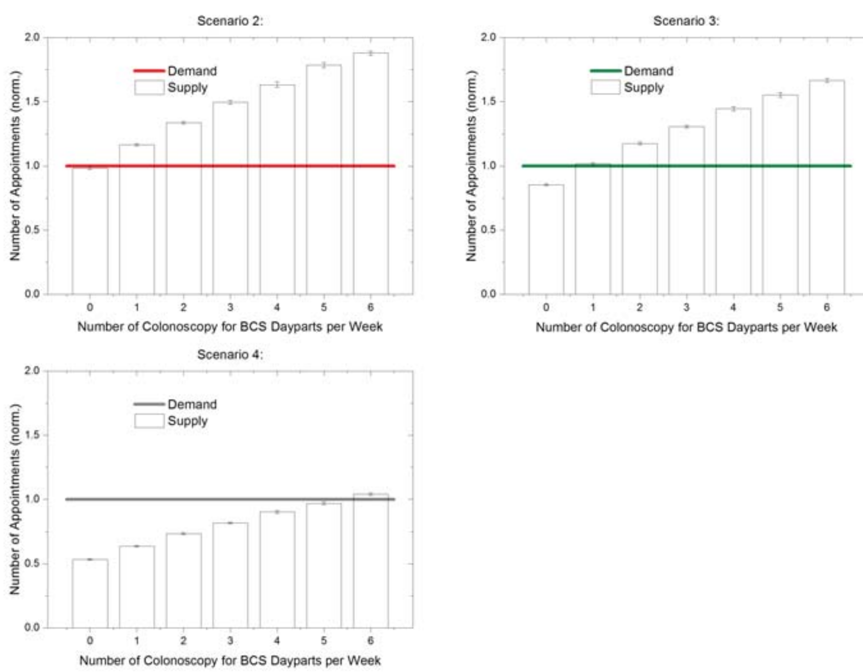


FIGURE 6.7: Number of available appointment slots for CO BCS appointments relative to the demand with increased desired number of Colonoscopy for BCS dayparts per week.

This results in the following advised master schedule adjustments.

Master Schedule Adjustments

- 0 Dayparts per week should be spend on Colonoscopy for BCS to be able to cope with the CO BCS demand in scenario 1.
- 1 extra daypart per week should be spend on Colonoscopy for BCS to be able to cope with the CO BCS demand in scenario 2.
- 2 extra dayparts per week should be spend on Colonoscopy for BCS to be able to cope with the CO BCS demand in scenario 3.
- 6 extra dayparts per week should be spend on Colonoscopy for BCS to be able to cope with the CO BCS demand in scenario 4.

These master schedule adjustments can directly be implemented in the master schedule simulation, and for each appointment APP_j the expected values S_{APP_j} can be determined for the seven already covered daypart categories. Next step 2 of the staff supply determination process can be applied to these results, such that, for example, CO BCS appointment slots can be changed into BE appointment slots. The expected percentage of the demand that can already be planned in the daypart categories covered up until now is shown in Figure 6.8.

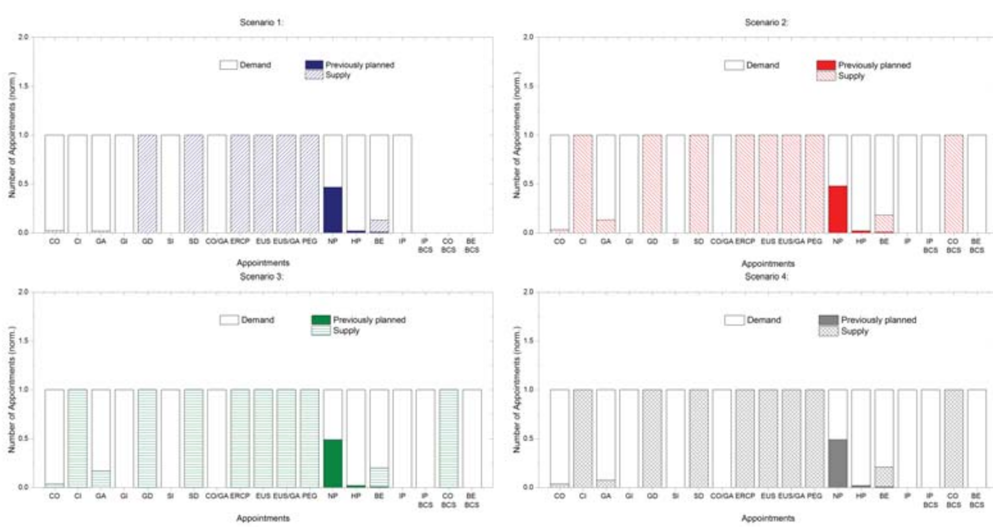


Figure 6.8: Percentage of planned appointments in discussed categories per BCS demand scenario relative to the modelled scenario demand.

The percentages labeled by 'previously planned', are the percentages planned in the categories discussed in the previous sections. In this case these are the categories Visitor, and External Outpatient Clinic. The 'supply' category, represents the supply of the currently discussed categories Colonoscopy for BCS, ERCP, and EUS.

6.4 Intake Categories

In this section the categories Intake for BCS and Intake will be added to the master schedule. Both categories can only be scheduled during predetermined dayparts of the week. Figure 6.9 shows the expected number of dayparts per week spend on Intake for BCS and Intake relative to the desired number of dayparts per week.

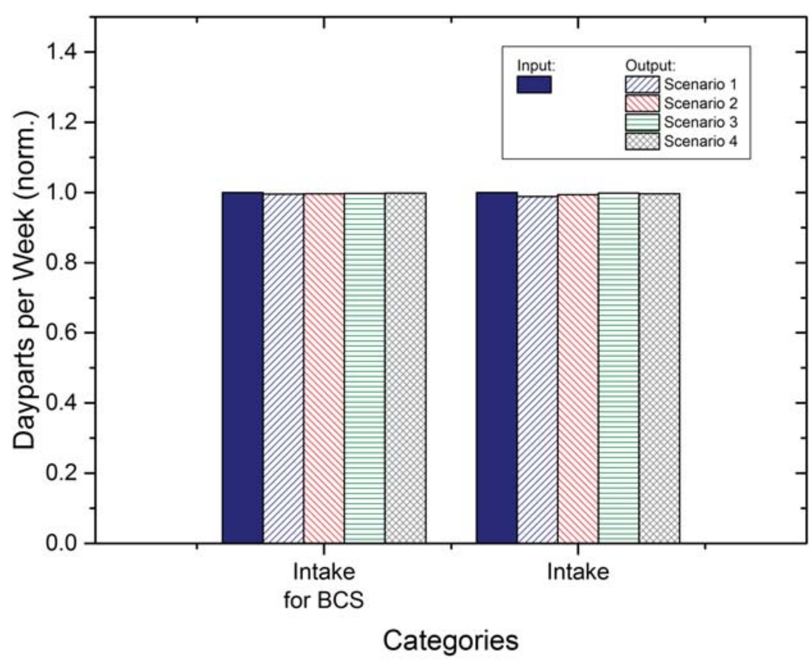


Figure 6.9: Number of dayparts per week per category relative to desired simulation input.

These daypart categories are specially designed for the appointments IP BCS and IP. As with the CO BCS, ERCP, SD, GD, EUS and EUS/GA appointments in the previous section, these appointment can only be scheduled during the Intake for BCS and Intake dayparts.

Another important thing to mention is that the appointments IP BCS and IP are performed by a physician together with a qualified nurse. The nurse will perform the complete appointment, while the physician comes in during part of the appointment to perform specific check-ups and answer questions.

Let each IP or IP BCS appointment take x minutes for the nurse, and $y < x$ minutes for the physician. So during a daypart containing z minutes $a = \lfloor \frac{z}{x} \rfloor$ IP or IP BCS appointments can be planned. However, a physician only needs y minutes per daypart, resulting in $z - a \cdot y$ unused minutes for the physician. This time can be filled with HP, or BE appointments.

Figure 6.10 shows, for each of the four demand and corresponding supply scenarios, the resulting supply in appointment slots for the four category specific appointments relative to the demand. Again the 'previously planned' label depicts the percentage of the demand that has already found a appointment slot in dayparts categorized by daypart categories discussed in previous sections.

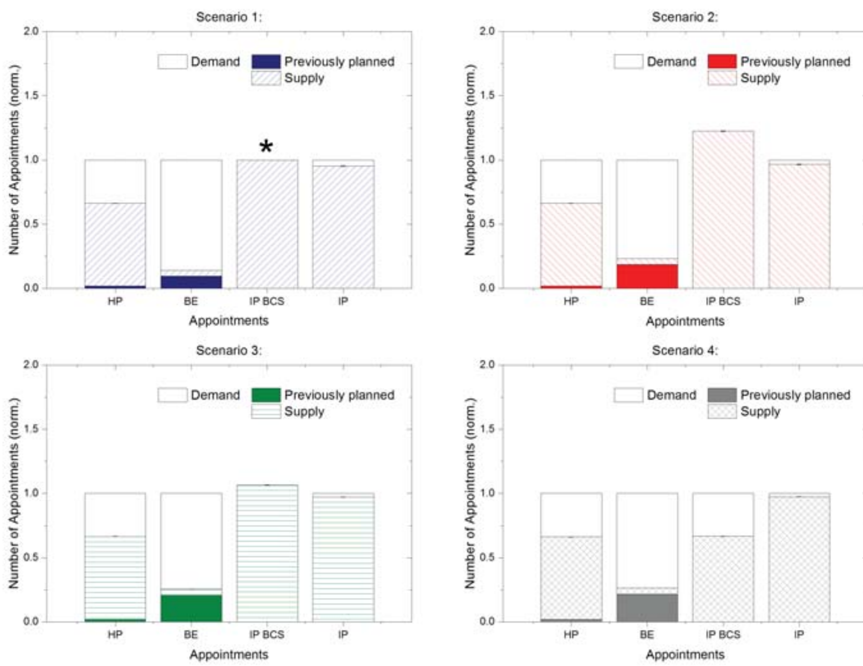


FIGURE 6.10: Average number of available appointment slots per year for the category specific appointments relative to demand per scenario. (*: IP BCS demand in scenario 1 is 0, and supply is > 0, causing the relative supply to be infinite.)

As with the CO BCS demand in the previous section, the demand for IP BCS in scenario 1 is 0 while the current supply is positive. Therefore it can be concluded that for scenario 1, 0 dayparts per week should be spend on Intake for BCS.

In scenario 2 and 3 too many appointment slots are reserved for IP BCS, while in scenario 4 there exists a shortage.

First we investigate what happens if the number of desired dayparts per week spend on Intake for BCS is decreased in scenarios 2 and 3. This results in Figure 6.11

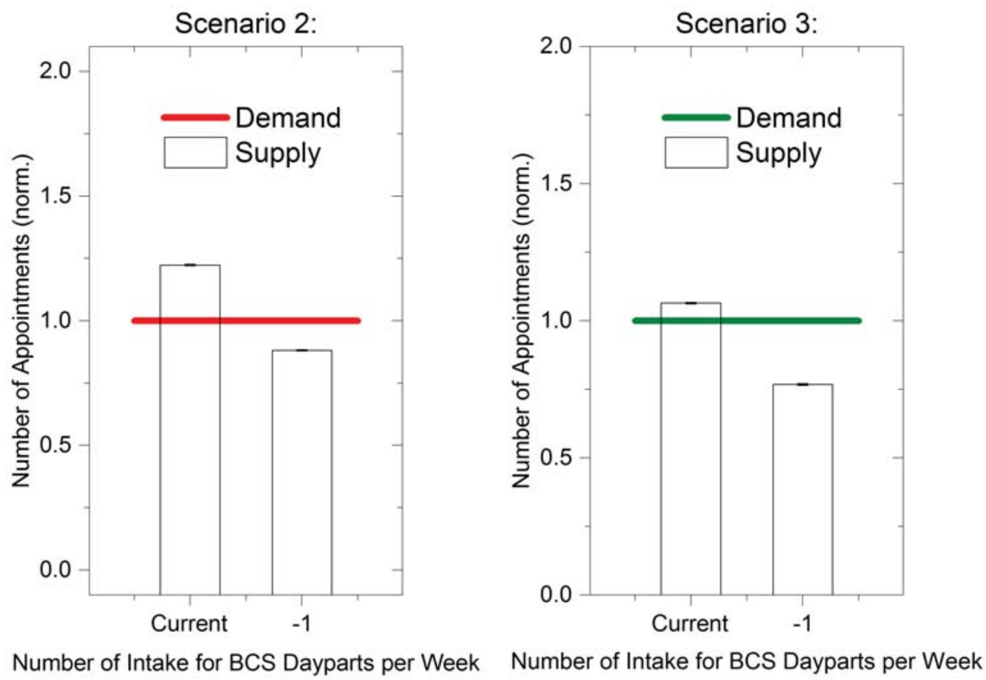


FIGURE 6.11: Number of available appointment slots for IP BCS appointments relative to the demand with decreased desired number of Intake for BCS dayparts per week.

Decreasing the desired number of dayparts per week results in expectation in an appointment slot shortage. However, especially the difference between supply and demand in scenario 2 is very small. Therefore, another option is introduced. Currently the desired number of dayparts per week spend on Intake for BCS is fixed for every week. However, what happens if this desired number of dayparts per week differs between odd and even weeks? Figure 6.12 shows what happens if one decreases the desired number of dayparts per week only in the even weeks.

In scenario 3 this change is still insufficient for the demand. However, in scenario 2, this new biweekly scenario is sufficient for the demand. Therefore, the following master schedule adjustments can be introduced.

Master Schedule Adjustments

- 0 Dayparts per week should be spend on Intake for BCS to be able to cope with the IP BCS demand in scenario 1.
- 1 less daypart per week should be spend on Intake for BCS during the even weeks to be able to cope with the IP BCS demand in scenario 2.

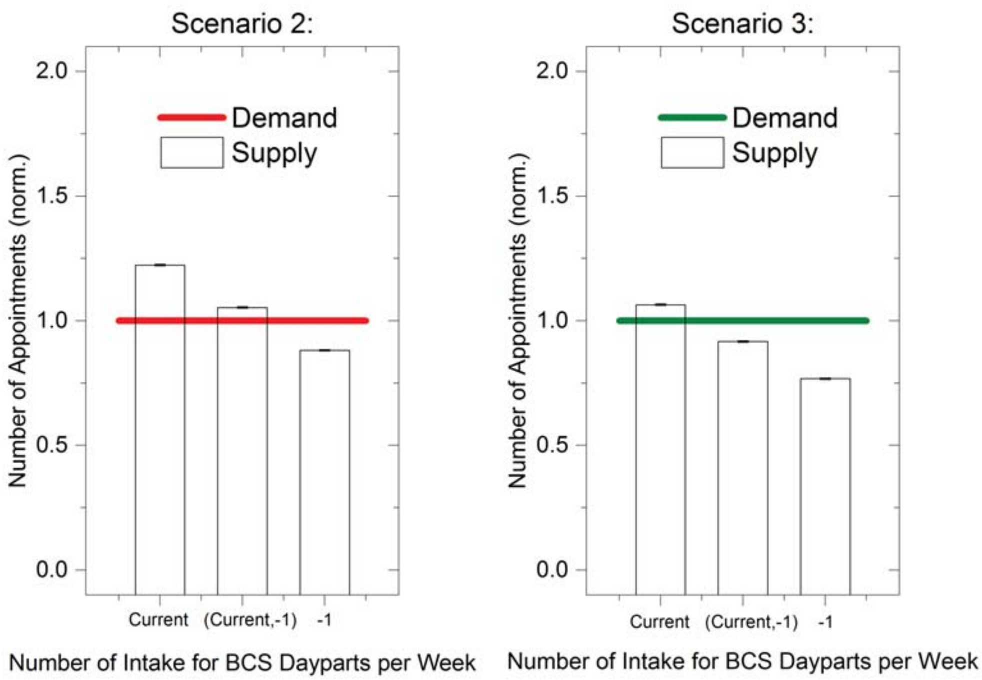


FIGURE 6.12: Number of available appointment slots for IP BCS appointments relative to the demand with decreased desired number of Intake for BCS dayparts in the even weeks, and in all weeks.

To meet the IP BCS demand in scenario 4 there again exist two options to increase the IP BCS appointment slot supply.

1. Increase the number of qualified physicians for the Intake for BCS category.
2. Increase the desired number of dayparts per week.

All physicians are already qualified for the Intake for BCS category. Therefore, only option 2 can be applied to increase the IP BCS appointment slot supply. This results in Figure 6.13.

This shows that at least 3 extra dayparts per week are needed to meet the demand. All this results in the following master schedule adjustments.

Master Schedule Adjustments

- 3 extra dayparts per week should be spend on Intake for BCS to be able to cope with the IP BCS demand in scenario 4.

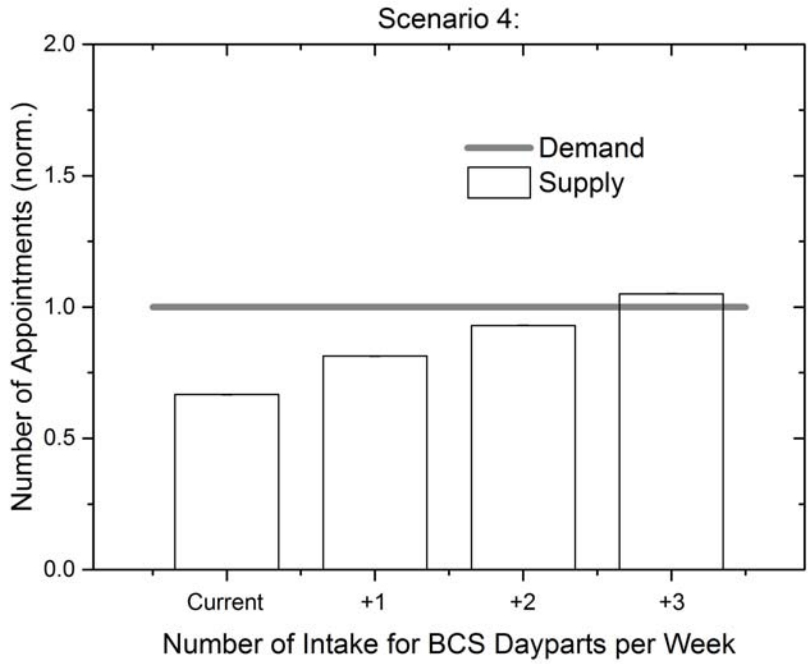


Figure 6.13: Number of available appointment slots for IP BCS appointments relative to the demand with increased desired number of Intake for BCS dayparts per week.

Figure 6.10 also shows a slight shortage in IP appointment slots per year. Again already all physicians are qualified for the Intake category. Therefore, the only option is to increase the desired number of Intake dayparts per week. While the difference between supply and demand is very small in percentage, only the desired number of Intake dayparts per week is increased in the odd weeks. This results in enough appointment slot supply for the IP appointments, see Figure 6.14.

Therefore, the following master schedule adjustments can be approved.

Master Schedule Adjustments

- 1 extra daypart per week should be spend on Intake during the odd weeks to be able to cope with the IP demand in scenarios 1, 2, 3, and 4.

Finally, Figure 6.15 shows the expected percentage of the demand that can be scheduled in the dayparts categorized by the categories covered until now, and all excess appointment slots and unused time is used for the non-category specific appointments.

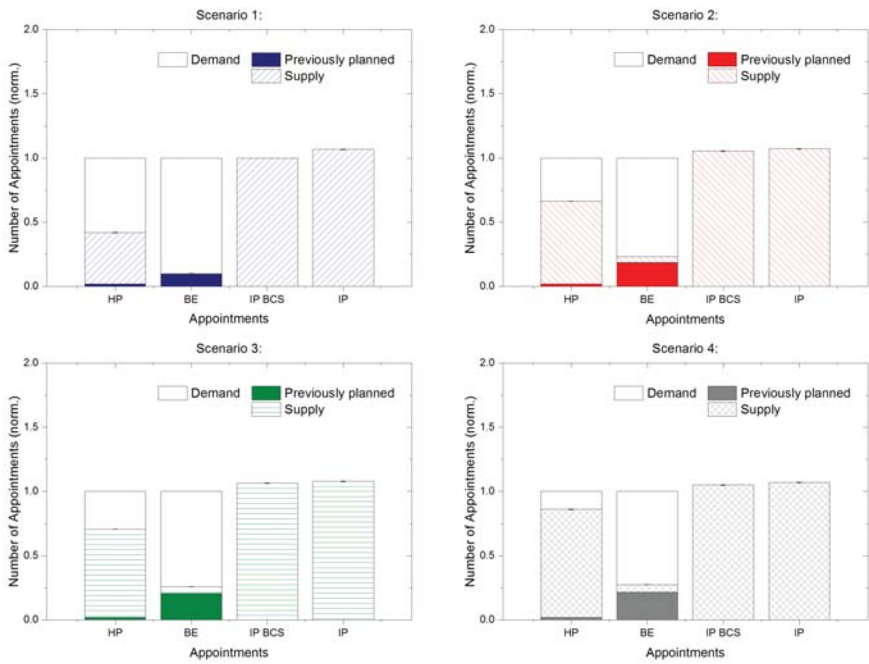


FIGURE 6.14: Average number of available appointment slots per year for the category specific appointments relative to demand with increased desired number of Intake dayparts in the odd weeks.

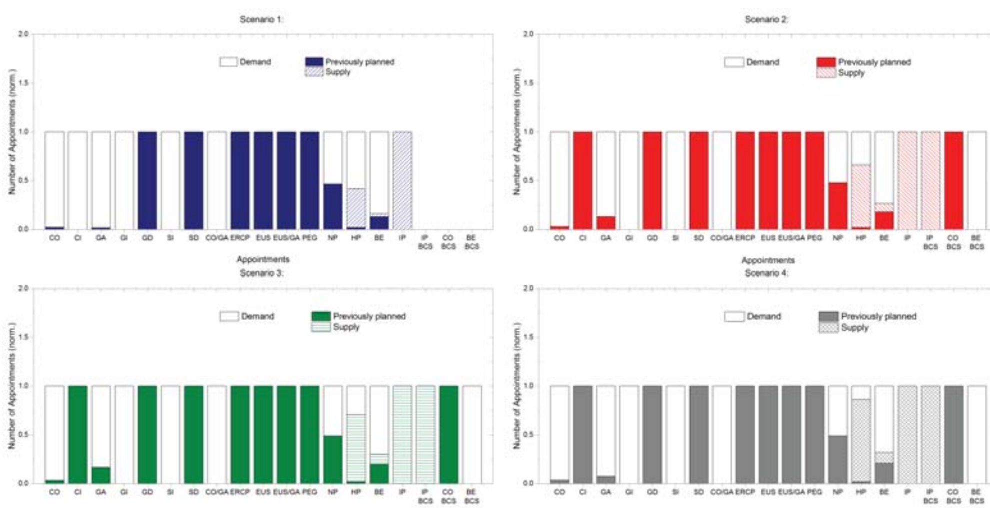


FIGURE 6.15: Percentage of planned appointments in discussed categories per BCS demand scenario relative to the modelled scenario demand.

6.5 Colonoscopy and Gastroscopy/Sigmoidoscopy for Extra Staff Members, and Supervision

The categories Colonoscopy and Gastroscopy/Sigmoidoscopy are both available for physicians and extra staff members. Their scheduling however differs between these two staff types. Therefore, they are introduced separately for both staff types. This section contains the two categories for the extra staff members. Each extra staff member is either allowed to perform regular colonoscopies (CO) or regular gastroscopies and regular sigmoidoscopies (GA or SI). This is the only task available for extra staff members and therefore all dayparts during which they are not absent are categorized either by Colonoscopy or Gastroscopy/Sigmoidoscopy.

The current group of extra staff members also needs supervision from one physician. For the simulation it has been assumed that one daypart per week belonging to any of the available physicians is reserved for supervision. During this supervision daypart the physician is not available for treating patients. As with the other categories, Figure 6.16 shows the simulated average number of dayparts per week spend on the three categories under consideration, relative to their desired simulation input.

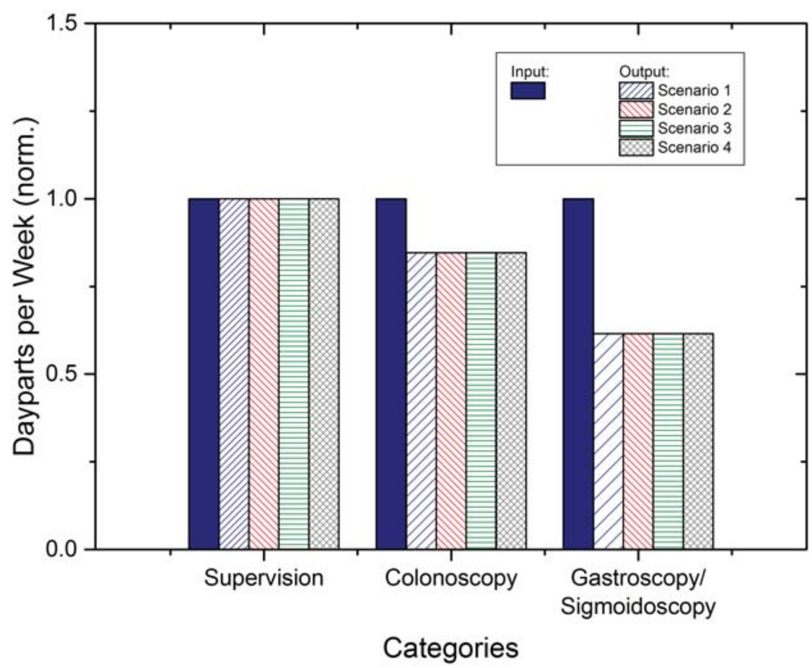


Figure 6.16: Number of dayparts per week per category relative to desired simulation input.

Especially the Gastroscopy/Sigmoidoscopy dayparts are not scheduled as desired. This is due to the fact that extra staff members are also entitled to vacation days, which influences the extra staff members availability for Colonoscopy or Gastroscopy/Sigmoidoscopy.

The number of available appointment slots for appointments CO, GA, and SI per year in the extra staff member dayparts can be determined. This results in Figure 6.17. When determining these values, it is important to take into account that a colonoscopy performed by an extra staff member takes more time than the same appointment performed by a physician, see page 3.

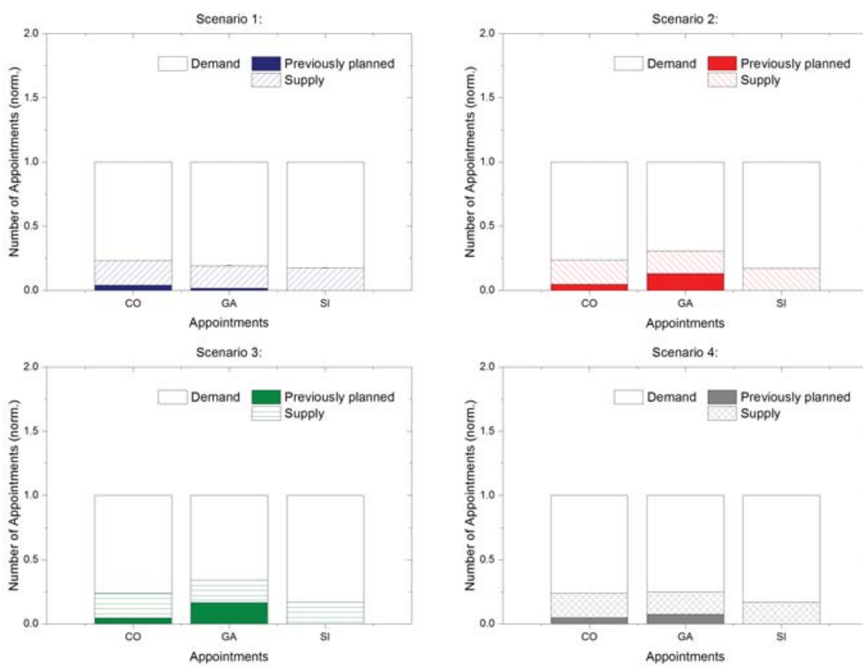


FIGURE 6.17: Average number of available appointment slots per year for the category specific appointments relative to demand per scenario.

The extra staff members only contribute a small amount to the supply needed for the CO, GA, and SI appointment demand.

Due to the introduction of the supervision dayparts, less time is available for appointment performance in the master schedule. To determine how this affects the capacity, again an analysis of the available minutes in the master schedule will be performed comparable to the analysis in section 6.2.2.

At the moment there exist three types of appointments.

1. Appointments for which an appointment slot is available in a physicians master schedule.

2. Appointments for which an appointment slot is available in an extra staff members master schedule.

3. Appointments for which no appointment slot is available in the master schedule yet.

The first and last type of appointments will have regular duration, and the second type of appointments have extended duration if they are colonoscopies. The sum of these extended durations will determine a new estimate for the demand in minutes. This value can be determined for each of the four scenarios.

For each of the four supply scenarios one can compare this demand with the number of minutes available in the master schedule under the currently used supply scenario scheduling rules. Figure 6.18 shows the result of this comparison together with the influence of adding one or two extra physicians to the supply scenario.

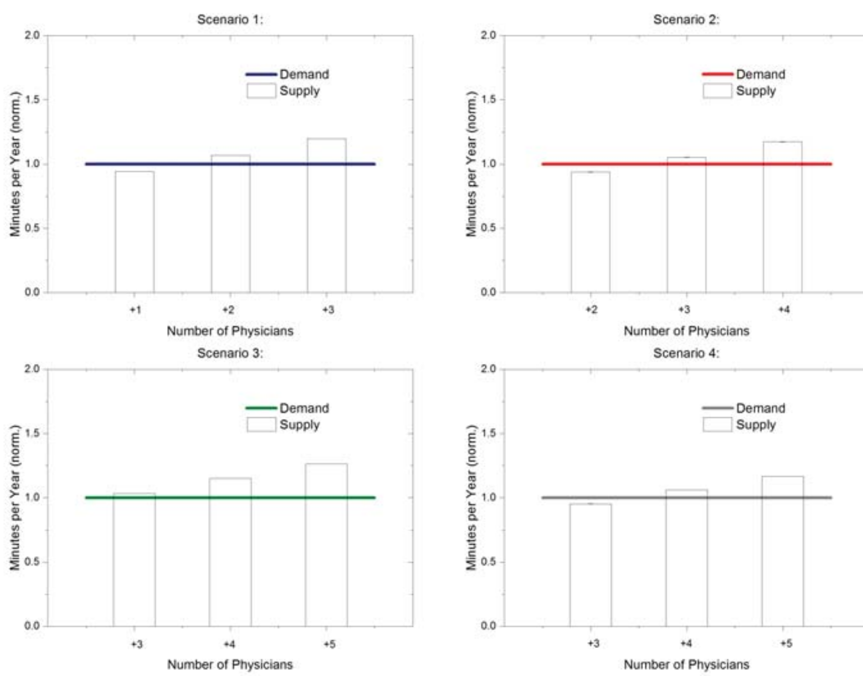


FIGURE 6.18: Simulated master schedule supply with increased number of available physicians compared to the modelled demand in minutes (rel. to demand scenario 1).

It can be seen that in all but the third scenario, an extra staff member is needed additional to the already added staff members, to be able to cope with the demand in minutes. This results in the following master schedule adjustments.

Master Schedule Adjustments

- Additional to the current number of available physicians, at least 2 extra physicians are needed to be able to cope with the regular demand in scenario 1.
- Additional to the current number of available physicians, at least 3 extra physicians are needed to be able to cope with the regular demand in scenarios 2 and 3.
- Additional to the current number of available physicians, at least 4 extra physicians are needed to be able to cope with the regular demand in scenario 4.

6.6 Colonoscopy, Gastroscopy/Sigmoidoscopy and Outpatient Clinic

The last categories that need introduction are Colonoscopy, Gastroscopy/Sigmoidoscopy and Outpatient Clinic for physicians. These categories are used to fill up all so far uncategorized dayparts in the master schedule.

It is attempted to divide the three categories over these not yet categorized dayparts according to a predetermined ratio. Let this ratio be $(r_{CO}, r_{GA/SI}, r_{OC})$, where r_{OC} is the probability of an empty daypart being categorized by category Outpatient Clinic etc. The currently used ratio is

$$(r_{CO}, r_{GA/SI}, r_{OC}) = (0.333, 0.167, 0.5). \tag{6.1}$$

Another desired quality of the master schedule is that during each daypart at least one physician is available at the endoscopy unit. This means that during each daypart at least one physician has to have his daypart categorized by category:

1. Colonoscopy for BCS
2. EUS
3. ERCP

If this is not the case, at least one physician needs to have a daypart categorized by category Colonoscopy or Gastroscopy/Sigmoidoscopy.

Finally, it is attempted to balance the number of dayparts spend on endoscopies in the morning and afternoon for all days in the master schedule. This while during each endoscopy nurses need to be available to assist. It is attempted to schedule the nurse staff schedule in days instead of dayparts.

All these rules are included in the simulation and this results in a simulated master schedule with the ratios between Colonoscopy, Gastroscopy/Sigmoidoscopy and Outpatient Clinic dayparts per year found in Figure 6.19.

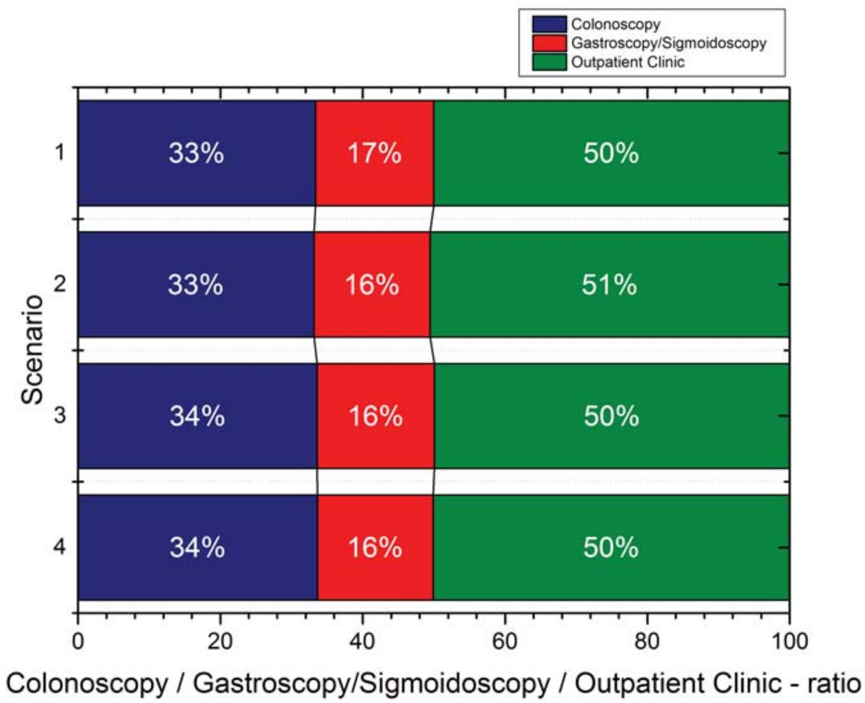


Figure 6.19: Colonoscopy, Gastroscopy/Sigmoidoscopy and Outpatient Clinic Ratio, given the input ratio is $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.333, 0.167, 0.5)$

Figure 6.20 shows the relative number of appointment slots that can be created in the dayparts categorized by these three categories.

As can be seen not enough appointment slots can be created to perform all SI appointments in all four scenarios. Also, a relatively large number of excess BE appointment slots can be created. SI are appointments that need to be scheduled in dayparts categorized by Gastroscopy/Sigmoidoscopy, and BE in dayparts of category Outpatient Clinic. Therefore, $r_{GA/SI}$ is increased, and r_{OC} is decreased. We have decided to take ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.333, 0.217, 0.45)$. This results in Figure 6.21, where it can be seen that with this ratio the master schedule supply will meet the demand.

However, it can be seen that the demand for the appointments related to category Colonoscopy is barely met. To try to make the relative excess of appointment slots

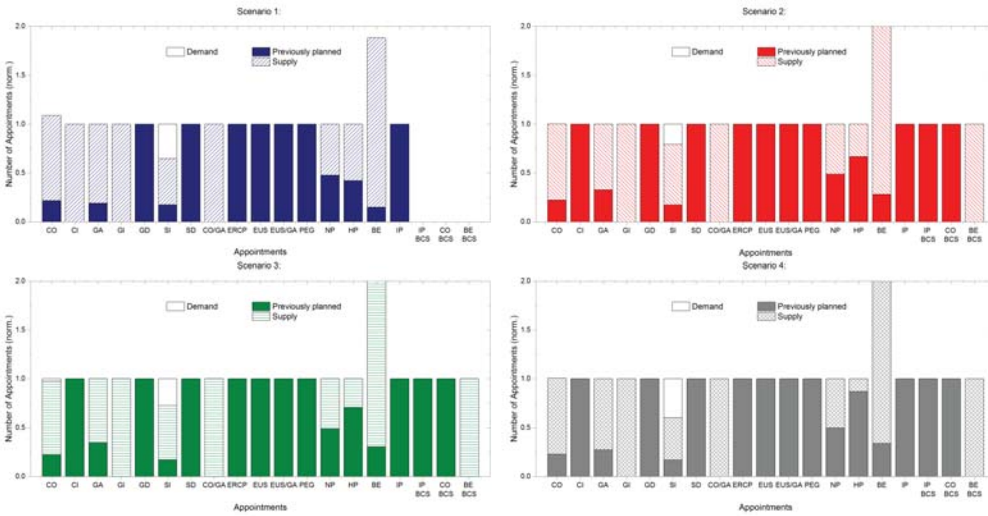


FIGURE 6.20: Percentage of planned appointments in discussed categories per BCS demand scenario relative to the modelled scenario demand with ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.333, 0.167, 0.5)$.

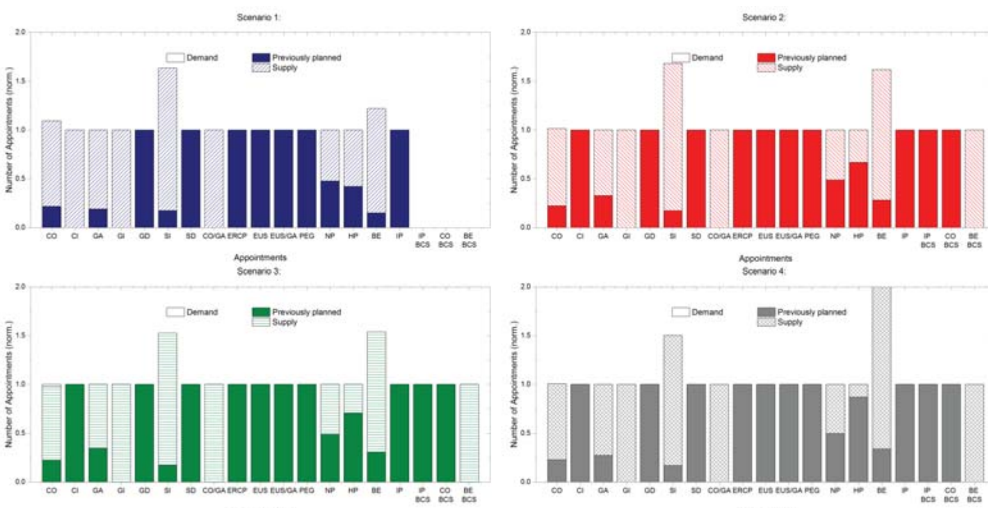


FIGURE 6.21: Percentage of planned appointments in discussed categories per BCS demand scenario relative to the modelled scenario demand with ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.333, 0.217, 0.45)$.

created for appointment CO comparable to the relative excess of appointment slots for SI, a slight increase in Colonoscopy dayparts is initialized by using the new ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.36, 0.19, 0.45)$. This results in Figure 6.22. Again the supply meets the demand in all four scenarios.

It is important to note that a small change in this ratio, results in barely meeting or not meeting the demand. So the master schedule is very tight in all four scenarios, meaning that if there is a slight difference in demand, the master schedule supply might not be sufficient.

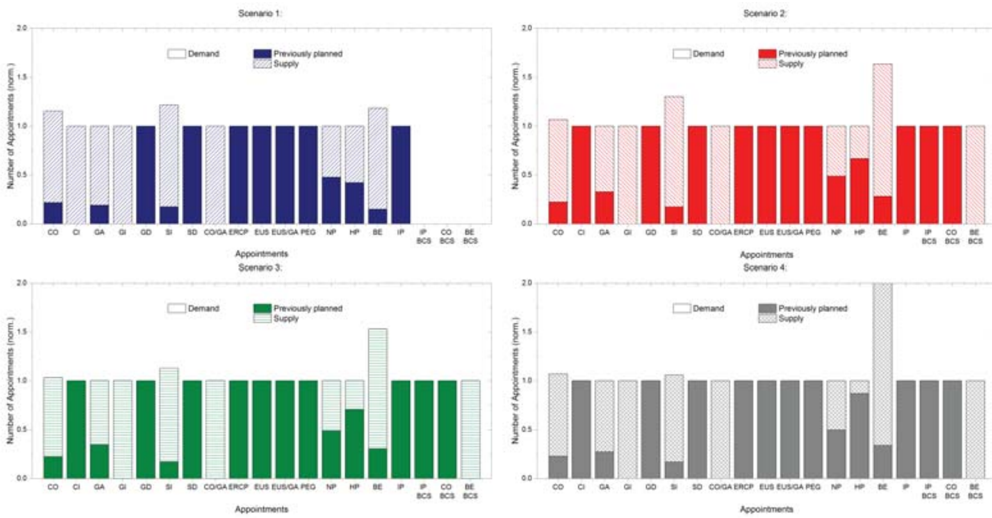


FIGURE 6.22: Percentage of planned appointments in discussed categories per BCS demand scenario relative to the modelled scenario demand with ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.36, 0.19, 0.45)$.

6.7 Master Schedule Summary

During the last sections several master schedule adjustments have been made to construct a master schedule that can provide enough appointment slots to meet the expected patient demand in all four scenarios. To summarize this chapter, table 6.1 shows all master schedule adjustments for each of the four scenarios. All presented values are additions to the current weekly values, except for the cases '0 (in total)'. In these cases the number of times is set to 0 times per week. Also, the values between brackets mean (change in odd week, change in even week).

	Scenario			
Adjustment Type	1	2	3	4
Number of				
Extra physicians	+2	+3	+3	+4
Colonoscopy for BCS dayparts per week	0 (in total)	+1	+2	+6
Intake for BCS dayparts per week	0 (in total)	(0,-1)	+0	+3
Intake dayparts per week	(+1,0)	(+1,0)	(+1,0)	(+1,0)
Advised $(r_{CO}, r_{GA/SI}, r_{OC})$-ratio	$(0.36, 0.19, 0.45)$			

TABLE 6.1: Summary of all master schedule adjustments for the 4 supply scenarios.

These master schedule adjustments will expectedly result in a master schedule which provides a staff supply sufficient to cope with the associated scenario patient demand.

Chapter 7

Appointment Planning

In chapter 6 for each of the four patient demand scenarios a master schedule supply scenario has been determined. In this chapter these demand scenarios and corresponding supply scenarios will be combined by simulating the actual planning of the appointments in the staff member's calendars, which are defined by the master schedule.

7.1 Appointment Planning Reminder

Remember that for each appointment A_i there exists a preferred returning time PRT_i, and maximum allowed access time $MAAT_i$. Also, remember from (5.17) that T_i is the appointment date for appointment A_i and

$$T_i \quad = \quad T_{i-1} + 10 \cdot (PRT_i + W_i). \tag{7.1}$$

where W_i is the waiting time for appointment A_i. To make sure the equation holds for all $i = 0, 1, 2, ...$, Variable T_{-1} is equal to the application date of the first appointments.

Define W_{APP_j} as the random variable depicting the waiting time for an appointment APP_j. In this chapter we are interested in the expected waiting time for each appointment APP_j, so $E[W_{APP_j}]$.

In section 3.3.2 the maximum allowed access time $MAAT_i$ has been introduced as the desired upper bound in the transition time between appointment A_{i-1} and A_i. So it is desired that for each appointment date it holds

$$T_i \quad \leq \quad T_{i-1} + 10 \cdot MAAT_i \tag{7.2}$$

Resulting in

$$PRT_i + W_i \quad \leq \quad MAAT_i \tag{7.3}$$

During the modelling phase it has been assumed that

$$PRT_i + 2 \quad = \quad MAAT_i. \tag{7.4}$$

So if the model predicts a PRT of x weeks, the predicted associated MAAT is $x + 2$ weeks. So to satisfy the desired relation in (7.3), W_i should be

$$W_i \quad \leq \quad 2 \tag{7.5}$$

Not all appointments might be planned within the desired maximum allowed access time. Therefore, it will also be interesting to investigate the probability of not meeting the maximum allowed excess time, so $P(W_{APP_j} > 2)$. The hospital also requested investigation of $P(W_{APP_j} > 4)$, so the probability of the waiting time exceeding 4 weeks.

7.2 Simulating Appointment Planning

The simulation is used to reveal information about the three interesting values $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$. For this each simulation will consist of 21 years of simulated master schedule, after which the simulation will loop through all dayparts from daypart 1 in year 1, to daypart 520 in year 20. During each daypart new patients will arrive, existing patients are treated, and their next appointments will be scheduled according to the appointment planning rules mentioned in section 2.3. As was explained in section 2.4 the year 21 will be used as extra year to plan appointments with an application date in year 20. Remember that an appointment can be planned during a daypart if and only if

- The daypart is equal or after the application date + PRT.
- The staff member responsible for the daypart is qualified to carry out the appointment.
- There is enough time left for the appointment during the daypart.
- The appointment allowed during the daypart according to the daypart category.

and an appointment is allowed during the daypart according to the daypart category if and only if

- The appointment is a category specific appointment.
- The appointment is a non-category specific appointment, and
  - There is not enough time left during the daypart to plan a category specific appointment, or
  - the difference between the current date and the appointment date is less than 1 week.

The simulation output will contain a list of appointments were each appointment belongs to a patient, has an appointment date, a PRT, and an application date. Out of these values, one can determine the waiting time for each appointment. For the rest of this chapter the following procedure will be applied to estimate these average waiting times $W_{APP_j,Y}$ out of the simulation results.

1. Run 10 simulations over 20 years.
2. For each of these 10 simulations determine for each year $Y = 1, 2, 3, ..., 20$ and appointment APP_j for $j = 1, 2, 3, ..., 19$
   (a) the number of appointments APP_j with application date in year Y. Let this be $n_{APP_j,Y,k}$ were k is the simulation number.
   (b) the number of appointments APP_j with a waiting time over 2 or 4 weeks in year Y. ($n^{>2}_{APP_j,Y,k}$, and $n^{>4}_{APP_j,Y,k}$)
   (c) the sample mean of the waiting time for appointments APP_j in year Y of simulation k, $\bar{W}_{APP_j,Y,k}$,
   (d) the sample variance of $\bar{W}_{APP_j,Y,k}$. Let this be $s^2_{APP_j,Y,k}$.
3. Determine the weighted mean and weighted variance over all 10 simulations to get a total sample mean $\bar{W}_{APP_j,Y}$.

$$\bar{W}_{APP_j,Y} = \frac{\sum_{k=1}^{10} n_{APP_j,Y,k} W_{APP_j,Y,k}}{\sum_{k=1}^{10} n_{APP_j,Y,k}} \tag{7.6}$$

It is assumed that in all 10 simulations the variance is equal, and therefore the total sample variance $s^2_{APP_j,Y}$ can be estimated by the pooled variance. [15, p.338]

$$s^2_{APP_j,Y} = \frac{\sum_{k=1}^{10}(n_{APP_j,Y,k} - 1)s^2_{APP_j,Y,k}}{\sum_{k=1}^{10}(n_{APP_j,Y,k} - 1)} \tag{7.7}$$

Also, note that the 95% confidence interval for $\bar{W}_{APP_j,Y}$ is equal to $[\bar{W}_{APP_j,Y} - x, \bar{W}_{APP_j,Y} + x]$ where x is

$$x = 1.96\frac{s_{APP_j,Y}}{\sqrt{n_{APP_j,Y}}} \tag{7.8}$$

Also, define $n^{>2}_{APP_j,Y}$, and $n^{>4}_{APP_j,Y}$ as

$$n^{>x}_{APP_j,Y} = \sum_{k=1}^{10} n^{>x}_{APP_j,Y,k} \text{ for } x = 2, 4 \tag{7.9}$$

7.2.1 Warm-Up Period

At the beginning of the simulation, no appointments have yet been planned. Resulting in shorter waiting times in the first years of the simulation in comparison to the other years. Therefore, it is not valid to take the weighed average of $\bar{W}_{APP_j,Y}$ over all 20 years Y to determine an approximation for $E[W_{APP_j}]$. A warm-up period is needed to ensure that the system has filled up properly. The length of the warm-up period will be determined in the following way.

Define $n_{Y,k}$ as the number of applications in year Y of simulation k, so

$$n_{Y,k} = \sum_{j=1}^{19} n_{APP_j,Y,k} \tag{7.10}$$

After this define n_Y as the average number of applications in year Y for all ten simulations, and $s_{n,Y}$ as the standard deviation of n_Y over the ten simulations.

Figure 7.1 shows $n_{Y,k}$ and n_Y for each simulation year Y and all ten simulations k for each of the four demand scenarios. For each demand scenario the corresponding supply scenarios determined in the previous chapter has been used to determine the master schedule in the simulations.

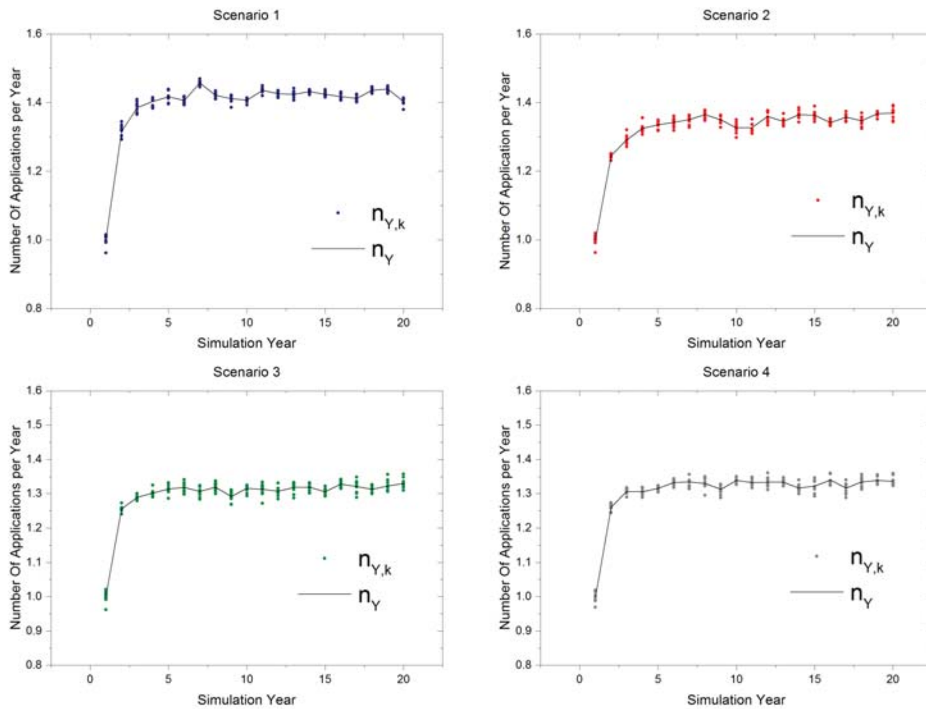


FIGURE 7.1: Number of appointment applications in the the 20 simulation years Y in the 10 simulations.

All four figures suggest that the number of applications stabilizes approximately after year 4. Stabilization is equal to expecting that $E[n_Y] = E[n_{Y+x}]$ with $x \geq 1$. To prove the assumption that the number of applications stabilizes after 4 years, one has to prove that it can be expected that $E[n_4] = E[n_{4+x}]$ for all $x \geq 1$. It is assumed that if one can prove that this is true for $E[n_4] = E[n_5]$, that the number of applications indeed stabilizes after 4 years. To test the assumption, a pooled t-test is suggested. [15, p. 337-341]

1. The two compared samples will be $\{n_{4,k}\}_{k=1,2,3,\ldots,10}$ and $\{n_{5,k}\}_{k=1,2,3,\ldots,10}$, so both sample sizes will be equal to 10. The parameters of interest are $E[n_4]$ and $E[n_5]$.
2. $H_0 : E[n_4] = E[n_5]$
3. $H_1 : E[n_4] \neq E[n_5]$
4. Significance level $\alpha = 0.05$
5. The test statistic is

$$t_0 = \frac{n_4 - n_5}{S_p\sqrt{\frac{1}{10} + \frac{1}{10}}} \tag{7.11}$$

where S_p is the pooled estimator of the sample standard deviations $s_{n,4}$ and $s_{n,5}$. [15, p.338]

6. Now H_0 is rejected if $t_0 > t_{0.025,10} = 3.581$ or $t_0 < -t_{0.025,10} = -3.581$.

7. Each scenario will result in the following test statistic value, and therefore the following conclusions

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
t_0	-2.441	-2.090	-2.255	-2.534
Accept H_0	True	True	True	True

So for the rest of the chapter it is assumed that the warm-up period takes 3 years. All values of interest will be determined over years 4 to 20. So

$$\begin{aligned} E[W_{APP_j}] &= \frac{\sum_{Y=4}^{20} \bar{W}_{APP_j,Y}}{17} \\ P(W_{APP_j} > x) &= \frac{\sum_{Y=4}^{20} n_{APP_j,Y}^{>x}}{\sum_{Y=4}^{20} n_{APP_j,Y}} \quad \text{for } x = 2, 4 \end{aligned} \tag{7.12}$$

7.3 Current Situation Waiting Times Compared to Supply Scenarios

The procedure suggested in the previous part of this chapter can be applied to the current situation. So only with the current available staff members, and current master scheduling rules. The used patient demand will be equal to the patient demand in scenario 1, so only regular patients and no BCS patients. Figure 7.2 shows $W_{APP_j,Y}$ and $s_{APP_j,Y}$ for all simulation years $Y = 1, 2, 3, ..., 20$ and all appointments APP_j.

As can be seen the waiting times drastically increases, especially for the endoscopies. Due to this increase it is meaningless to determine the expected value $E[W_{APP_j}]$ for all appointments, because the waiting times do not stabilize. Stabilization will in this case mean that $\bar{W}_{APP_j,Y}$ is ≤ 2 weeks for all APP_j and all Y.

Also, one can see a large dip from year 15 onwards. This because only 21 years of master schedule are available for appointment planning during the simulations. For example the average waiting time for the colonoscopies CO in year 14 is equal to $\bar{W}_{CO,14} \approx 300$ weeks, or approximately 6 years. Therefore, if a patient applies for a colonoscopy and his waiting

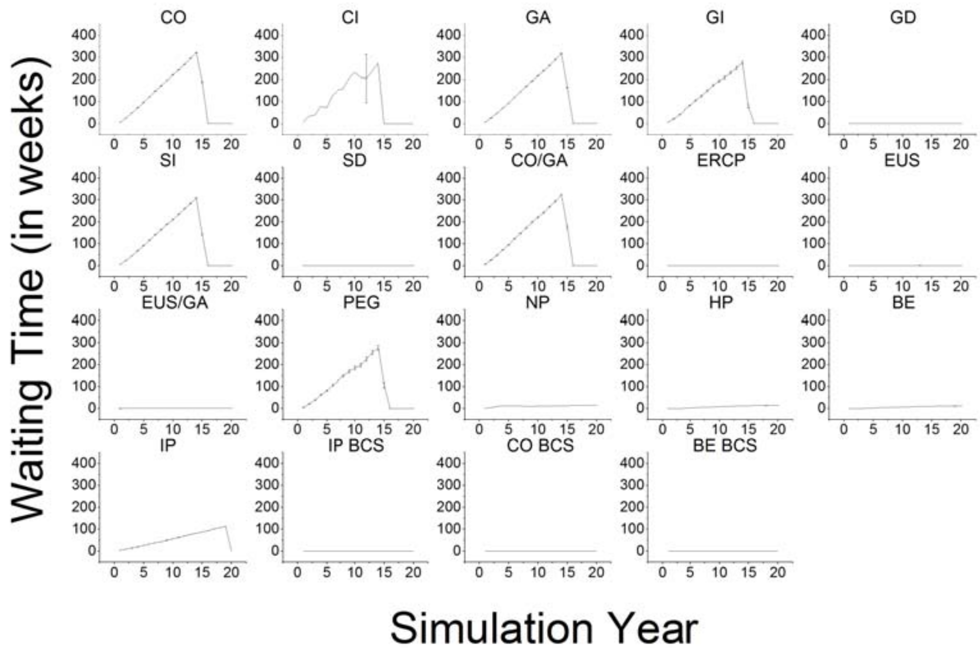


FIGURE 7.2: Sample average waiting time $\bar{W}_{APP_j,Y}$ and sample standard deviation $s_{APP_j,Y}$ for simulation years $Y = 1, 2, 3, ..., 20$ and appointments APP_j in the current situation.

time exceeds 6 years, his appointment needs to be scheduled in year 22. However, this year does not exist in the simulation and therefore, the appointment can not be planned and the appointment will not be taken into account into the determination of $\bar{W}_{APP_j,15}$. This problem only occurs if the patients waiting time exceeds 52 weeks.

The last thing that comes to the attention is the increasing of $s_{APP_j,Y}$ as $\bar{W}_{APP_j,Y}$ is increasing. So the spreading of the waiting time increases as the waiting time increases. This can be explained by the fact that one starts looking for an appointment slot in the daypart with $W = 0$. If the average waiting time is 2 weeks, then on average 20 dayparts need to be checked, before finding an appointment slot. However, if the average waiting time equals 400 weeks, then on average 4000 dayparts need to be checked. Therefore, if the waiting time is increases, a larger spreading is possible.

Now to determine the influence of the suggested supply scenarios in the previous chapter, Figure 7.3 shows $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for all year Y and appointments APP_j.

As can be seen, the waiting times for all appointments have strongly decreased by using the new supply scenario. However, the waiting times for appointments EUS and EUS/GA still strongly increase over the simulation years. This means not enough appointment slots are available for these appointments. Similar figures occur in simulation

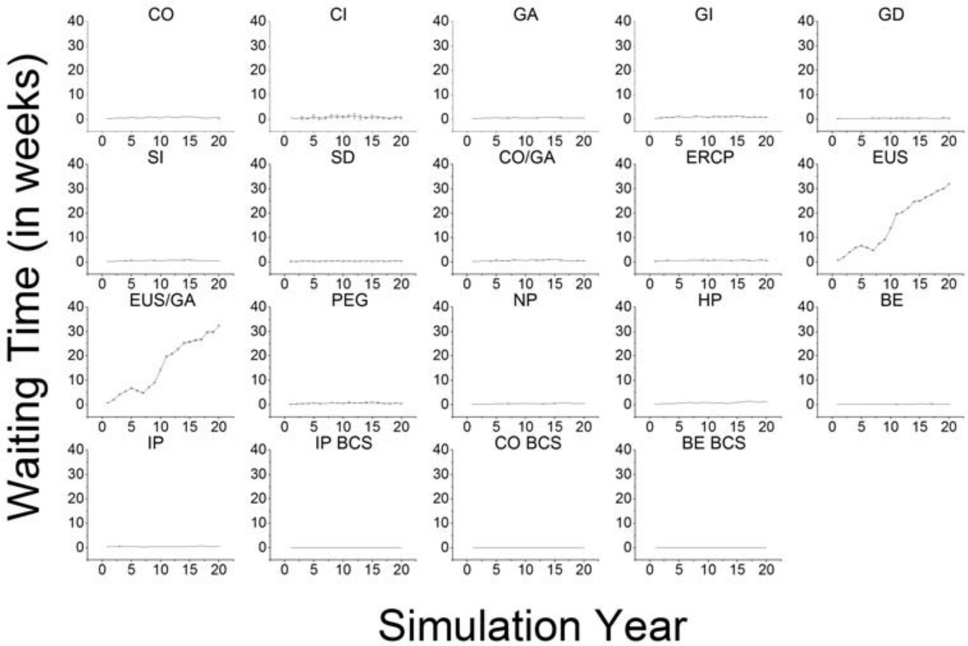


FIGURE 7.3: Sample average waiting time $\bar{W}_{APP_j,Y}$ and sample standard deviation $s_{APP_j,Y}$ for simulation years $Y = 1, 2, 3, ..., 20$ and appointments APP_j for demand and supply scenario 1.

demand and supply scenarios 2,3 and 4, as can be seen in table 7.1. This table contains three values for the two appointments EUS and EUS/GA and for scenarios 2,3 and 4. First $\bar{W}_{APP_i,4}$ and $\bar{W}_{APP_i,20}$ will reveal whether the waiting time increases between the first year after the warm-up period and the last year of the simulation. To avoid not noticing a dip similar to the dip in Figure 7.2, also $\max_{Y=4,5,6,...,20}\{\bar{W}_{APP_j,Y}\}$ is added to the table. In Figure B.1,B.2 and B.3 in Appendix B the complete simulation results figure can be found.

TABLE 7.1: Simulation results for $\bar{W}_{APP_j,Y}$ for demand and supply scenarios 2,3 and 4.

	Scenario 2		Scenario 3		Scenario 4	
	EUS	EUS/GA	EUS	EUS/GA	EUS	EUS/GA
$\bar{W}_{APP_j,4}$	9.05	8.97	6.21	6.44	6.22	6.06
$\bar{W}_{APP_j,20}$	31.32	32.13	8.91	9.22	6.24	5.77
$\max_{Y=4,5,6,...,20}\{\bar{W}_{APP_j,Y}\}$	31.32	32.13	13.62	14.07	9.49	9.26

Tables 2.2 and 2.3 show that EUS and EUS/GA can only be planned during the EUS dayparts and therefore the number of EUS dayparts per week should be increased to create more appointments slots. Running the simulation for demand and supply scenario 1 with this extra EUS daypart per week results in Figure 7.4.

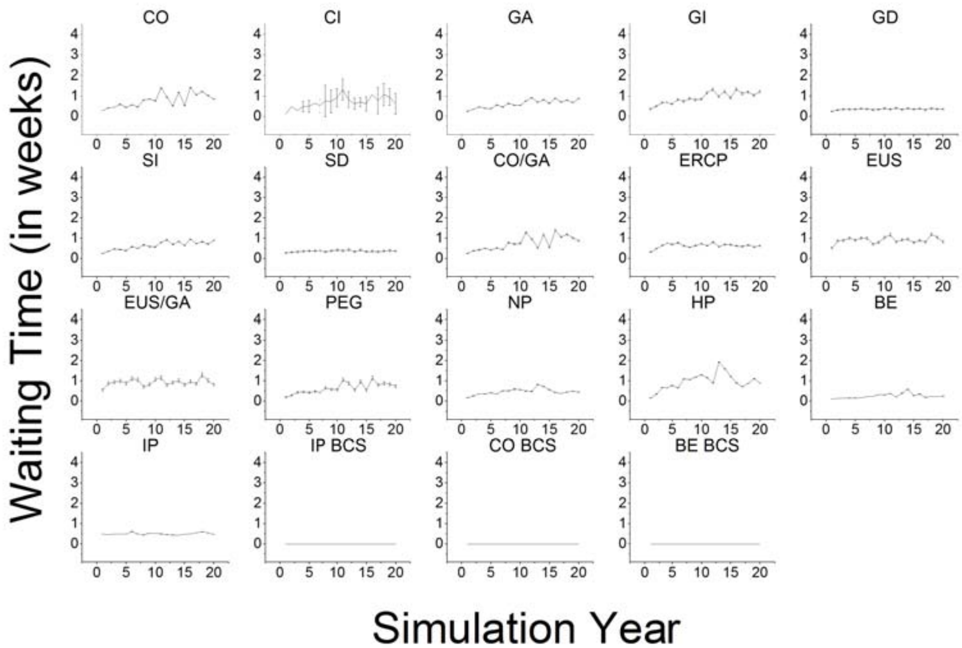


FIGURE 7.4: Sample average waiting time $\bar{W}_{APP_j,Y}$ and sample standard deviation $s_{APP_j,Y}$ for demand and supply scenario 1 with one extra EUS daypart per week.

In this case all extra waiting times are ≤ 2 weeks which is desired for the waiting time (see (7.5)) and all waiting times seem stabilized between year 4 and year 20. Therefore, the three values of interest $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$ can be determined as in (7.12). This results in table 7.2. The maximum expected values and probabilities are colored red and the minimums are colored green.

TABLE 7.2: $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$ for scenario 1.

	CO	CI	GA	GI	GD	SI	SD	CO/GA	ERCP	EUS
$E[W_{APP_j}]$	0.86	0.7	0.67	1	0.36	0.69	0.37	0.83	0.66	0.93
$P(W_{APP_j} > 2)$	0.137	0.128	0.072	0.175	0.005	0.085	0.006	0.13	0.073	0.141
$P(W_{APP_j} > 4)$	0.008	0.024	0.011	0.036	0	0.014	0	0.008	0.003	0.033

	EUS/GA	PEG	NP	HP	BE	IP	IP BCS	CO BCS	BE BCS	
$E[W_{APP_j}]$	0.96	0.71	0.51	1.06	0.28	0.5				
$P(W_{APP_j} > 2)$	0.145	0.116	0.08	0.226	0.018	0.006				
$P(W_{APP_j} > 4)$	0.032	0.013	0.024	0.058	0.001	0				

As can be seen in this table, $E[W_{APP_j}] \leq 2$ for all appointments APP_j. Also, out of all appointments APP_j the probability of an HP application being scheduled after the MAAT is the highest, namely 0.226. The same holds for the applications schedule at least 2 weeks after the MAAT, namely probability 0.058. For all other appointments, these probabilities are lower.

For scenario 2, 3 and 4 these results are different. Figure 7.5 shows the simulation results for demand and supply scenario 2 with the extra EUS daypart per week. Appendix figures B.4 and B.5 show the same figure for simulation results 3 and 4.

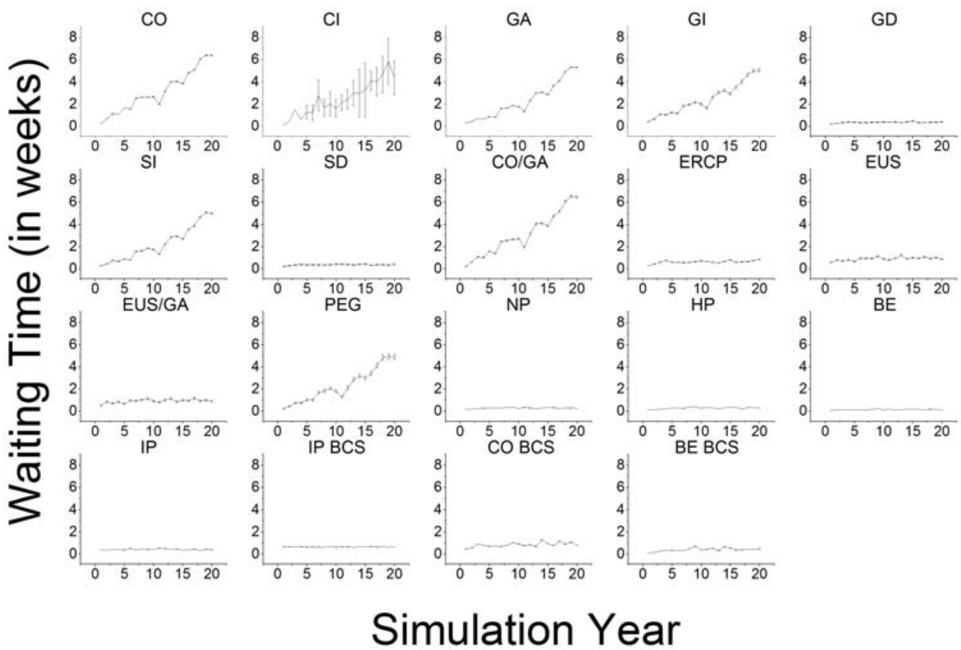


FIGURE 7.5: Sample average waiting time $\bar{W}_{APP_j,Y}$ and sample standard deviation $s_{APP_j,Y}$ for demand and supply scenario 2 with one extra EUS daypart per week.

As can be seen the EUS and EUS/GA waiting times seem to have stabilized. Therefore, the following extra master schedule adjustments will be introduced.

Master Schedule Adjustments

- 1 extra daypart per week should be spend on EUS to be able to decrease the EUS and EUS/GA waiting time in scenarios 1,2,3, and 4.

However, the endoscopies CO, CI, GA, GI, SI, CO/GA and PEG still have increasing waiting times in all three scenarios. To fix this problem extra Colonoscopy and/or Gastroscopy/Sigmoidoscopy dayparts need to be created. There are two ways to create extra of these dayparts, namely

1. Increase r_{CO} and $r_{GA/SI}$ and consequently decrease r_{OC} in the ratio $(r_{CO}, r_{GA/SI}, r_{OC})$.
2. Adding an extra staff member to perform extra CO, or GA and SI.

The first solution is the cheapest solution, and is therefore preferred. The suggested ratio in chapter 6 is $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.39, 0.21, 0.40)$. For scenario 2 this results in Figure 7.6. The results for scenarios 3 and 4 can be found in figures B.6 and B.7.

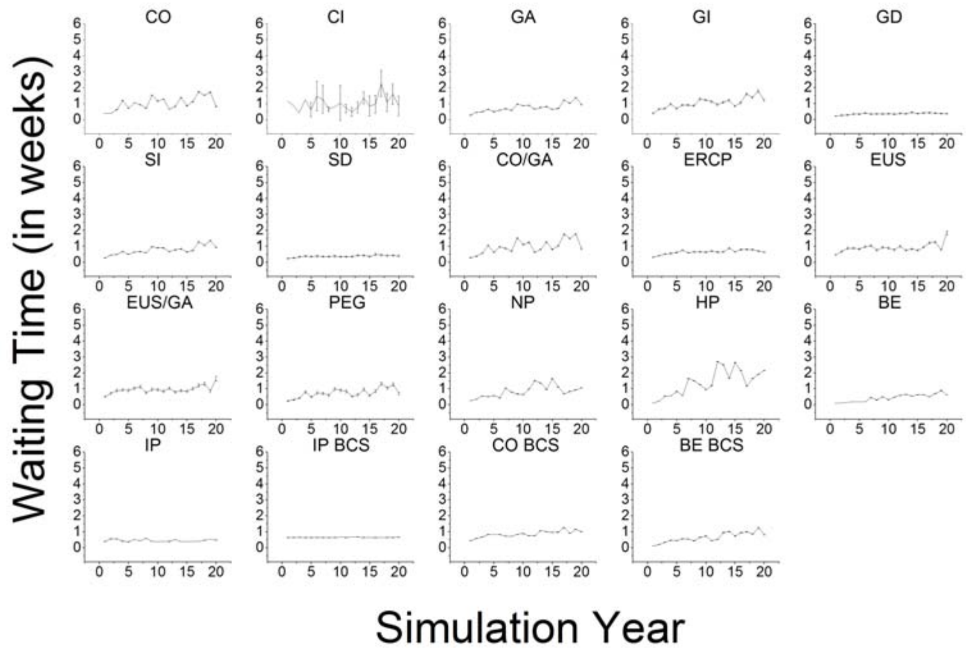


FIGURE 7.6: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 2 with changed ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.39, 0.21, 0.40)$.

It can be seen that in the scenario 2 results the waiting time for the HP appointments slightly increases. The same happens in scenarios 3 and 4. If r_{OC} is decreased even more, the waiting time for the HP appointments will consequently increase. Therefore, changing the ratio is not a suitable solution.

The second solution is the addition of an extra staff member. Extra staff members either perform CO, or GA and SI (see section 6.5). The most likely extra staff member will be an CO extra staff member, and therefore, this staff member will be added in scenarios 2, 3, and 4. Also, one daypart Supervision per week will be added to the physicians master schedule. The only question is, how many dayparts per week are needed for this extra staff member. It turns out that three dayparts per week are needed in all three scenarios. For the simulation results see figures 7.5, B.4 and B.5. Three dayparts seems a lot, but remember that because of the addition of one extra staff member, one extra Supervision daypart is added per week. Also the extra staff members take more time to perform a colonoscopy. So to make up for the time lost because of the extra Supervision daypart per week, at least two Colonoscopy dayparts per week are needed in the master schedule of the new extra staff member. Therefore only the third daypart will result in actual extra appointment slots for CO appointments.

Master Schedule Adjustments

- 1 extra staff member performing CO is needed for 3 dayparts per week to be able to decrease the CO, CI, GA, GI, SI, CO/GA and PEG waiting times per week in scenarios 2, 3, and 4.

Tables 7.3, 7.4 and 7.5 show the value $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$ for these three scenarios.

TABLE 7.3: $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$ for scenario 2.

	CO	CI	GA	GI	GD	SI	SD	CO/GA	ERCP	EUS
$E[W_{APP_j}]$	0.58	0.43	0.77	1.04	0.34	0.78	0.36	0.59	0.64	0.94
$P(W_{APP_j} > 2)$	0.049	0.06	0.097	0.181	0.005	0.103	0.006	0.049	0.067	0.144
$P(W_{APP_j} > 4)$	0.002	0	0.016	0.044	0	0.018	0	0.002	0.004	0.035

	EUS/GA	PEG	NP	HP	BE	IP	IP BCS	CO BCS	BE BCS	
$E[W_{APP_j}]$	1	0.51	0.36	0.4	0.16	0.42	0.64	0.8	0.38	
$P(W_{APP_j} > 2)$	0.157	0.058	0.035	0.047	0.001	0.003	0	0.023	0.011	
$P(W_{APP_j} > 4)$	0.038	0.003	0.007	0.001	0	0	0	0	0	

TABLE 7.4: $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$ for scenario 3.

	CO	CI	GA	GI	GD	SI	SD	CO/GA	ERCP	EUS
$E[W_{APP_j}]$	1.35	0.94	1.23	1.53	0.36	1.23	0.38	1.4	0.65	0.85
$P(W_{APP_j} > 2)$	0.278	0.191	0.21	0.305	0.006	0.216	0.008	0.289	0.071	0.121
$P(W_{APP_j} > 4)$	0.051	0.04	0.044	0.109	0	0.053	0	0.051	0.004	0.023

	EUS/GA	PEG	NP	HP	BE	IP	IP BCS	CO BCS	BE BCS	
$E[W_{APP_j}]$	0.87	1.03	0.41	0.4	0.19	0.46	0.53	0.8	0.48	
$P(W_{APP_j} > 2)$	0.12	0.194	0.041	0.044	0.005	0.008	0	0.009	0.022	
$P(W_{APP_j} > 4)$	0.02	0.048	0.01	0.001	0	0	0	0	0.001	

TABLE 7.5: $E[W_{APP_j}]$, $P(W_{APP_j} > 2)$ and $P(W_{APP_j} > 4)$ for scenario 4.

	CO	CI	GA	GI	GD	SI	SD	CO/GA	ERCP	EUS
$E[W_{APP_j}]$	0.91	0.88	0.93	1.26	0.36	0.94	0.39	0.94	0.67	0.92
$P(W_{APP_j} > 2)$	0.145	0.149	0.133	0.232	0.006	0.141	0.008	0.15	0.074	0.136
$P(W_{APP_j} > 4)$	0.019	0.048	0.027	0.07	0	0.032	0	0.022	0.005	0.033

	EUS/GA	PEG	NP	HP	BE	IP	IP BCS	CO BCS	BE BCS	
$E[W_{APP_j}]$	0.94	0.76	0.28	0.15	0.11	0.41	0.48	1.26	0.34	
$P(W_{APP_j} > 2)$	0.141	0.12	0.015	0	0	0	0	0.139	0.01	
$P(W_{APP_j} > 4)$	0.033	0.022	0.002	0	0	0	0	0.004	0	

Tables 7.2, 7.3, 7.4, and 7.5 reveal the expected waiting times and exceeding probabilities for each appointment APP_j. However, the final values of interest are $E[W_{A_i}]$, $P(W_{A_i} > 2)$ and $P(W_{A_i} > 4)$ for $A_i \in \{O, S\}$. So the expected waiting and exceeding

probabilities for an average endoscopy or outpatient clinic consultation. These can be found in table 7.6.

TABLE 7.6: $E[W_{A_i}]$, $P(W_{A_i} > 2)$ and $P(W_{A_i} > 4)$ for $A_i \in \{O, S\}$ for scenarios 1, 2, 3, and 4.

	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
A_i	S	O	S	O	S	O	S	O
$E[W_{A_i}]$	0.78	0.76	0.69	0.33	1.20	0.35	0.97	0.17
$P(W_{A_i} > 2)$	0.110	0.146	0.070	0.032	0.211	0.033	0.139	0.003
$P(W_{A_i} > 4)$	0.011	0.037	0.009	0.002	0.042	0.003	0.020	0.000

So with the given demand and supply scenarios, the expected waiting time for an endoscopy is approximately between 0.20 and 0.97 weeks, 1 or 5 working days. For an outpatient clinic this is between 1 and 4 working days. What seems worrying is the high probability of W exceeding the 2 weeks, so the MAAT, for endoscopies in scenario 3. The only solution for this problem seems the addition of another CO daypart for the extra staff member.

An important value for the hospital is the time between the application for the first appointment and the actual first appointment date, so $PRT_0 + W$. This is called the access time. Remember from section 2.1 that $MAAT_0$ is a maximum of 6 weeks if the first appointment is an endoscopy, and 8 weeks if it is a consultation, so the access time can not exceed $MAAT_0$. Also, remember that it is has been assumed that the corresponding PRTs are $PRT_0 = 4$ and $PRT_0 = 6$. However, these assumptions were made from the GHD perspective, because it is not desirable to fill up all available time with appointments for new patients right away. In real life $PRT_0 = 0$ for all appointments, while patients desire to have their first appointment as soon as possible. This assumption would turn the access time into W.

If one assumes $PRT_0 = 0$ instead of $PRT_0 = 4$ or 6, the patients simply arrive 4 or 6 weeks earlier in the system for the planning of their first appointment. If the system is stable, so the utilization rate $\rho < 1$ and consequently enough staff capacity is available to cope with the demand, this earlier arrival should not influence the waiting time. Because one simply pushes the patient's total treatment path forward 4 or 6 weeks. If this is the case, the expected access times for endoscopies and consultations in the four scenarios are equal to the values found next to $E[W_{A_i}]$ in table 7.6.

To check whether the access times indeed correspond to these waiting times, four extra simulations have been done in which $PRT_0 = 0$ for all appointments. Out of the simulation results both the access times and waiting times for appointments other than the first appointment, have been determined. This results into the values in table 7.7.

TABLE 7.7: $E[W_{A_i}]$ for $A_i \in \{O, S\}$ for scenarios 1, 2, 3, and 4 subdivided into access times and waiting times for follow-up appointments.

		Scenario 1		Scenario 2		Scenario 3		Scenario 4	
A_i	i	S	O	S	O	S	O	S	O
$E[W_{A_i}]$	0	0.68	3.69	0.55	2.30	1.02	2.72	0.68	1.58
	≥ 1	0.47	0.91	0.52	0.21	0.73	0.27	0.72	0.13

As can be seen the access times for endoscopies are slightly lower than the waiting times in table 7.6. But remember that these waiting times and access times are both in weeks, where each week contains 5 days. So the differences are approximately equal to 1 day. The same holds for the difference between the previous waiting times, and the waiting times for follow-up appointments in the new simulations for both endoscopies and consultations. However, the access times for the consultations are much higher than the waiting times in table 7.6, especially in the first scenario.

The reason for this effect is unknown. To make sure the access time does indeed stabilize and is not increasing over the simulation years, Figure 7.7 shows the average access times for endoscopies and consultations per simulation year per simulation scenario. As can be seen, indeed after approximately 4 years the access times stabilize. Only in the access time for consultations in scenario 1, a small increase can be observed after year 17. This figure leads to the conclusion that the increased access times are not caused by non-stabilized access times.

Nevertheless, given that any non-urgent consultation should be planned within 8 weeks and any non-urgent endoscopy within 6 weeks, one can conclude that the expected access times in all four scenarios are sufficient for non-urgent treatments. For urgent treatments it is expected that the majority of maximum allowed access times is equal to 2 weeks or more. As a result, in these cases the access times might not be sufficient for consultations.

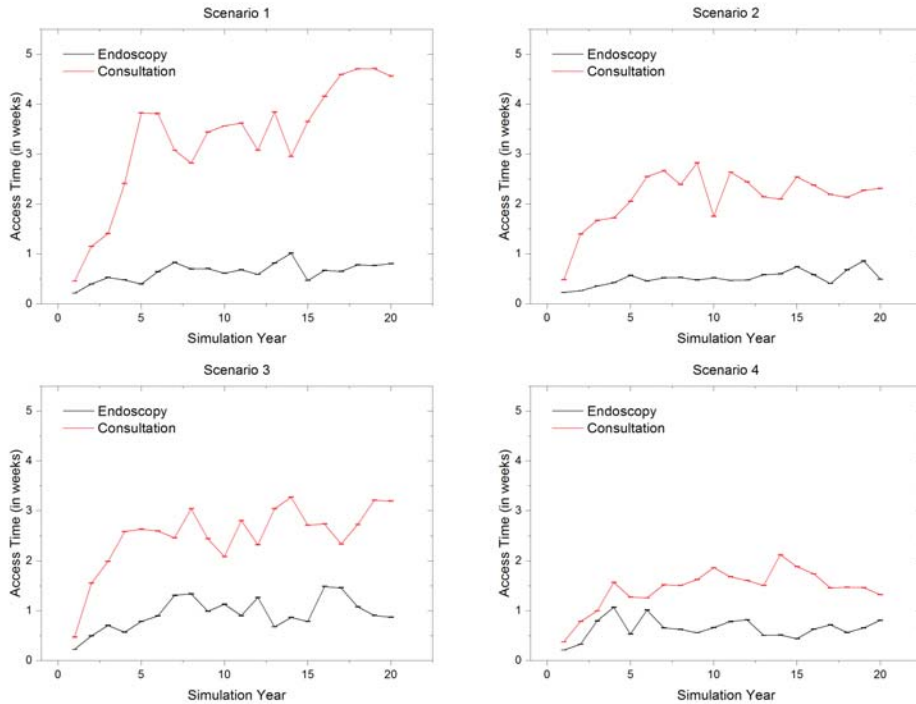


Figure 7.7: Access times for Endoscopies and Consultations in the four demand scenarios.

7.4 Staff Pooling Influence

The appointment planning until now assumed that every qualified physician or staff member was suitable to perform an appointment. However, as was introduced in section 2.3.1 this is not the case in actual GHD appointment planning. Patients have their own physician and are preferably treated by this physician. It is assumed that waiting times increase due to this extra requirement, because the set of allowed appointment slots is reduced.

However, if the waiting for the main physician causes the appointment to be planned after the MAAT, then this is not always preferred. There is a difference between the consultations and endoscopies in this case. For consultations the main physician is preferred above planning within the MAAT, while in these types of appointments personal contact is an important factor. For the endoscopies the main physician is less important.

To add the main physician to the simulation, define Z_{A_i} as the number of weeks during which it is attempted that each appointment of type $A_i \in \{O, S\}$ is scheduled with the main physician. If no appointment slot can be found with the main physician within Z_{A_i} weeks, or the main physician is not qualified for the appointment, then the simulation returns to daypart $T_{i-1} + PRT_i$ and looks for a suitable appointment slot with any staff member.

If the main physician is not included, the variables Z_O and Z_S are equal to 0 weeks, because one immediately starts looking for a suitable appointment slot with any staff member. In the case of the consultations it is currently desired that $Z_O = \infty$, because it is more important that the consultation is planned with the main physician then within the MAAT. For the endoscopies remember that $MAAT_0$ is equal to 6 weeks for regular applications. Therefore it is assumed that this is also the average MAAT for any follow-up endoscopy, and it is assumed that the current Z_S is equal to 6 weeks.

To investigate the influence of the main physician, three different scenarios for (Z_S, Z_O) will be investigated, namely

1. $(Z_S, Z_O) = (0, 0)$, or the situation without main physician.
2. $(Z_S, Z_O) = (0, \infty)$, or the situation without main physician for endoscopies and with main physician for consultations.
3. $(Z_S, Z_O) = (6, \infty)$, or the situation with main physician for endoscopies for the first 6 weeks and with main physician for consultations for all weeks.

In this section all results will be scenario 1 results. The supply scenario will include the extra EUS daypart proposed in the previous section. Figure 7.8 shows the average waiting time $\bar{W}_{APP_j,Y}$ for all three introduced (Z_S, Z_O) scenarios.

Remember the first 12 appointments and CO BCS are of type S, and NP, HP, BE and BE BCS are of type O. As can be seen, $\bar{W}_{APP_j,Y}$ increases if the associated Z_{A_i} is increasing. If one calculates $E[W_{A_i}]$ for these three scenarios this results in table 7.8.

Table 7.8: $E[W_{A_i}]$ for $A_i \in \{O, S\}$ and the three pooling scenarios 0-0, 0-∞ and 6-∞.

	$E[W_{A_i}]$	
A_i	S	O
0-0	0.78	0.76
0-∞	0.67	2.43
6-∞	2.07	1.99

So if no staff pooling is used during the planning of consultations, then the expected average waiting time for consultations will increase by approximately 1.6 weeks, or 8 working days. If staff pooling is not used for both appointment types then the waiting times in both appointment types is expectedly increased 1.2 weeks which equals approximately 6 working days. Both scenarios cause an expected increase of over 1.5 week.

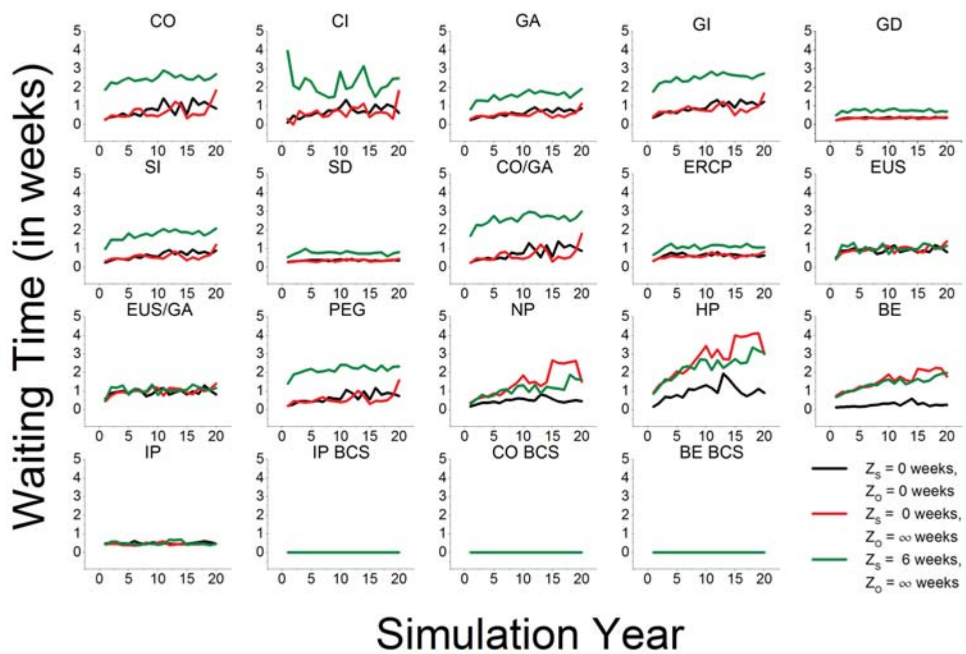


FIGURE 7.8: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 1 with with main physicians.

Also, remember that the waiting time should be ≤ 2 weeks. In both pooling scenarios the expected average waiting time is ≥ 2 weeks, so if staff pooling is not used the appointments are in expectation not planned within their MAAT. For regular patients this might not be a problem. However, in emergency situations the MAAT is a more strict boundary. It might therefore be useful to differentiate between emergency appointments and non-emergency appointments. For example, if the MAAT is ≤ 3 weeks one should use pooling while planning the appointment, and should not use pooling otherwise.

TABLE 7.9: $E[W_{A_i}]$ for $A_i \in \{O, S\}$ and the pooling scenarios 6-∞ if $MAAT_i > 3$ weeks and $0-0$ otherwise.

	$E[W_{A_i}]$	
A_i	S	O
6-∞ if $MAAT_i > 3$	1.71	1.11

This will increase the waiting time in the pooling scenario $0-0$ with approximately 1 week for endoscopies en 0.5 weeks for outpatient clinic consultations, which is less than in the currently used $6-\infty$ scenario.

Chapter 8

Conclusion

Throughout this report the planning process at the JBZ GHD has been investigated, modelled and simulated to determine whether the current capacity is sufficient to cope with the regular patient care demand, and the increasing demand caused by the BCS program. To do so, the planning process has been split-up into three phases. First, the patient demand has been investigated. Secondly, the staff supply has been explored, and finally combined in the appointment planning.

The patient demand has been modelled using a Markov model designed to determine the patient treatment path for all patients visiting the GHD, where each modelled patient treatment path contains a list of appointments, and preferred returning times. This patient treatment path model, combined with a predetermined negative binomially distributed number of arrivals per daypart for regular patients, made it possible to determine the expected yearly patient demand per appointment. To include the expected increase of BCS patient arrivals, four different demand scenarios have been investigated. The first scenario only contained the arrivals, and consequently only the demand, of regular patients, while the other three scenarios also contained the arrivals of BCS patients according to different but weekly fixed arrival rates.

Next, the staff supply has been determined by simulating the currently used staff scheduling rules in a JAVA simulation program. The currently used staff scheduling rules result in a block schedule in which each block corresponds to a daypart in a staff member's calendar. This block schedule is called the master schedule and determines for each staff member and for all dayparts, the staff members main task during this daypart. First, the expected number of minutes per year available for appointments was determined out of simulated master schedules containing only the currently available staff members. Comparison of this result to the expected yearly patient demand in minutes in the four previously mentioned demand scenarios led to the conclusion that the current staff capacity is insufficient for all four scenarios. At least two extra physicians are needed to be able to cope with the current regular patient demand. Addition of BCS patients resulted in the expected necessity of three or four extra physicians, depending on the BCS arrival rate.

After addition of these extra physicians, several master schedules have been simulated to determine the number of appointments slots available for each appointment. For each master schedule this result has been compared to the expected yearly patient demand per appointment for each of the four scenarios. If expected supply turned out to be insufficient, adjustments were made to the master schedule category scheduling rules, which resulted in four different supply scenarios, each containing a list of different category scheduling rules (see table 6.1 on page 85). These category scheduling rules in expectation result in an master schedule during which enough appointment slots are available to cope with the patient demand in the associated demand scenario.

Finally, to estimate the expected access time, expected waiting time, and the waiting time exceedance probabilities, the patient treatment path model was added to the JAVA master schedule simulation together with extra rules for appointment planning. This resulted in a holistic simulation of the GHD planning process in which both staff supply and patient demand can be changed by changing either the number of available staff members, the master schedule category scheduling rules or the patient arrival rate. To obey all maximum allowed access time rules, the waiting time should be smaller or equal to 2 weeks for all appointments. Simulation results for all four demand scenarios suggested that to achieve this, extra changes should be made to the supply and therefore the master schedule. Also, in the scenarios containing BCS patients, an extra staff member is needed for at least three dayparts per week to decrease the waiting time for regular colonoscopies, gastroscopies and sigmoidoscopies. All changes would result in expected waiting times of 2 weeks or less in all four demand scenarios and for both outpatient clinic consultations and endoscopies (see table 7.6 on page 99).

After determining these necessary changes the preferred returning time for the first appointment was set to 0 weeks instead of the previously used 4 or 6 weeks, depending on the appointment type. This was done to model the fact that an arriving patient wants to be treated as soon as possible. The resulting expected access times for the two appointment types in the four demand scenarios, given all advised changes, can be found in table 7.7 on page 100. The reason for the difference between the access times and waiting times for the follow-up appointments is unknown. Given that any non-urgent consultation should be planned within 8 weeks and any non-urgent endoscopy within 6 weeks, one can conclude that the expected access times in all four scenarios are conform the non-urgent treatment access time standards. For urgent treatments it is expected that the majority of maximum allowed access times is equal to 2 weeks or more. So in these cases the access times might not be sufficient.

In the last part of chapter 7 the influence of staff pooling has been investigated. During the appointment planning, it is assumed that each qualified staff member is suitable to treat each patient. However, at the GHD patients are preferably treated by their main physician, who is responsible for the patient's treatment. Results in table 7.8 on page 102 show that the introduction of a main physician will increase the waiting time for each appointment by approximately 1.5 week. A mixed scenario during which staff pooling is used for patients with a maximum allowed access time of 3 weeks or less, and the main physician in non-urgent situations, has resulted in an expected increased waiting time of 1 week for endoscopies, and 0.5 week for consultations (see table 7.9 on page 103).

Chapter 9

Discussion

It is important to note that, in order to get to the conclusions discussed in the previous chapter, several different assumptions had to be made. Some of these assumptions might strongly influence the outcome of the research. Their influence will therefore be discussed in this chapter.

Non-Increasing Regular Patient Arrival The first assumption involves patient arrival. During this research four different scenarios have been investigated, namely one scenario during which only regular patients arrived at the GHD, and three scenarios during which the same number of regular patients are combined with a predetermined number of BCS patients per week. As was stated in section 1.2, the BCS program will be introduced gradually between 2014 and 2019. Therefore, it is expected that the number of weekly BCS applications will increase in the upcoming years. However, it is also expected that the number of regular applications will increase in the upcoming years. The methods in this report however assume that the number of regular applications stays the same. If the regular demand increases, even more staff is needed.

Use of Excess Time In section 2.2.2 the so-called non-category specific appointments have been introduced. These appointments are used throughout the simulation to fill up extra unused time at the end of dayparts. However, discussions with hospital staff revealed that this method is only used during outpatient clinic dayparts such as 'Outpatient Clinic' or 'Intake'. This because the actual duration of consultations is much more likely to equalize the time reserved for it. In contrast to endoscopies which often exceed the reserved time. If the excess time during endoscopic dayparts can not be used for non-category specific appointments, extra appointment slots should be created for these non-category specific appointments. The proposed supply scenarios in this report however do not offer enough extra time to cope with all of the non-category specific appointments outside of the endoscopic dayparts. So extra time should be created somewhere in the master schedule. Most likely this implies the requirement of an extra physician or extra staff member. However, if the actual duration of an endoscopy approximately equalizes the reserved time, then the excess time stays unused, resulting in non-optimal use of the available time.

It is therefore important to investigate and redefine a good and more trustworthy average duration for the endoscopies, or introduce a probability distribution for the endoscopy duration, such that the excess time at the end of a daypart, usable for non-category specific appointments, can be predicted more accurately. Especially short appointments such as, for example, call-back appointments are very suitable for filling up this excess time. This will increase the efficient use of the available time, and consequently will result in an increased number of treated patients.

Maximum Allowed Access Times for First Time Visitors The next assumption involves the maximum allowed access time for first time visitors. As introduced in section 2.1 the JBZ has made agreements with general practitioner (GPs) and other external physicians about the maximum number of weeks between the first application and first appointment date. In this report it is assumed that the MAAT for endoscopies is 6 weeks, and 8 weeks for outpatient clinic consultations. However, these values are based on the maximum non-urgent agreements. There exist several exceptions in which case the MAAT is lower than 6 or 8 weeks. If the waiting time is stabilized, this will only bring the appointment dates of all appointments in this patients treatment path forward. However, if the waiting time is not stabilized the number of patients present in the system will increase, so the offered load will increase. The supply will stay the same, and this will result in increasing waiting times, and not meeting the MAAT.

Call-Back Appointments During the last weeks of the research, discussions with staff members also revealed another issue that influences the patient demand. The current workload clearly causes long waiting times. However, in some cases patients might be offered a call-back appointment at short notice instead of a check-up consultation for which they have to wait longer. It is desired by the physicians to actual perform this check-up consultation instead of the call-back appointment. However, a check-up consultation takes more time, resulting in a larger demand and consequently a larger necessary staff supply. For future research it is therefore interesting to investigate which part of the call-back consultations is preferably a check-up consultation, and how this influences the staff supply.

Chapter 10

Outlook

In the previous chapter already a few interesting examples have been given on how to extend the research discussed in this report. However, the research in this report mainly uses discrete event simulation to achieve information about waiting and access times. In this chapter two different other research topics will be introduced and discussed

Changing Staff Scheduling Procedures In chapter 6 the current block schedule and category scheduling rules are used, changed and extended to improve the staff supply. However, this block schedule puts limitations to the available appointment time. Other staff scheduling methods might increase efficient use of the available time. Gupta and Denton [10] suggests other scheduling options, such as an open scheduling system. In this scheduling system physicians request appointment time for one appointment at a time instead of reserving one complete daypart for a specific appointment type. This method increases the flexibility of appointment scheduling, because no time is reserved for a specific appointment, unless an application has been received for this appointment.

Changing Appointment Planning Procedure Besides changing the staff scheduling rules, also changes in the appointment planning might be interesting to investigate. As was described in section 2.3 and chapter 7 the currently used method plans a patient's next appointment during the first daypart after the preferred returning time, during which the appointment is allowed according to the staff schedule, and enough time is available for the appointment. Dexter et al. [5] call this the 'Next Fit' planning algorithm. This paper focuses on determining an operating room block scheduling strategy, which maximizes the use of the available time in each assigned block. As in chapters 6 and 7, a simulation method is described to determine the appropriate amount of surgery blocks per week. In addition to that, three appointment planning algorithms are investigated, different from the 'Next Fit' planning algorithm. The purpose of these planning algorithms is to increase the use of the available block time. For example, in the 'First Fit' algorithm an appointment is planned during a the first block during which sufficient time is available, and at least one other appointment has already been planned. This to minimize the number of blocks spend on surgery, and at the same time maximizing the time used during each block. A new empty block is created if and only if no other block is available within a reasonable amount of time during which sufficient time is available, and at least one other appointment has already been planned. So the block schedule is rather build around the applications instead of predetermined according to expected application figures. This planning algorithm might make it possible to respond more accurately to unexpected increases or decreases in the applications for specific appointment types. Besides this specific example of an appointment planning algorithm, several other appointment planning options are available as for example can be found in Hulshof et al. [11]. This literature review not only offers literature on tactical planning issues such as appointment planning, but provides a complete taxonomy to categorize all possible planning problems in health care.

Queueing Approach The used methods in this report to model and analyze the GHD planning processes are a Markov model combined with discrete event simulation. As was stated by Fone et al. [7], a discrete event simulation will give the opportunity to include several individual patient, and physician details, while still being able to estimate the effect of an individual change on the total patient population. This makes discrete event simulation a suitable method to investigate the strongly interdependent GHD planning processes. Besides discrete event simulation another commonly used modelling method for hospital patient flows is queueing theory. One of the benefits of queueing models is that they are in general simpler compared to simulation models [6]. This transparency of queueing models simplifies the determination of the influence of suggested changes on the final result. Meanwhile, the use of a queueing model requires simplification of the problem, and therefore, it requires making more assumptions. This makes queueing models less suitable for investigating large detailed patient flow systems.

A queueing model can be very useful to zoom in on a smaller part of a larger planning problem, and investigate possible improvements in this part. At the GHD it is hard to split the planning process in different parts due to the interdependence of all parts of the planning process. For example, two different parts might be the planning at the outpatient clinic and endoscopy unit. However, if a physician is available at the outpatient clinic, he is unavailable at the endoscopy unit and vice versa. This might be solvable by using a polling system, which contains multiple queues (e.g. consultation and endoscopy) attended by one server (the responsible physician) [2]. Cicin-Sain et al. [3] offer a paper in which a polling model is used to model an emergency room. However, as with most emergency room models, this model focusses on a different time horizon. At emergency departments the time horizon is equal to hours and the focus lies on unexpected walk-ins, while at the GHD most treatments are in advanced planned appointments and the time horizon is equal to days or weeks. Still there exist queueing models which make it possible to model the entire GHD process.

A general example of a queueing model useful in large hospital patient flow problems can be found in Creemers and Lambrecht [4]. They offer a queueing model which can be used to investigate the waiting times in a hospital department involving consultation, surgery and recovery. It involves n consultation stations, n surgery stations, and m recovery stations. Here n is the number of available physicians, and m the number of available recovery wards. The consultation and surgery station are $G/G/1$ queues, because they are only served by one physician. The recovery stations are $G/G/c$ queues, where c is the number of available recovery beds in the corresponding recovery ward. This model can easily be translated to the GHD situation, while the surgery stations can be replaced by endoscopy stations, and the recovery stations can be omitted. Recovery after an endoscopy at the JBZ is controlled by a different department, and it is assumed that enough recovery beds are available to cope with the maximum daily number of endoscopies.

However, in this model assumptions have been made that are not justified for the GHD situation. For example, it is assumed that each physician has his own consultation station and his own surgery station, and that no patient crossover can take place between physicians. At the GHD this is preferred for consultations, and simple endoscopies. However, for specialized endoscopies such as ERCPs, patient crossover is necessary, while only a part of the physicians is qualified to perform these endoscopies (see section 1.1). To implement this fact into the queueing model, three extra $G/G/c$ stations need to be added to the model, where each station represents one of the specialized endoscopies ERCP, EUS and Colonoscopy for BCS, and c the associated number of qualified physicians. The addition of these three extra stations results in an extra modelling issue. Each station is only available for a given amount of shifts per week. This is modelled by assuming that each station is available for a given shift, for example a daypart, followed by a 'vacation'. As was stated before each physician has his own consultation station and surgery station. The average vacation length for the consultation station and the corresponding surgery station are clearly related to each other, because they are served by the same physician. However, the addition of a specialized endoscopy station results in the interrelatedness of the station availabilities of all stations belonging to a staff member qualified for this specialized endoscopy.

Another assumption concerns the patient treatment paths. It is assumed that each patient starts with one or more consultations, followed by surgery, and finished by a number of check-up consultations. However, at the GHD patients can have multiple endoscopies during their treatment path, or no endoscopy. It is difficult to generalize the patient treatment paths for the different patient groups (see section 2.1), but it might not be impossible. If the two suggested changes can be implemented, then the queueing model seems suitable for modelling the GHD patient flow.

As was stated in section 2.1 access times for the first appointment depend on urgency, complaint and appointment type. Up until now it has been assumed that no difference will be made between urgent and non-urgent patients, and patients are treated according to a first-come-first-serve service policy. The described queueing model might be interesting to use for investigating the influence of introducing different priority levels to the system. Another interesting problem might be the investigation of periods with increased demand for treatments. According to the GHD staff, examples of peak moments are the BBQ season, or the days after Christmas, due to problems caused by eating differently. Both of these issues are commonly observed at emergency departments [8]. However, as was stated before, at emergency departments the time horizon is equal to hours. It might be possible to generalize queueing results for emergency departments into a more general result for the suggested GHD queueing model.

Appendix A

Summary of Used Variables and Terminology in Patient Treatment Path Model

A summary of the used variables and terminology.

States

- O: state depicting the Outpatient Clinic
- S: state depicting the Endoscopy Unit
- L: transition state if the PRT after the last appointment is ≥ 26 weeks.
- H: state depicting Home, or the exiting the Markov process.

Transitions

- Short term transition: Transitions between states O,and S, with PRT between 0 and 25 weeks.
- Long term transition: Transitions from state L to states O, and S, with PRT between 26 and 51 weeks.
- Home transition: Transition form state L to state H, with PRT over 52 weeks.

Transition Probabilities

- p_{G_i}: Probability of an arriving patient belonging to patient group $i \in \{1, ..., 12\}$.

- p_F: Probability of a patient starting their treatment path at state O.
- $p_{A,B}$: Probability of going from state A to state A, with $A, B \in \{O, S, L, H\}$.

Transition Times

- PRT: Preferred returning time. Lower bound on the transition time between two states. The preferred number of weeks between that patients last en next appointment.
  - PRT_i: PRT for appointment appointment A_i.
  - $PRT_{A,B}$: PRT between states A, and B with $A \in \{O, S, L, H\}$, and $B \in \{O, S, L\}$.
  - $PRT_{A,}$: PRT between state A, and any follow-up appointment in set $\{O, S\}$, with $A \in \{O, S\}$.
- $MAAT$: Maximum allowed access time. Upper bound on the transition times between two states, and the maximum number of allowed weeks between the last and next appointment.
  - $MAAT_i$: MAAT for appointment A_i. It is assumed that $MAAT_0 = 6$ if $A_0 = S$, and $MAAT_0 = 8$ if $A_0 = O$.
  - $MAAT_{A,B}$: MAAT between states A, and B with $A \in \{O, S, L, H\}$, and $B \in \{O, S, L\}$. This value can be determine by the relation between $PRT_{A,B}$ and $MAAT_{A,B}$ found in found in eq. 3.25.
  - $MAAT_{A,}$: MAAT between state A, and any follow-up appointment in set $\{O, S\}$, with $A \in \{O, S\}$.
- $T_{A,B}$ for $A, B \in \{O, S\}$: the discrete probability distribution vector for the short term transition PRT between states A and B, where

$$T_{A,B}^{(i)} = P(PRT_{A,B} = i - 1) \text{ for } 1 \leq i \leq 26 \quad \text{(A.1)}$$

- T_L: the discrete probability distribution vector for the long term transition PRT between states L and a state in set $\{O, S\}$, where

$$T_L^{(i)} = P(PRT_{L,} = i - 1) \text{ for } 1 \leq i \leq 26 \quad \text{(A.2)}$$

It is important to note that by definition $P(PRT_{A,L} = 26) = 1$ for all $A \in \{O, S\}$.

- δ: number of weeks between the PRT and $MAAT$. It is assumed that $\delta = 2$ at the GHD. The relation between $PRT_{A,B}$ and $MAAT_{A,B}$ is

$$MAAT_{A,B} = PRT_{A,B} + \begin{cases} \delta & \text{if } A \in \{O,S,L\} \text{ and } B \in \{O,S\} \\ 0 & \text{if } A \in \{O,S\} \text{ and } B = L \end{cases} \tag{A.3}$$

Detailed Appointments

- D_A^k: the vector associated with the discrete probability distribution to determine the detailed appointments in the treatment path, where $A = O$ (resp. S) if the distribution is over all outpatient clinic consultations (resp. all endoscopies), and $k = 1$ (resp. 2, or 3), if the appointment is in phase 1 (resp. 2, or 3) of the treatment path. (for details on treatment path phases, see section 4.1). For $B \in \{O,S\}$

$$P(A_0 = APP_j | A_0 = B) = (D_B^1)^{(j)} \tag{A.4}$$

and if $i \geq 1$

$$P(A_i = APP_j | A_i = B) = \begin{cases} (D_B^3)^{(j)} & \text{if } A_k = NP \text{ for a } 0 \leq k < i \\ & \text{or } A_0 = CO, CI \text{ or } CO/GA \\ (D_B^2)^{(j)} & \text{otherwise} \end{cases} \tag{A.5}$$

Appendix B

Appointment Planning Simulation Results

In this appendix the detailed simulation result figures, used in chapter 7 will be shown.

Waiting Times with Chapter 6 Supply Scenarios

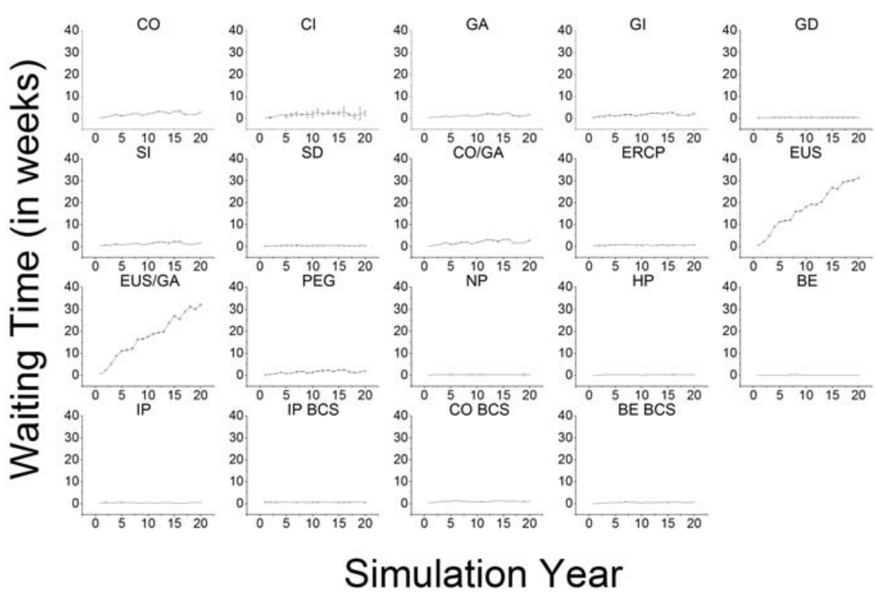


FIGURE B.1: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 2.

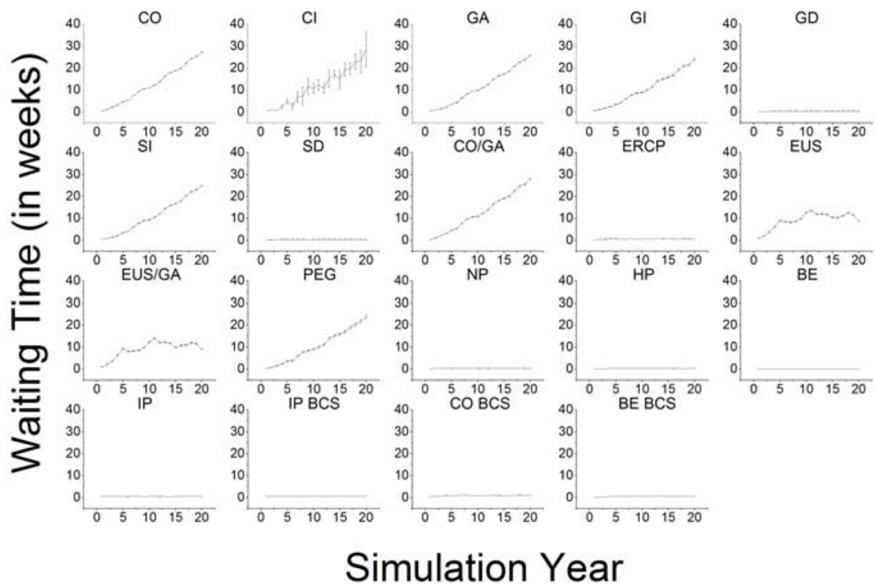


FIGURE B.2: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 3.

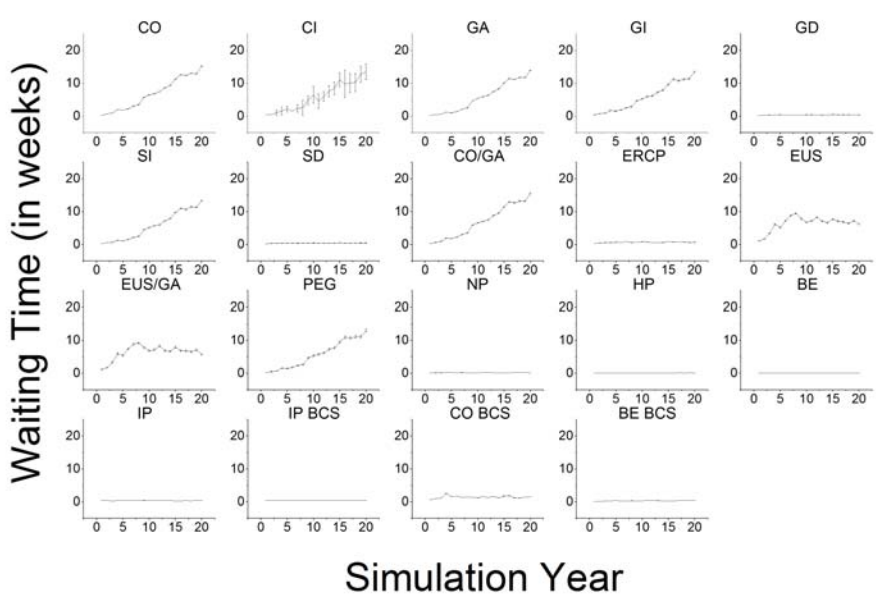


FIGURE B.3: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 4.

Waiting Times with Extra EUS Daypart Per Week

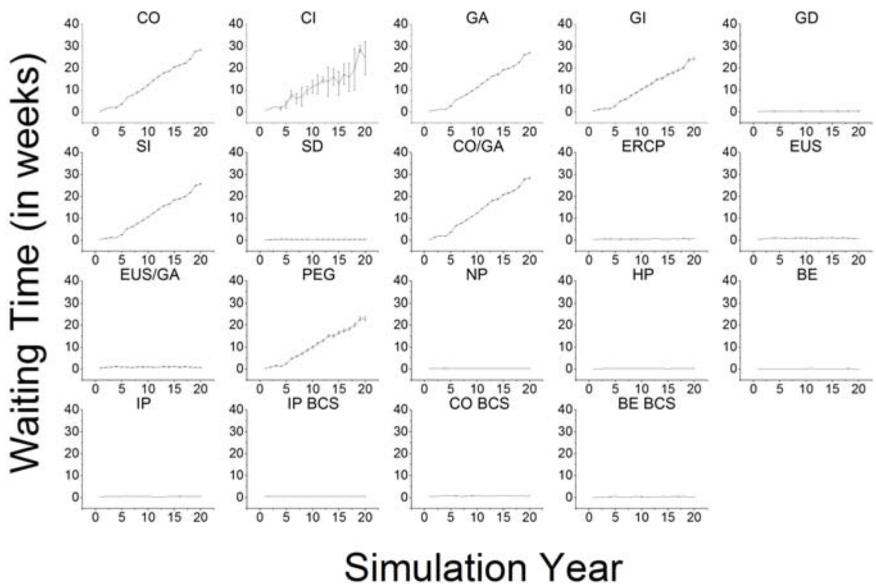


FIGURE B.4: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 3 with one extra EUS daypart per week.

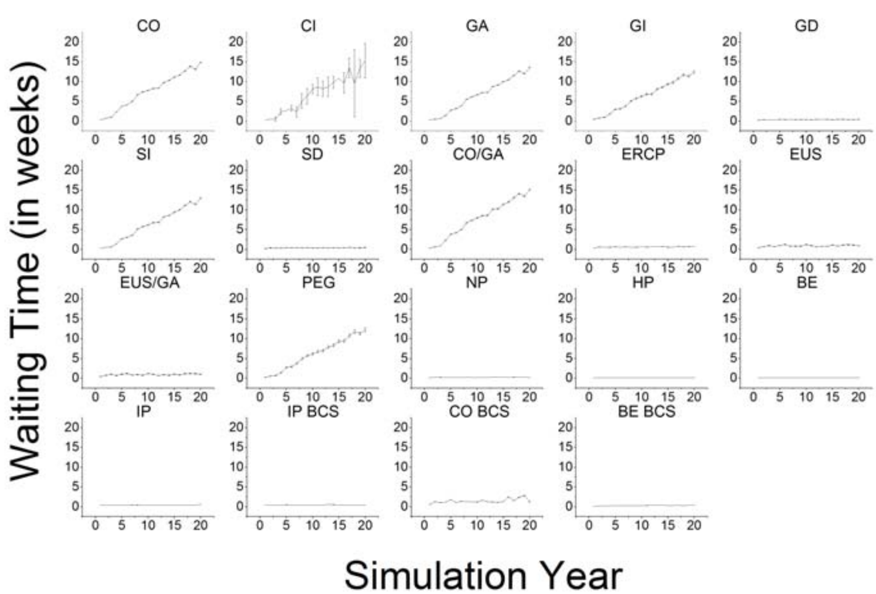


FIGURE B.5: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 4 with one extra EUS daypart per week.

Waiting Times with Change Ratio $(r_{CO}, r_{GA/SI}, r_{OC})$

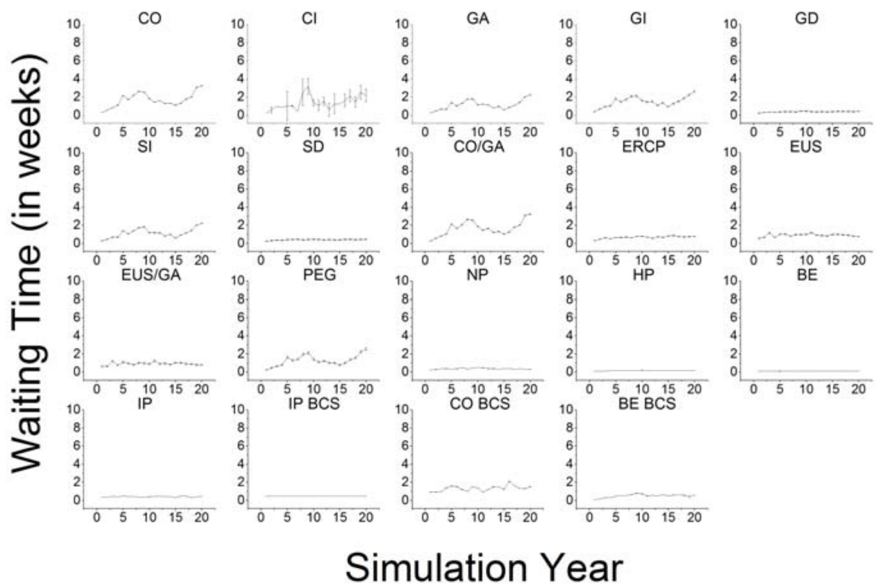


FIGURE B.6: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 3 with changed ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.39, 0.21, 0.40)$.

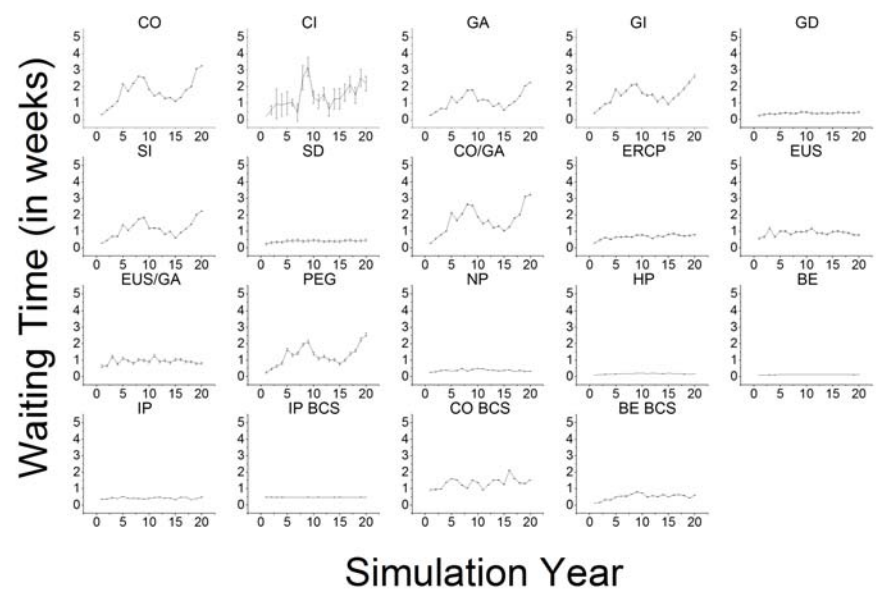


FIGURE B.7: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 4 with changed ratio $(r_{CO}, r_{GA/SI}, r_{OC}) = (0.39, 0.21, 0.40)$.

Waiting Times with Extra CO Staff Member

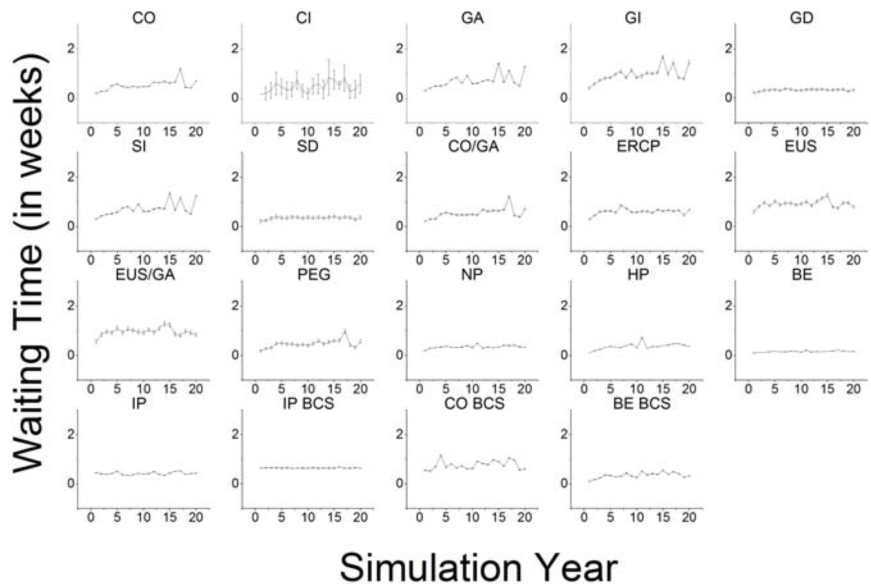


FIGURE B.8: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 2 with extra staff member performing CO for 3 dayparts per week.

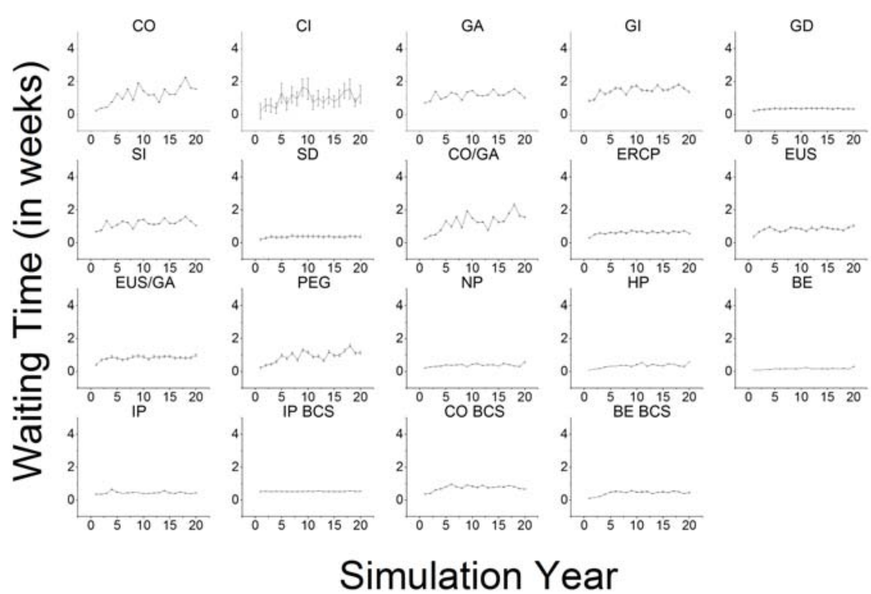


FIGURE B.9: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 3 with extra staff member performing CO for 3 dayparts per week.

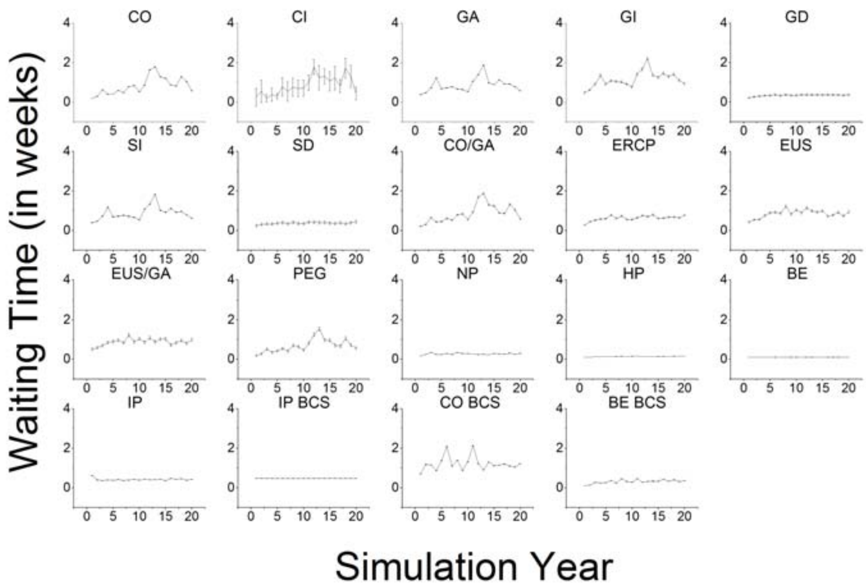


FIGURE B.10: $\bar{W}_{APP_j,Y}$ and $s_{APP_j,Y}$ for demand and supply scenario 4 with extra staff member performing CO for 3 dayparts per week.

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