Same day access: mission (im)possible?

A study on the possibility to improve same day access at the radiology department of the NKI-AVL hospital

Master thesis Industrial Engineering & Management
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University of Twente
Enschede - The Netherlands

NKI-AVL
The Netherlands Cancer Institute
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Management summary

In the radiology department of the NKI-AVL (Netherlands Cancer Institute – Antoni van Leeuwenhoek hospital), a same day appointment for ultrasound examination is not an can not always be offered to the patient. This results in unnecessary visits to the NKI-AVL hospital and a long diagnostic trail. Currently, 24% of all patients who need an ultrasound examination is examined on the same day as their request. These same day appointments lead to disturbances in the regular process, and long waiting times for patients.

This study determines the performance of the ultrasound modality in different scenarios for improving same day access in the radiology department. First, we determine the current performance of the ultrasound modality. Next, we develop various scenarios to a) anticipate the current same day demand, and b) facilitate open access at the radiology department. We construct a simulation model to evaluate the performance of the ultrasound modality in each scenario.

Analyzing the current performance of the ultrasound modality shows that other day outpatients (73,9% of all patients) wait an average of 7,31 days for their appointment, and other day inpatients (1,9%) wait 2,25 days on average. For outpatients, we analyze the waiting time in minutes on the day of the examination. Other day outpatients wait an average of 7,21 minutes for their examination to start. Same day outpatients (14,0%) wait an average of 58 minutes between the request at the radiology desk and the start of the examination. Utilization of the ultrasound modality is hard to determine because of lack of data, but generally more examinations are performed than the regular capacity admits. Average daily overtime is 30 minutes: 16,4% of all work is performed in overtime.

To anticipate the current same day demand, we evaluate three schedules by comparing these with the zero measurement (base measurement of the current situation). In Schedule 1, slots are reserved in the schedule when same day demand is expected. Goal is to minimize the waiting time for same day patients. Schedule 2 reserves a block of same day slots at the end of each day part. Advantage of this schedule is clarity for personnel and patient. Schedule 3 is a combination of Schedules 1 and 2: a minimal amount of slots reserved during the day, and a block of same day slots at the end of the day. Goal is to reduce the risk of idle time.

Computational results show that reserving slots when same day demand is expected (Schedule 1) leads to decreased average waiting times for same day patients (65 minutes in the zero measurement, to 50 minutes using Schedule 1), and other day outpatients (7,5 to 3,0 minutes). The use of two blocks to handle same day demand (Schedule 2), and reserving a minimal amount of same day slots during the day (Schedule 3) both lead to increased average waiting times for same day patients (Schedule 2: 86 minutes, Schedule 3: 81 minutes). For all three scenarios the average overtime is slightly higher than in the zero measurement. In terms of average idle time per day, Schedule 3 performs best. Advantage of Schedule 2 and Schedule 3 is that the risk of idle time can be further reduced in practice.

When striving for open access, the simulation study shows that the mammapoli mornings and lunch breaks lead to high waiting times. We cope with this problem in two possible ways: 1) we

increase the capacity, and 2) balance the demand to the available capacity of the ultrasound modality.

Increasing capacity leads to shorter waiting times and more patients served on the same day, but on the other hand increased idle time. When daily opening the ultrasound modality between 8.50 AM and 5 PM, 91,6% of all patients is served on the same day, with an average waiting time of 12 minutes. Average idle time per day is 149 minutes in this scenario. Balancing demand leads to better overall performance of the ultrasound modality. Using the current capacity, with mammapolis, lunch breaks, and Wednesday afternoon closed, we compare the results with the current demand pattern and the balanced demand pattern. The average waiting time for same day patients reduces more than an hour (from 105 minutes to 42 minutes), the amount of same day patients increases (from 69,1% to 86,4%), and the average idle time per day decreases (from 46,6 minutes to 41,1 minutes).

Overview of main computational results									
	Other day patients			**Same day patients**					
	Ratios		Waiting time	Ratios		Waiting time	Avg converted	Avg overtime	Avg idle time
Scenario	*%inpatient*	*%outpatient*	*outpatient(minutes)*	*%inpatient*	*%outpatient*	*SDP (minutes)*	*per day (%)*	*per day (minutes)*	*per day (minutes)*
Anticipate current same day demand									
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Schedule 1	2,8%	73,8%	3,00	10,3%	13,0%	50,50	-	25,25	27,95
Schedule 2	2,8%	73,6%	10,56	10,3%	13,3%	86,43	-	28,30	28,12
Schedule 3	2,7%	73,6%	9,85	10,5%	13,3%	81,02	-	27,23	25,63
Facilitate open access									
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Open access	2,7%	28,2%	2,46	9,0%	60,1%	105,62	31,4%	38,97	46,57
Increase capacity	1,1%	7,3%	minus 0,73	10,7%	80,9%	12,12	9,5%	29,22	148,90
Balance demand	1,2%	12,4%	0,33	10,8%	75,6%	41,58	13,9%	39,30	41,05

Implementation of the strive for open access can be done in steps: start with Tuesday or Friday (where no mammapoli reservations are scheduled), evaluate, and possibly extend the implementation for the other weekdays. Although balancing demand to availably capacity is complex, a combination of (limited) increase of capacity and (partly) balanced demand leads to better overall performance.

Future research is recommended on patient preferences, and on the patient flow from the outpatient clinic to the radiology department. Extending this study for the radiology department as a whole is interesting.

Management samenvatting

Op de afdeling radiologie van het NKI-AVL (Nederlands Kanker Instituut – Antoni van Leeuwenhoek ziekenhuis), kan een echo onderzoek niet altijd op dezelfde dag als de aanvraag aangeboden worden aan de patiënt. Dit leidt tot onnodige bezoeken aan het Antoni van Leeuwenhoek ziekenhuis en een vertraagde diagnose. Op dit moment wordt 24% van alle patiënten die een echo onderzoek nodig heeft onderzocht op dezelfde dag als de aanvraag van het onderzoek. Deze 'same day' afspraken veroorzaken verstoringen van het reguliere proces en lange wachttijden voor patiënten.

Deze studie onderzoekt de prestatie van de echografie modaliteit in verschillende scenario's met als doel 'same day access' (onderzocht worden op dezelfde dag als de aanvraag) op de afdeling radiologie te verbeteren. Eerst wordt de huidige prestatie van echografie bepaald. Vervolgens ontwikkelen we verscheidene scenario's om a) te anticiperen op de huidige 'same day' vraag, en b) 'open access' te faciliteren, waarbij aan elke patiënt een onderzoek op dezelfde dag als de aanvraag wordt aangeboden. We construeren een simulatiemodel om de prestatie van de echografie modaliteit in elk scenario te evalueren.

Wanneer we de huidige prestaties van echografie onderzoeken blijkt dat poliklinische patiënten die niet op dezelfde dag worden geholpen (73,9% van de patiënten) gemiddeld 7,31 dagen wachten op hun onderzoek, klinische andere dag patiënten (1,9%) wachten gemiddeld 2,25 dagen. Voor poliklinische patiënten onderzoeken we de wachttijd in minuten op de dag van het onderzoek. Andere dag poliklinische patiënten wachten gemiddeld 7,21 minuten op de start van het onderzoek. Poliklinische patiënten die op dezelfde dag worden onderzocht (14,0%) wachten gemiddeld 58 minuten tussen de aanvraag bij de balie en de start van het onderzoek. De bezetting van de echografie modaliteit is lastig te bepalen door een tekort aan geschikte data, maar in het algemeen worden er meer onderzoeken verricht dan de reguliere capaciteit toelaat. Per dag wordt gemiddeld 30 minuten buiten reguliere werktijd gewerkt (16,4% van al het werk).

We evalueren drie schedules om op de huidige 'same day' vraag te anticiperen, door deze schedules met de nulmeting van de huidige situatie te vergelijken. In Schedule 1 zijn planning slots gereserveerd wanneer 'same day' vraag wordt verwacht. Het doel is de wachttijd voor patiënten te verkorten. Schedule 2 reserveert een blok van 30 minuten voor 'same day' patiënten aan het eind van elk dagdeel. Voordeel van dit schema is duidelijkheid voor zowel het personeel als de patiënt. Schedule 3 combineert Schedule 1 en Schedule 2: reserveer een minimaal aantal slots gedurende dag, en een 'same day' blok aan het eind van de dag. Doel is het risico op 'idle time' (de radioloog heeft geen patiënten) te reduceren.

De simulatie laat zien dat het reserveren van slots wanneer 'same day' vraag wordt verwacht (Schedule 1) leidt tot aan afname in de wachttijden voor poliklinische 'same day' patiënten (65 minuten in de nulmeting naar 50 minuten bij Schedule 1), en poliklinische andere dag patiënten (7,5 naar 3,0 minuten). Het gebruik van twee 'same day' blokken (Schedule 2), en het reserveren van een minimaal aantal slots gedurende de dag (Schedule 3) leiden tot toename van wachttijd voor 'same day' patiënten (Schedule 2: 86 minuten, Schedule 3: 81 minuten). Voor alle drie scenario's is de gemiddelde overtijd per dag iets hoger dan in de nulmeting. Schedule 3 presteert het beste ten aanzien van gemiddelde 'idle time' per dag. Het voordeel van Schedule 2 en Schedule 3 is dat het risico op 'idle time' in de praktijk nog gereduceerd kan worden.

De resultaten van de simulatie laten zien dat wanneer we streven naar 'open access', de mammapoli ochtenden en de lunchpauzes leiden tot lange wachttijden. Met dit probleem gaan we om op twee mogelijke manieren: 1) het uitbreiden van de capaciteit, en 2) het balanceren van de vraag aan de beschikbare capaciteit van de echografie modaliteit.

Het uitbreiden van de capaciteit leidt tot kortere wachttijden en meer patiënten die op dezelfde dag worden onderzocht, maar aan de andere kant een toename in 'idle time'. Wanneer de echografie modaliteit dagelijks tussen 8.50 uur en 17.00 uur is geopend, wordt 91,6% van alle patiënten op dezelfde dag onderzocht, met een gemiddelde wachttijd van 12 minuten. De gemiddelde 'idle time' per dag is 149 minuten. Het balanceren van de vraag leidt tot betere overall prestaties van de echografie modaliteit. Wanneer we de huidige capaciteit gebruiken, met de mammapoli ochtenden, lunchpauzes en woensdagmiddag gesloten, vergelijken we de resultaten met het huidige vraagpatroon voor echografie onderzoeken en het gebalanceerde vraagpatroon. De gemiddelde wachttijd voor 'same day' patiënten vermindert dan met meer dan een uur (van 105 minuten naar 42 minuten), het aantal 'same day' patiënten neemt toe (van 69,1% naar 86,4%), en de gemiddelde 'idle time' per dag neemt af (van 46,6 minuten naar 41,1 minuten).

Overzicht van de belangrijkste resultaten									
	Andere dag patiënten			**'Same day' patiënten**					
	Ratios		Wachttijd	Ratios		Wachttijd	Gem converted	Gem overtijd	Gem 'idle time'
Scenario	*%klinisch*	*%polikl*	*polikl (minuten)*	*%klinisch*	*%polikl*	*polikl (minuten)*	*per dag (%)*	*per dag (minuten)*	*per dag (minuten)*
Anticiperen op de huidige 'same day' vraag									
Nulmeting	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Schedule 1	2,8%	73,8%	3,00	10,3%	13,0%	50,50	-	25,25	27,95
Schedule 2	2,8%	73,6%	10,56	10,3%	13,3%	86,43	-	28,30	28,12
Schedule 3	2,7%	73,6%	9,85	10,5%	13,3%	81,02	-	27,23	25,63
'Open access' faciliteren									
Nulmeting	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Open access	2,7%	28,2%	2,46	9,0%	60,1%	105,62	31,4%	38,97	46,57
Capacitieit uitbreiden	1,1%	7,3%	minus 0,73	10,7%	80,9%	12,12	9,5%	29,22	148,90
Vraag balanceren	1,2%	12,4%	0,33	10,8%	75,6%	41,58	13,9%	39,30	41,05

Het implementeren van het streven naar 'open access' kan in stappen: start met de dinsdag en de vrijdag (op deze dagen zijn geen mammapoli ochtenden), evalueer, en breid de implementatie eventueel uit voor de andere weekdagen. Hoewel het balanceren van de vraag een complexe taak is, leidt een combinatie van (beperkte) uitbreiding van de capaciteit en (gedeeltelijk) balanceren van de vraag tot betere overall prestaties voor de echografie modaliteit.

Toekomstig onderzoek naar patiëntvoorkeuren en de patiëntenstroom vanuit de polikliniek naar de afdeling radiologie wordt aangeraden. Het uitbreiden van dit onderzoek voor de hele afdeling radiologie is interessant.

Preface

In 2007, I gained some experience in hospitals in two ways. The year started in a hospital in Nijmegen, where surgery on my leg lead to the first challenge of 2007: endure a long road of rehabilitation and uncertainty. A few months later, May 2007, it was time for the next challenge: accomplish my graduation project in the Antoni van Leeuwenhoek hospital to finish the master Industrial Engineering and Management.

The first challenge I undervalued, the other was more fun than I expected. Although many students complain about the graduation phase, in my case various factors cause a more positive view. First, the starting point of the project was luxurious: all data needed for the study were already collected. Maarten den Braber, thanks for that! Second, my supervisors constantly kept me on the right track. Erwin Hans helped me to clearly structure the project, make short and concise formulations and keep an open mind when searching for possible solutions. The critical view of Wim van Harten focused on the possibilities for practical implementation. In our frequent meetings, he surprised me with thorough questions on all details. For Saar Muller of the radiology department, not any detail (especially concerning data analysis) escapes her very quick and thorough analysis. Brainstorming and discussion with Saar kept me sharp and critical. Without the (sometimes critical) feedback of Erwin, Wim, and Saar, this project would not have lead to the concrete results presented in the study, and maybe would even not be finished yet!

There are also a few others I would like to thank. Jelle Teertstra and Theo van Ooij, who initiated the project and provided important input for the study. I thank all radiologists, technicians and Petra Haagsma from the radiology department, who answered my questions and showed me around. Wineke van Lent, thanks for your frequent feedback on my output. Martijn Mes from the University of Twente, who helped me to overcome some troubles with the simulation model. Daily lunch breaks with Jorrita, Lilian, Loes, Wineke, Eva, Inge, Pien, Chantal, Leonard and Relinde were always fun and a welcome variation, especially during peak days.

Finally, I thank my parents, other family, and my friends for making 2007 a year never to forget..!

Amsterdam, December 2007

Rozan Gilles

Table of contents

Glossary

Patient groups

Outpatient: a patient who visits the hospital, not admitted in the hospital

Inpatient: a patient who is admitted in the hospital

Other day outpatient (ODOP): an outpatient whose appointment is not on the same day as the prescription

Same day patient (SDP): an outpatient examined on the same day as the prescription

Other day inpatient (ODIP): an inpatient whose appointment is not on the same day as the prescription

Emergency patient (EP): an inpatient examined on the same day as the prescription

Mammapoli patient: an outpatient going through a trail of consultations and examinations to diagnose possible breast cancer in one day

Ultrasound examinations

Regular examination: an examination for which one planning slot of 10 minutes is reserved

Longproc examination: an examination for which two or more planning slots of 10 minutes are reserved

Other definitions

Radiology Information System (RIS): information system of the radiology department containing data on patients and patient flow

Same day demand: the request of any type of patient for an examination on the same day as the prescription

Same day access / Open access: the strive to offer all patients an appointment on the same day as the request for examination

1 Introduction

This chapter first describes the background of the research (Section 1.1), followed by an introduction to the context in which the research takes place: the NKI-AVL (Section 1.2). We expand on the problem, which is the starting point for this research (Section 1.3). This leads to the formulation of the research objective and research questions. On the basis of these research questions we describe the research approach(Section 1.4).

1.1 Background

In the Netherlands Cancer Institute – Antoni van Leeuwenhoek hospital (NKI-AVL), during recent years, process improvement project have played an important role. Improving quality, safety and efficiency of healthcare processes are the main objectives of these projects (NKI-AVL 2005).

The Institute of Medicine (IOM) defines quality of care as *"the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge"* . IOM splits up the desired health outcomes; health care needs to be *safe*, *effective*, *patient-centred*, *timely*, *efficient* and *equitable*. Nowadays, as increasing demand causes waiting lists to grow, the focus on timely and efficient care is essential (Institute of Medicine 2000).

Chief radiologist (J. Teertstra) and chief technician (Th. van Ooij) of the radiology department of NKI-AVL initiated this project by placing a request to examine the possibility for patients visiting the department to be examined on the same day as their request. Currently, patients who need an examination at the radiology department, especially for ultrasound, make an appointment at the radiology desk for the examination(s). An appointment on the same day is not and cannot always be offered to the patient. This results in unnecessary visits to the NKI-AVL and a long diagnostic trail for the patient. When nevertheless a same day appointment is given to a patient, this leads to disturbances in the regular process and long waiting times for patients.

In order to improve this situation, this research focuses on facilitating same day access for patients visiting the radiology department, by first focusing on the ultrasound modality. Besides performing this research for ultrasound, we consider the issues and differences when applying the study on other modalities of the radiology department.

1.2 Context: NKI-AVL

1.2.1 NKI-AVL

The NKI-AVL consists of the Netherlands Cancer Institute and the Antoni van Leeuwenhoek hospital, both domiciled in Amsterdam. These two entities work together closely in order to deliver high quality fundamental and clinical research as well as hospital services and radiotherapy. NKI-AVL has 1468 FTE personnel and 180 beds (NKI-AVL 2006).

In short, the mission of NKI-AVL is to "combat cancer by means of patient care, research and education". By combining highly specialized care and scientific research, synergy leads to accurate treatment of oncology patients, leading scientific research and the education of highly qualified people.

Figure 1 shows the structure of the organization. Overhead of the hospital and the research institute are shared.

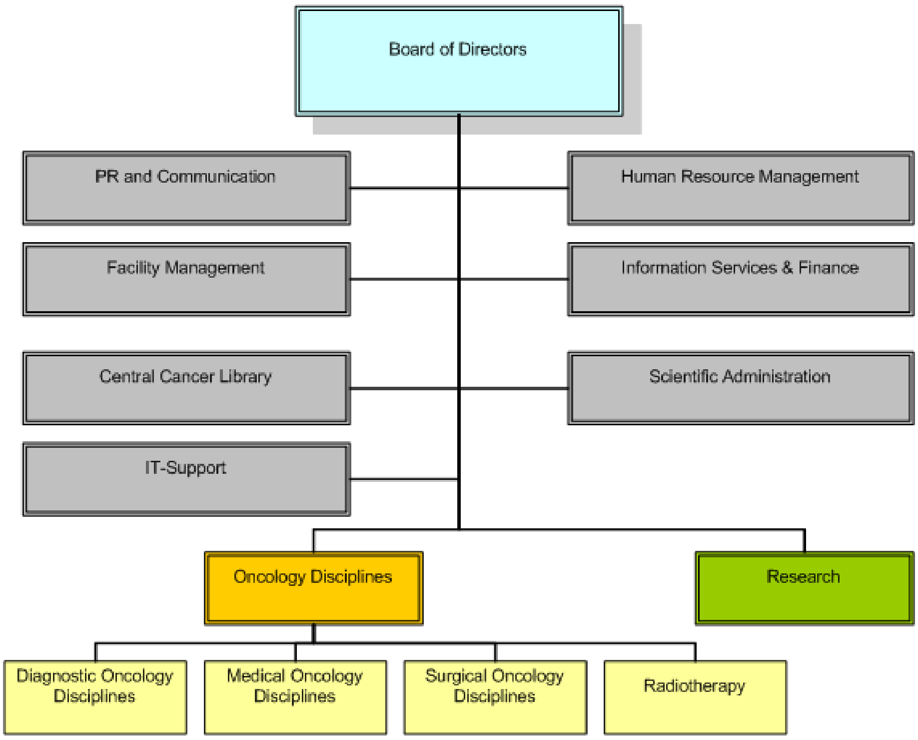

Figure 1 – Organization chart of NKI-AVL

In this research, we focus on the radiology department, which is part of the cluster Diagnostic Oncology Disciplines (DOD). In Section 1.2.2, we introduce the radiology department.

1.2.2 The radiology department

The radiology department performs diagnostic examinations on different modalities: the CT scanner, MRI scanner, bucky (X-ray), ultrasound, and R/F intervention. Patients who visit the radiology department can be roughly divided into inpatients (patients admitted in the hospital), outpatients (patients visiting the outpatient clinic of NKI-AVL) and external patients (patients from another hospital for which NKI-AVL performs diagnostic procedures). Each patient that visits the radiology department is examined on one or more of the radiology modalities. In 2006, the radiology department performed almost 41000 examinations (Table 1).

Examinations radiology 2006	
Modality	*Number of examinations*
CT scanner	10159
MRI scanner	3833
Mammography	6230
Bucky	13008
Ultrasound	6331
R/F and intervention	1345

Table 1 - Procedures performed by radiology in 2005 (RIS 2006)

The radiology department employs 7 radiologists (6,5 FTE), 29 technologists (22 FTE) and 10 FTE administrative personnel. Two clinical physicists (1,5 FTE) are employed at the department (November 2007).

The department is involved in various improvement projects to speed up the process of diagnosing cancer on patients. An example is the 'mammapoli' trail; in the morning a patient visits a specialist in the outpatient clinic and is referred to the radiology department to be further diagnosed. Mammography and ultrasound are performed consecutively, and when necessary some tissue is taken and directly sent to the lab. During the lunch break the involved specialists meet and discuss the medical statuses of all patients and the most appropriate treatment. In the afternoon all patients are informed by the specialist from the outpatient clinic. The same routine is performed for some other specialties, e.g. head/neck and lung.

1.3 Problem description

Outpatients without a medical indication for diagnostics on the same day can generally be scheduled within a week on the ultrasound modality. The NKI-AVL treats patients coming from different areas in The Netherlands and even some from foreign countries. Unnecessary visits to NKI-AVL are not preferable, especially for those patients that do not live close to the hospital.

Patients who need an ultrasound examination on the same day as the prescription, and outpatients who request for an examination on the same day are scheduled in slots of the schedule that are otherwise blocked for other patients or on slots which are not open. The patient waits in the hospital for the examination to take place, until there is (little) room for the examination in the schedule. This results in waiting times for the patient as well as high peaks in work pressure and work in overtime for the radiology department.

These problems were the starting point for Den Braber (2007)'s preliminary study. Den Braber collected data concerning the entire ultrasound process in the radiology department. After a first analysis of the collected data from the Radiology Information System (RIS), Den Braber mainly concludes that:

1. Already 30% of all ultrasound patients are scheduled on the ultrasound modality on the same day as their request for examination at the desk.

2. By using another base schedule, peaks in 'same day' demand can be anticipated.

3. Radiologists are the bottleneck in the ultrasound examination process (Chapter 2). Den Braber suggests to (temporarily) use radiologists from other radiology modalities (Den Braber 2007).

We use the data collected by Den Braber, as well as the main results of the preliminary study of Den Braber during this research.

Increasing the number of same day examinations for ultrasound requires capacity and demand to be in balance, and an efficient appointment schedule. This is the focus of our research.

While the central problem in this research to some extent applies to all modalities in the radiology department, we primarily analyze the ultrasound modality in this study, in order to reduce complexity. We do pay attention to the relationship and the differences between ultrasound and other radiology modalities concerning patient scheduling.

1.4 Research objective and approach

The objective of this research is:

"Determine the performance of the ultrasound modality in different scenarios for improving same day access in the radiology department"

In order to reach the research objective, we answer the following research questions:

1. *What is the current performance of the ultrasound modality?*

Chapter 2 describes the current process of the ultrasound modality. We identify different patient groups, describe the examination process, analyze the examination duration and identify possible disturbances in the scheduling process. In collaboration with the stakeholders of the radiology department we define performance measures. Analyzing data on the process provides insight in the current performance. Section 2.3 briefly describes the other modalities of the radiology department.

To analyze the current process and get familiar with the routines of the department we interview various employees at the radiology department, and follow the work of various employees during the day. For quantitative analysis we use data from the Radiology Information System (RIS). Den Braber collected data from the RIS in his preliminary study (Den Braber 2007). These data contain various time stamps for all patients that visited the radiology department in 2006.

2. *Which scenarios can be developed for the ultrasound modality?*

Chapter 3 describes the literature on open access, appointment systems and the use of simulation in healthcare. Conclusions of this chapter are the starting point for the development of various scenarios (Chapter 4). Next to the literature, we use the input of stakeholders from the radiology department for scenario development. Section 4.1 describes the steps in a simulation study. Section 4.2 focuses on the development of various scenarios to a) anticipate the current same day demand and b) facilitate open access at the radiology department. Relevant settings for the simulation are illustrated in Section 4.3

3. *What is the performance of the ultrasound modality in various scenarios?*

We evaluate the constructed scenarios of Chapter 4 using a simulation model. Chapter 5 describes the constructed simulation model of the radiology department. We describe the input and output of the model as well as the assumptions made while modeling. Section 5.3 describes the validation of the model.

Chapter 6 describes the computational results for a) anticipating current same day demand and b) facilitating open access. For both parts various scenarios are evaluated. Section 6.3 gives insight in the relation of the ultrasound modality with the other modalities of the radiology department.

After discussion (Section 7.1) of the results, we draw conclusions (Section 7.2) and formulate recommendations (Section 7.3) for the radiology department, and for further research.

Figure 2 visualizes the structure of this report.

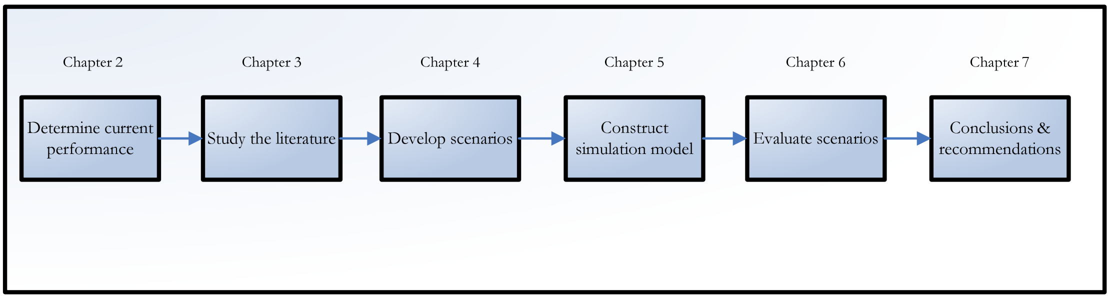

Figure 2 – Structure of the report

2 Analysis of current scheduling process

This chapter structures the process of ultrasound: we introduce different patient groups (Section 2.1.1), and describe the process of ultrasound step by step (Section 2.1.2). Section 2.2 describes the performance of the ultrasound modality through a number of performance indicators, identified in collaboration with the stakeholders of the department. Section 2.3 briefly describes the other radiology modalities. Section 2.4 summarizes the conclusions of this chapter.

2.1 Process description: ultrasound

2.1.1 Patient groups

We distinguish the following types of patient groups that visit the radiology department for an ultrasound examination: 'emergency patients', 'same day patients', 'other day inpatients' and 'other day outpatients'. Unfortunately, the information system does not register whether a patient is an emergency patient or not. From practice it follows that most inpatients examined on the same day as the prescription seem to be patients with an emergency indication. Although not all inpatients examined on the same day have this indication, we assume *inpatients* examined on the *same day* to be *emergency patients*. Inpatients stay in the hospital, outpatients visit the hospital. Although a fraction of all outpatients could have an emergency indication, we assume that outpatients are never 'emergency patients'. However, outpatients do request for an examination on the same day as the prescription for several reasons: e.g. to prevent unnecessary visits to the NKI-AVL. We classify *same day patients* as *outpatients* examined on the *same day* as the prescription. We classify *other day outpatients* as *outpatients* whose appointment is *not on the same day* as the prescription. We classify *other day inpatients* as *inpatients* whose appointment is *not on the same day* as the prescription. Table 2 provides an overview of the patient groups.

Patient types		
patient type	*definition*	%
emergency patients	*inpatients* examined on the same day as the prescription	10,2%
same day patients	*outpatients* examined on the *same day* as the prescription	14,0%
other day outpatients	*outpatients* whose appointment is *not on the same day* as the prescription	73,9%
other day inpatients	*inpatients* whose appointment is *not on the same day* as the prescription	1,9%

Table 2 – Classification of patient types

Some patients only need ultrasound examination(s) (63,4%), others combine their appointment with an appointment on one of the other radiology modalities (e.g. bucky, CT-scanner) (36,6%).

The radiology department separately registers 'mammapoli' patients. These are patients that make use of 'speed diagnostics'. Section 2.1.1 clarifies this term. In the schedule of ultrasound, capacity is reserved for this patient group. In this study, we do not consider 'mammapoli' patients. Therefore, in all data we use, we exclude this patient group.

2.1.2 Ultrasound examination process

Patient flow

Each patient that visits the radiology department is scheduled at the radiology desk, waits in the waiting room for the examination to take place, and is examined by a radiologist. After the examination the radiologist reports his findings, and finally the report is authorized and sent to the requesting specialist. All steps in this process are registered in the Radiology Information System (RIS) for each patient, by manually changing the status of the patient. Figure 3 shows Den Braber (2007)'s patient flow model, which shows the statuses that are registered in the RIS. Table 3 explains the most relevant statuses of this research project. We refer to Appendix A for the entire patient flow model of Den Braber.

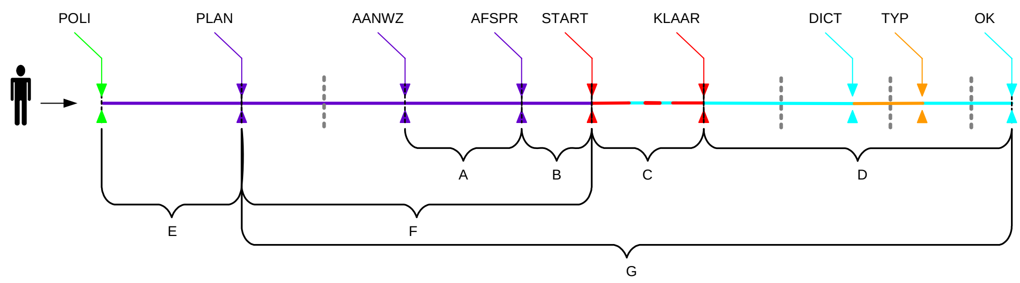

Figure 3 – Patient flow model (Den Braber 2007)

Statuses in patient flow model	
PLAN	*radiology desk employee enters appointment*
AANWZ	*patient enters waiting room*
AFSPR	*appointment time*
START	*patient enters examination room*
KLAAR	*patient leaves examination room*

Table 3 – Relevant statuses of patient flow model

Resources

Two ultrasound examination rooms are available at the radiology department. Both rooms are equipped with different ultrasound equipment, but capable to do all possible ultrasound examinations. Many radiologists switch between the two rooms: when the radiologist performs an examination in room one, preparation of the next patient starts in room two. A few radiologists do not work in both rooms, for instance because of preference for equipment in either of the two rooms.

Normally, one radiologist performs all ultrasound examinations during the day. Occasionally, when it is very busy, a second radiologist performs examinations as well, until the queue of patients to be examined has declined. The radiologists are assisted by one or two technicians. The radiologist is the bottleneck in the process: radiologist capacity determines the capacity of the ultrasound modality.

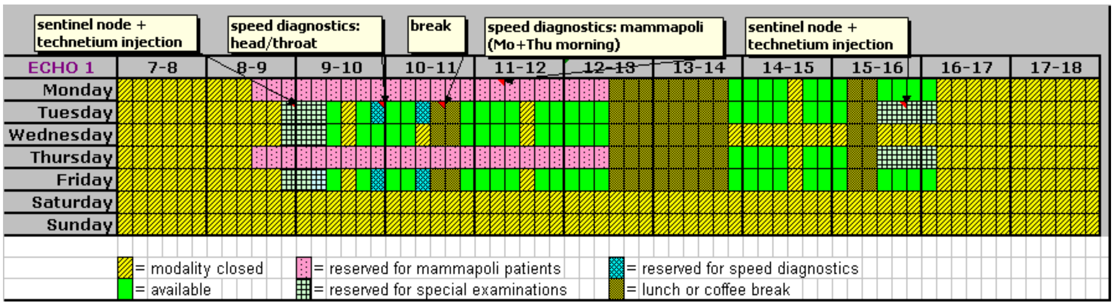

Figure 4– Schedule used for ultrasound

The ultrasound schedule consists of ten-minute-slots. Figure 4 shows the current schedule used for scheduling patients. All green slots are available for scheduling patients. The yellow slots indicate that the modality is closed. On Wednesday afternoons, the radiologists are having a meeting: the ultrasound modality is closed. In practice, only emergency patients are examined then. For some days, in the morning and in the afternoon one slot is indicated yellow; this is a buffer slot to cope with disturbances in the program. The grey slots indicate a coffee or lunch break. Some slots have a different colour, these are reserved for special examinations such as 'sentinel node' and 'speed diagnostics' (Section 2.1.5). When these special slots are not filled, they become available as normal green slots a few days before the specific date of the time slot. Monday and Thursday mornings are always reserved for 'mammapoli': speed diagnostics for breast cancer examinations. In practice, all patients are scheduled on Echo1 (examination room 1). When this schedule is full, and an emergency patient or same day patient needs to be scheduled, the patient is scheduled in Echo2 (in which all slots are indicated yellow).

The examination

Employees at the radiology desk schedule all patients that need ultrasound examination at the radiology department. Other day inpatients and other day outpatients are scheduled on the first planning slot that is available and that suits the patient. Depending on the expected duration of the examination, one or more planning slots (10 minutes or e.g. 30 minutes) are reserved. The radiology desk strives for scheduling all patients within seven days from the date of request. There are also patients who need to be diagnosed for periodic control purposes: these patients are scheduled on the date when control is needed (e.g. after six months). Emergency patients and same day patients are examined on the same day as the request for examination, despite the full schedule for ultrasound. One radiology desk employee is responsible for fitting these patients in the full schedule. After consultation of the radiologist and/or the technician about the current status of the regular program, the patient is scheduled and informed. The moment a patient is scheduled at the radiology desk, status PLAN is assigned to the patient.

On the day of the appointment the patient shows up at the radiology desk before entering the waiting room. The employee changes the status of the patient manually into AANWZ (present).

Before the radiologist starts the examination, the patient is prepared for the examination by the technician. At that moment the status is manually changed into START. When the radiologist is ready to perform the examination, (s)he enters the examination room. This moment is not registered in the RIS. Ultrasound examination is performed by the radiologist, with assistance of a technician. The radiologist leaves the room after finishing the examination. This moment is not registered in RIS. When the patient is ready to go, (s)he leaves the examination room and the technician changes the status of the patient in the system into KLAAR (ready).

The radiologist can report the findings of the examination in two ways: online reporting and batch reporting. Using online reporting, the dictated report is directly transformed into a digital report. The radiologist checks and corrects this report and finally authorizes it. When batch reporting is used, the radiologist dictates the report and the secretary listens to the dictation and corrects the transcription. After the correction, the radiologist verifies the report and authorizes it. The patient's status finally changes to OK after authorization by the radiologist, and the report is sent to the requesting specialist.

Speed diagnostics

Some slots in the schedule are reserved for 'speed diagnostics'. The goal of speed diagnostics is to accelerate the process of diagnosing cancer and determine the appropriate treatment for the patient. At this moment there are four trails in speed diagnostics: lung, head/neck, gynecology, and the mammapoli trail. For ultrasound, only the head/neck and mammapoli trails are relevant, because in the other trails ultrasound is not included. Two planning slots per week are reserved for the head/neck trail on Tuesday. On Monday and Thursday mornings the ultrasound modality is reserved for the mammapoli trail.

Challenges

Currently, the main challenge is to offer patients an ultrasound examination on the same day the examination is prescribed: when a specialist requests for an 'emergency examination' or when a patient wants so. We want to reduce the waiting time for the patient, i.e. the time between making the appointment and the start of the ultrasound examination, while maintaining or improving the utilization rate and number of patients examined. We keep in mind that not all patients are eligible for 'same day' diagnostics: some need diagnostics on a periodic basis, or combine their ultrasound appointment with appointment(s) on other radiology modality(ies).

2.1.3 Examination duration

Figure 5 visualizes the difference between duration examination for the patient and the radiologist. The time between statuses START and KLAAR indicates the time the patient is in the examination room. The radiologist time per patient (time between RSTART and RKLAAR) is not registered in the RIS. Manual measurements, performed by technicians on duty, provide some insight in the radiologist time per patient. Examination duration varies: examination duration can be less than 10 minutes when a regular echo is made, but sometimes further examination, a punction or consultation of the specialist at the outpatient clinic by the radiologist is needed. This substantially lengthens the examination duration.

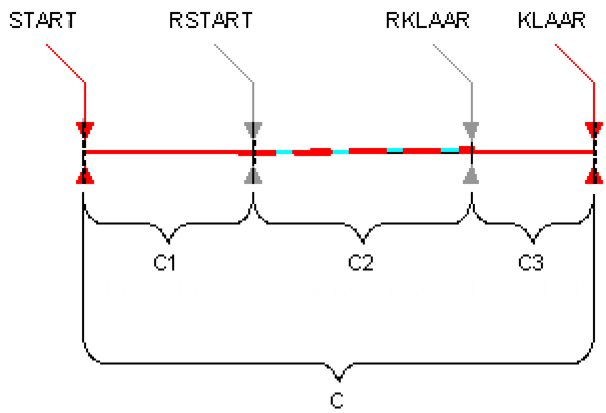

Figure 5 – Visualization of examination duration for the patient and the radiologist time (deducted from Patient flow model (Den Braber 2006))

Examination duration: patient

We distinguish *regular* examinations, for which a planning slot of 10 minutes is reserved (88%), and *longproc* examinations: examinations for which 20 or more minutes are reserved in the schedule of ultrasound (12%). Figure 6 shows the distribution of the patient time in minutes for regular examinations. Most examinations take 10 minutes, mean examination duration is 12,31 minutes for regular examinations. Skewness is 10,10 and standard deviation is 12,32 minutes: this indicates that examination duration deviates especially to the upper side of the mean. Figure 7 shows the distribution of the examination duration for longprocs. The distribution of longproc examination durations is more symmetric than the one for regular examinations (skewness is 2,80), but standard deviation is about the same (12,80 minutes) . Mean duration of a longproc examination is 18,33 minutes. Table 4 shows the summary statistics on examination duration for the patient, separated for regular examinations and longprocs.

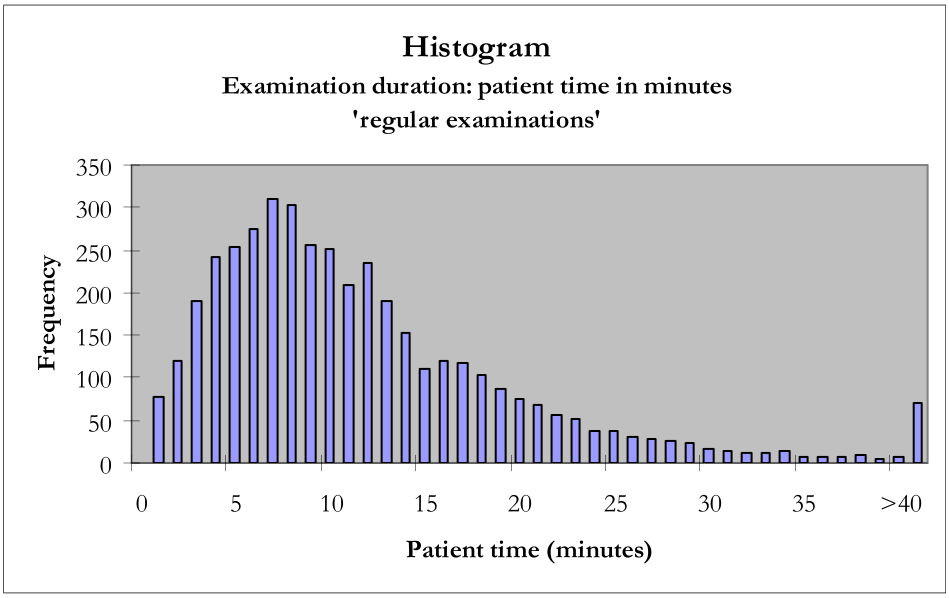

Figure 6 – Examination duration for the patient in minutes. Regular examinations: planned duration is 10 minutes. ((RIS 2006), all inpatients and outpatients (n=4217))

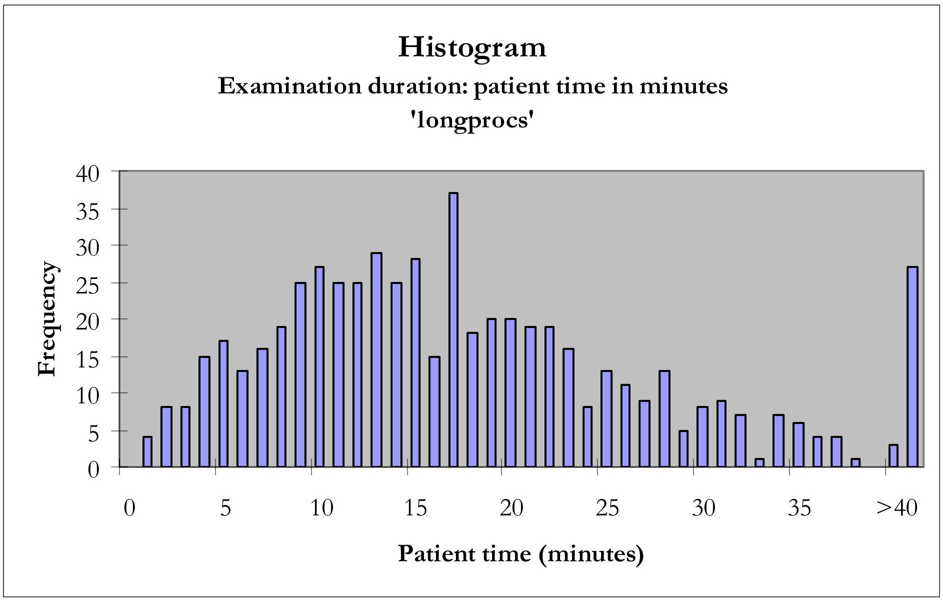

Figure 7 – Examination duration for the patient in minutes. Longprocs: planned duration >= 20 minutes. ((RIS 2006), all inpatients and outpatients (n=584))

Patient time in minutes		
	regular	*longproc*
Mean	12,31	18,33
Median	10	16
Modus	7	17
Standard Deviation	12,32	12,80
Variance	151,74	163,91
Skewness	10,10	2,80
Count	4217	584
Confidence Interval (95%)	0,37	1,04

Table 4 – Summary statistics on examination duration for the patient ((RIS 2006), all inpatients and outpatients, regular examinations (n=4217); longproc examinations (n=584))

Examination duration: radiologist

The histogram (Figure 8) and summary statistics (Table 5) follow from manual measurements performed on 66 patients. In these measurements we do not distinguish regular examinations and longprocs, as we did for patient time. Radiologist time is the time between entrance of the radiologist in the examination room to perform the examination, and exit of the radiologist after finishing the examination. The mean of the observed radiologist times is 7 minutes, but because the number of observations is low, the found mean is only an indication for the radiologist time.

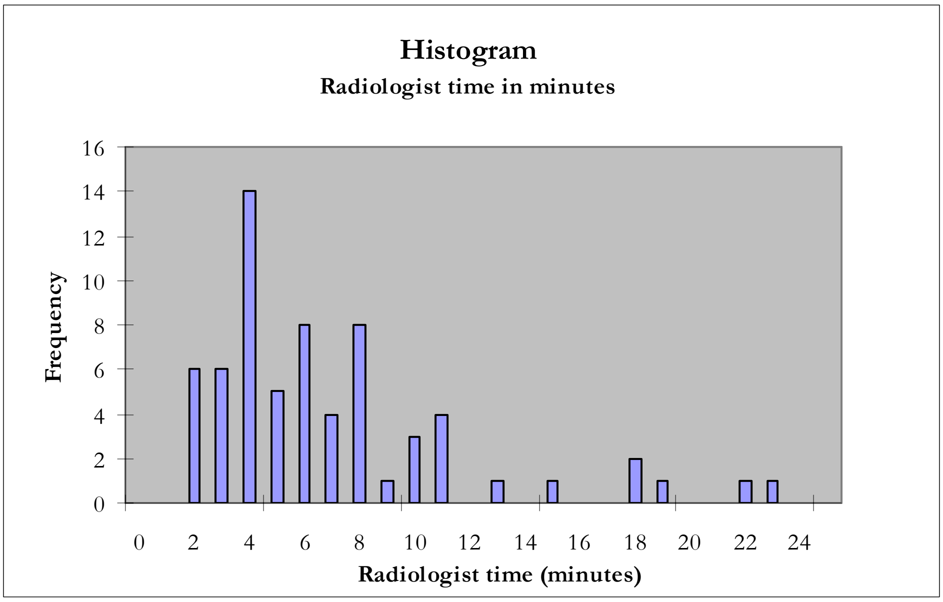

Figure 8 – Radiologist time in minutes (manual measurements, April/May 2007, n=66)

RadiologistTime	
Mean	7
Median	6
Modus	4
Standard Deviation	4,76
Variance	22,62
Skewness	1,68
Count	66
Confidence Interval (95%)	1,17

Table 5 – Summary statistics on radiologist time in minutes (manual measurements, April/May 2007, n=66)

2.1.4 Disturbances

Disturbances in the process can be caused by patients not showing up for their appointment, patients that come too late (or too early) for their appointment, and appointments that need to be rescheduled (requested by specialist or patient).

The RIS-data on 2006 show that no-shows are about the same for inpatients (3,7%) and outpatients (3,9%), but do depend on whether the appointment is on the same day as the prescription (2,2%) or not (4,6%).

Most other day outpatients show up before the appointment starts (86,5%), but people can be late for their appointment as well (13,5%). Figure 9 shows the arrival pattern of patients for their appointment, this is the time between AANWZ and AFSPR.

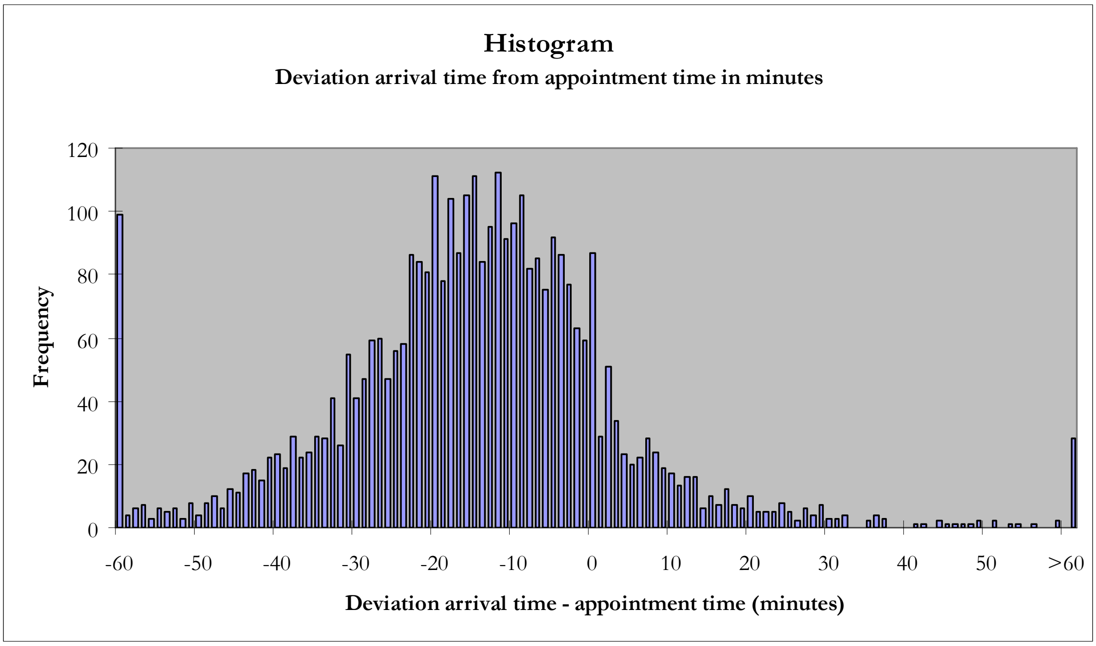

Figure 9 – Deviation of arrival time from appointment time ((RIS 2006), other day outpatients (n=3551))

2.2 Current performance

To determine the performance of the radiology department (especially the ultrasound modality), we select (quantifiable) measures for performance together with stakeholders of the radiology department. Stakeholders involved are the head radiologist, head technician and the clinical physicist of the department. We use data collected from the RIS on ultrasound in 2006 to determine the values for the chosen performance measures. This section describes the performance measures and the analysis performed to determine the current values of the measures.

2.2.1 Patient waiting time

We divide patient waiting time in waiting time in days and waiting time in minutes. Waiting time in days is a relevant measure for other day inpatients and other day outpatients, because they are not examined on the same day as the prescription. The waiting time in minutes is relevant for all outpatients (same day outpatients and other day outpatients), and of less relevance for all inpatients. This is because they are admitted in the hospital and therefore do not have to wait in the waiting room for their examination to take place. Waiting time in minutes provides insight in the time a patient waits in the hospital before the examination starts. This section discusses both measures in detail.

Waiting time in days

Patient waiting time in days is the time in days between the patient's request for examination and the day of the appointment. Not all patients request for an examination in the short term. Some patients schedule their appointment on a periodic basis, for example for control purposes. Analyzing the data on waiting time in days supports this: we identify several peaks, for example after 3 and 6 months. To measure performance, we analyze all other day patients that are scheduled within 21 days after their request for examination. Our choice for 21 days is based on the intention of the department to offer all patients an ultrasound examination within 21 days.

Figure 10 shows the histogram for the waiting time in days for other day inpatients and other day outpatients. As Table 6 shows, average waiting time for inpatients is significantly shorter than the waiting time for outpatients. Of all patients (including same day outpatients and emergency patients), 88% is scheduled within 21 days. Thus, the amount of patients scheduled for periodic control purposes is relatively low. The two minor peaks around 7 and 14 days can be explained by patients requesting specifically for an appointment after respectively 7 or 14 days. Within 7 days, 66% of all patients is scheduled, and within 14 days already 80% of all patients is scheduled.

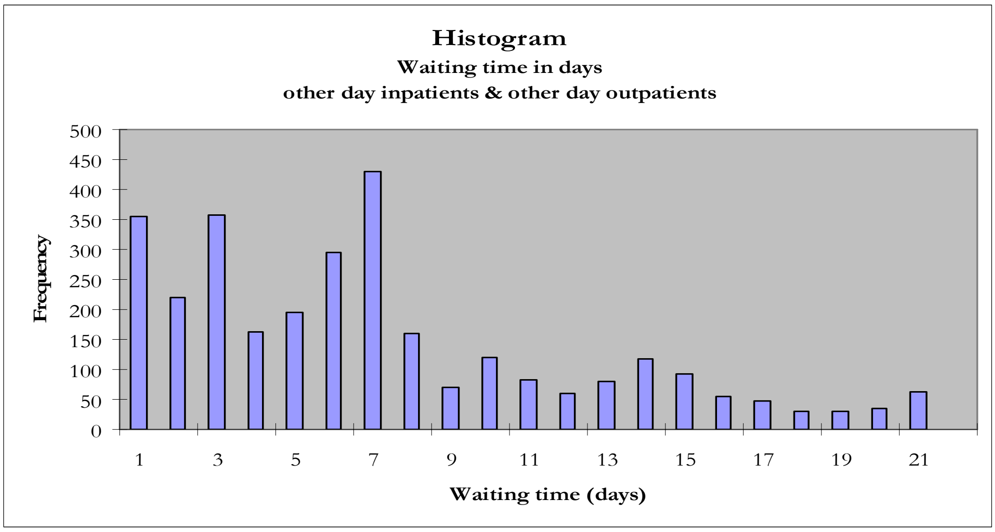

Figure 10 – Waiting time in days ((RIS 2006), other day inpatients and other day outpatients scheduled within 21 days (n=3053))

Waiting time in days			
	other day inpatients + outpatients	*other day outpatients*	*other day inpatients*
Mean	7,16	7,31	2,25
Median	6	6	1
Modus	7	7	1
Standard Deviation	5,14	5,12	2,58
Variance	26,42	26,26	6,64
Skewness	0,91	0,90	2,99
Count	3053	2962	91
Confidence Interval (95%)	0,18	0,18	0,54

Table 6 - Summary statistics on waiting time in days, separated for other day inpatients and other day outpatients ((RIS 2006), other day inpatients and outpatients (n=3053); other day outpatients (n=2962); other day inpatients (n=91), all scheduled within 21 days)

Waiting time in minutes

Next to waiting time in days, the time a patient waits in the hospital to get the ultrasound examination is an important measure. For same day patients, the waiting time is the time between the patient reporting at the radiology desk with the request, and the start of the ultrasound examination. For other day patients, we analyze the time between the appointment time and the start of the examination. In this way, patient-induced waiting time, caused by patients showing up too early for their appointment, is not considered. For patients that arrive too late, the time between arrival and start of the examination is considered. For this analysis we only use data on outpatients. Inpatients are admitted in the hospital, and do not have to wait in the waiting room. Figure 11 gives an overview of the formulas used, in terms of RIS statuses from the patient flow model.

Other day outpatients:
When patient arrives before appointment time
Waiting time = START – AFSPR
When patient arrives too late
Waiting time = START - AANWZ

Same day patients:
Waiting time = START - PLAN

Figure 11 – Formulas used to determine the waiting time in minutes

For other day outpatients the mean waiting time is 8,25 minutes (standard deviation 17,24) when all outpatients (including patients showing up too early, excluding outliers) are considered, but when we only consider positive waiting times the mean waiting time is 15,96 minutes (standard deviation 12,44). Of all other day outpatients, for 27% the examination starts before the appointment time. The histogram (Figure 12) shows a peak for 0 minutes. These are incorrect registrations, caused by patients who forgot to report their presence, and therefore excluded from our analysis. For same day outpatients the waiting time is longer: 57 minutes (Table 7). Of all same day outpatients, 27% waits more than 60 minutes for the examination. For 44% of this group the examination starts within 30 minutes. The histogram (Figure 13) shows that waiting times vary for same day outpatients (standard deviation is 71 minutes).

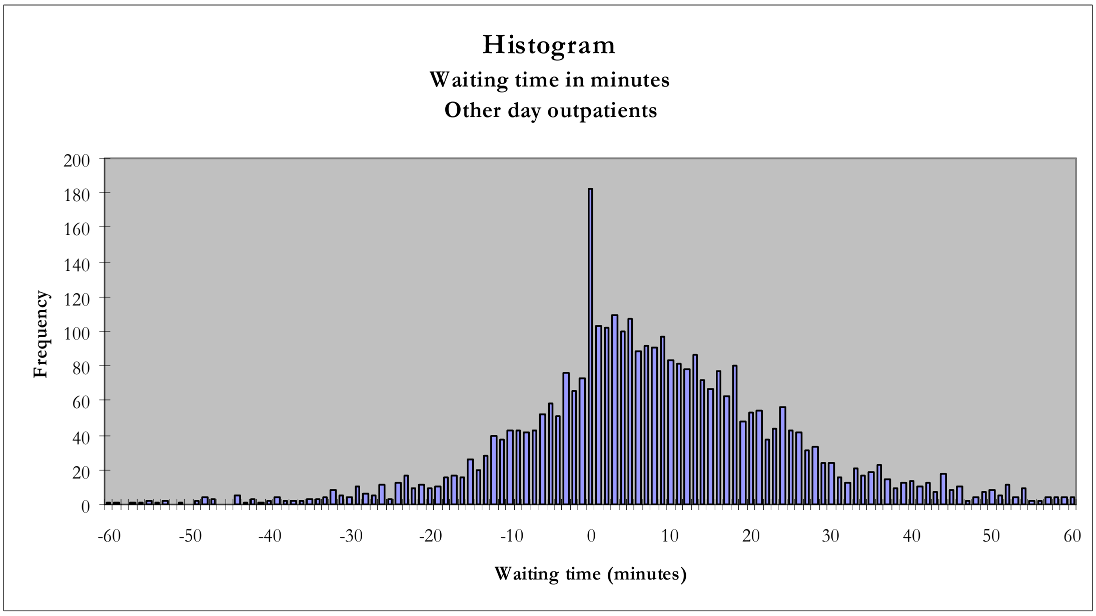

Figure 12 – Patient waiting time in minutes for other day outpatients. Time between AFSPR and START, corrected for late patients ((RIS 2006), other day outpatients, outliers excluded (n=3461))

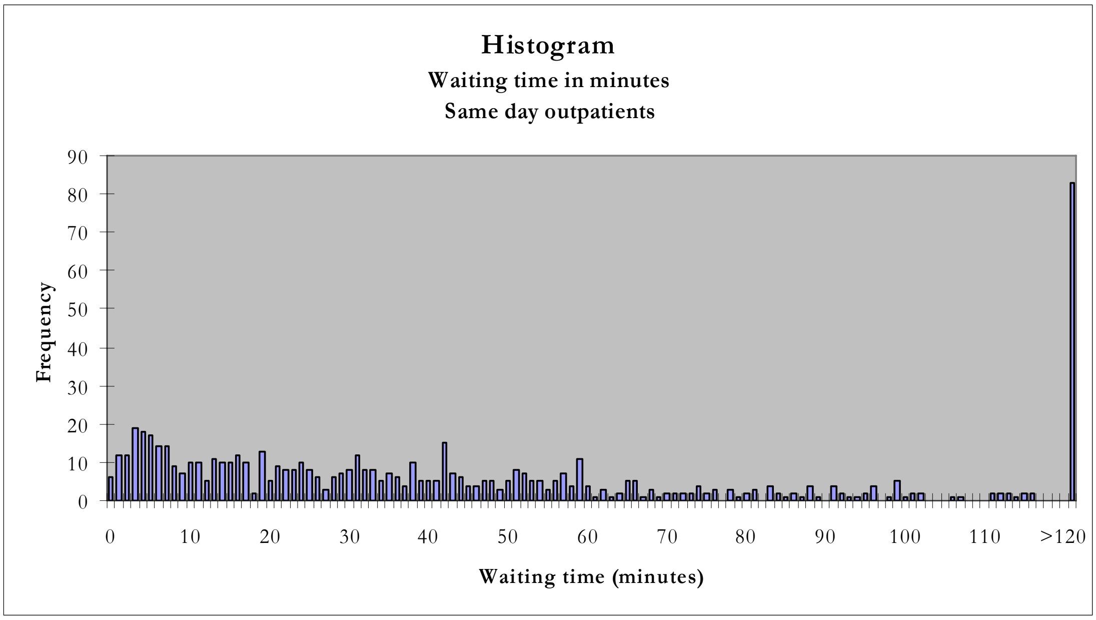

Figure 13 – Patient waiting time in minutes for same day outpatients. Time between PLAN and START ((RIS 2006), same day outpatients (n=671))

Waiting time in minutes			
	Other day outpatients ≠ 0 min	*Other day outpatients > 0 min*	*Same day outpatients*
Mean	8,25	15,96	57,64
Median	8	13	35
Modus	3	3	3
Standard Deviation	17,24	12,44	71,15
Variance	297,06	154,72	5062,39
Skewness	-0,05	1,14	2,49
Count	3279	2361	671

Table 7 – Summary statistics on waiting time in minutes ((RIS 2006), other day outpatients excluding 0 minutes waiting time, outliers neglected (waiting time between -60 and +60 minutes) (n=3279); other day outpatients excluding waiting time <= 0 minutes, outliers neglected (waiting time between +1 and +60 minutes) (n=2361); all same day outpatients (n=671))

2.2.2 Utilization

Utilization is a measure for the degree of use of available capacity. Concretely, we do not want the radiologist to be waiting for patients to arrive for an ultrasound examination. Ideally, all available planning slots are filled with examinations.

It is difficult to determine the current utilization rate. Mainly, because of the current "loose" schedule that is used. From section 2.1.3 it follows that the mean radiologist time is 7 minutes, which is less than the 10 minutes which are reserved in each slot. Thus, the planning slots of 10 minutes per patient seem to contain a 'buffer' of on average 3 minutes per slot. Empirically it seems that this 'buffer' provides flexibility for the radiology department to cope with emergency patients and same day outpatients. Next to the "loose" schedule, switching between examination rooms 1 and 2 causes overlap in the registered durations. Simply adding up the examination durations results in an extremely high utilization rate, which does not represent the actual usage of the capacity.

To get an indication of the utilization of the ultrasound modality we analyze the amount of planning slots filled and the amount of planning slots available in the schedule of 2006. We distinguish regular slots and slots for which the modality is closed (i.e., slots reserved for breaks, buffer slots, or slots outside regular working hours). Emergency patients or same day outpatients that do not fit in the regular schedule anymore, are scheduled on the yellow or red slots (indicating closure of the modality) after consultation of the radiologist/technician on duty. Slots reserved for special examinations or mammapoli patients are not considered. Table 8 shows the results of the analysis. Due to the reasons mentioned earlier, the utilization rate is extremely high (157%) when dividing the total number of planning slots filled by the number of available planning slots. Assuming that all filled slots take mean radiologist time of 7 minutes, this results in 42798 minutes of work, against 38950 minutes available (number of available slots * 10 minute slot length). These numbers result in an utilization rate of 110%. Overtime (Section 2.2.3), and the number of examinations performed (Section 2.2.4) provide more insight in the work pressure at the ultrasound modality.

Utilization of the planning slots			
No. of regular slots filled	3805		
No. of available regular slots	3895		
Utilization rate regular slots	97,7%		
No. of closed slots filled	2309		
Total no. of filled slots	6114	*x 7 min*	42798
Total no. of available slots	3895	*x 10 min*	38950
Overall utilization rate	157%		110%

Table 8 – Utilization of the ultrasound modality (RIS 2006)

2.2.3 Overtime

Ideally, all examinations are performed within the regular schedule of ultrasound. Therefore, we define overtime as the examination time performed outside the regular schedule, i.e. during coffee/lunch breaks and after the closing time of the ultrasound modality.

To determine the amount of work performed outside the regular working hours on ultrasound, we analyze the delays in the morning (work during lunch break) and afternoon and the work performed during coffee breaks. Table 9 shows the regular working hours and breaks.

Regular working hours				
	morning		*afternoon*	
Monday	8.30-12.30		13.50-15.10	15.30-16.10
Tuesday	8.50-10.30	10.50-12.30	13.50-15.10	15.30-16.10
Wednesday	8.50-10.30	10.50-12.30	*closed*	
Thursday	8.30-12.30		13.50-15.10	15.30-16.10
Friday	8.50-10.30	10.50-12.30	13.50-15.10	15.30-16.10

Table 9 – Regular working hours for ultrasound

The morning delay is the time between the *finish* of the latest examination that ends during the lunch break, and the *regular start* of the lunch break. The afternoon delay is the time between the *finish* of the latest examination that ends after the overtime starts, and the *regular program finish* of the day. For Wednesday afternoon we add up the processing times for examinations performed while the modality is closed. Work performed during coffee breaks is also work in overtime. To analyze the work done during breaks we study all examinations that finish during the coffee breaks. This study can provide only an approximation of the level in which breaks are skipped to serve patients. In practice, breaks might be only postponed a little, not skipped. Our analysis does not cover this. Total overtime is approximately 7620 minutes (127 hours), while total work during regular hours is 38950 minutes (649 hours) (all green slots * 10 minutes). Of all work performed, 16,4% is performed during overtime. Table 10 presents the total overtime, as well as the averages per day.

Overtime			
	minutes	*hours*	*avg. per day (min)*
morning delay	719	12,0	2,83
afternoon delay	878	14,6	3,46
work during breaks	6023	100,4	23,71
TOTAL work in overtime	**7620**	**127**	**30**
TOTAL work during regular hours	38950	649	153
% during overtime	19,6%		

Table 10 – Work performed in overtime (RIS 2006)

2.2.4 Number of ultrasound examinations performed

The number of ultrasound examinations performed is an indication for the utilization of the ultrasound modality. In 2006, 4802 ultrasound examinations were performed (Table 11). The *number of examinations* equals the *number of appointments*. Mammapoli patients are excluded.

Number of examinations		
Inpatient	*emergency*	489
	other day	91
Total inpatient		580
Outpatient	*same day*	671
	other day	3551
Total outpatient		4222
Total no. of examinations		4802

Table 11 – Number of examinations on ultrasound modality (RIS 2006)

2.2.5 Resources used

We refer to section 2.1.2 (*Resources*), where we describe the amount of resources currently used in terms of the schedule of the ultrasound modality, the equipment available and the personnel used for performing ultrasound examinations. Table 12 summarizes this.

Echography resources		
	number:	remarks:
Examination rooms	2	mostly switched between the rooms
Radiologists	1	occasionally 2
Technicians	1-2	depending on amount of personnel at radiology department

Table 12 – Overview of ultrasound resources

2.2.6 Effort needed to schedule a patient

Although we do not have data concerning the time which is needed at the radiology desk to plan a patient, any new scheduling approach should not be too cumbersome in use.

Currently, other day patients are scheduled on the first slot that is available and suits the patient. The effort needed to schedule these patients is minimal. However, emergency patients and outpatients that request for an examination on the same day are scheduled differently (for a flow chart of the scheduling process we refer to Appendix B). One employee at the radiology desk is responsible for fitting the emergency and same day patients in the schedules of the different modalities. After consultation of the radiologist and/or the technician on duty, the responsible employee schedules the patient on a planning slot and communicates this to the patient. The time this process takes varies: sometimes a only a few minutes, sometimes even an hour.

2.2.7 Correlation

Some measures defined in Section 2.2 correlate (negatively) with each other. For example, high utilization might result in high waiting times for patients. Although this need not be a linear correlation, this study provides insight in this relation. The stakeholders should decide on what they believe is the optimal balance between the measures.

2.3 A brief analysis of the other radiology modalities

To provide an overall view of the radiology department, this section briefly describes each modality. We describe the process of examination, the potential preparation for some examinations and the current scheduling issues, such as current waiting time and possible disturbances in the scheduling of patients.

2.3.1 CT-scan

Capacity: The radiology department uses two examination rooms, which it shares with the radiotherapy department and nuclear medicine respectively. Nevertheless, the radiology has full-time availability of a CT-scanner. CT examinations are performed by technicians: three technicians are generally assigned to the CT-scanner.

Scheduling: Usually, the waiting time varies between 2 and 3 weeks. Possible disturbances in the schedule are for example caused by some patients that do not show up for their appointment and emergency patients that need a CT-scan. Not all emergency indications lead to a CT examination on the same day: sometimes an appointment within a week is desired by the treating specialist. The CT-scanner is involved in speed diagnostics for gynecology, head/neck and lung. For these trails, several planning slots are reserved. Next to speed diagnostics, two slots per week are reserved for 'Hipec' screenings.

Preparation: A CT-scan is mostly performed on a patient after administering contrast fluid to the patient. Therefore, many patients prepare for the examination at home through drinking the contrast fluid the night before and during the day of the examination. Often, patients receive contrast fluid intravenously during the examination as well. For a few CT examinations preparation at home is not necessary: CT neck, CT thorax, CT liver and CT scans of bone structures and vertebras. For examinations concerning (part of the) abdomen, preparation at home is always necessary. A same day appointment for such examinations is not possible.

Examination: CT examinations are generally divided into CT-general, for which a planning slot of 10 or 20 minutes is reserved, and CT-intervention, with 40 minutes time reserved. Occasionally, 60 minutes are reserved for 'CT-angio' examinations. Actual examination duration varies due to possible consultation of the radiologist when the CT request is not clear and/or complications during the placement of the drip needle for contrast fluid. This leads to inefficiency.

Ultrasound patients that combine their appointment with this modality: 8,37% of all ultrasound patients combines the appointment with an appointment for a CT-scan (and possibly other appointments).

2.3.2 MRI-scan

Capacity: The radiology department has access to one MRI-scanner. This MRI-scanner is full-time scheduled. Two technicians prepare the patient and perform the examinations.

Scheduling: For general MRI-scans and mamma examinations and on the MRI-scanner, the waiting time usually is about 2 weeks. Disturbances in the scheduling process occur, e.g. through the arrival of emergency patients. These are complex to fit in the full schedule of the MRI-scanner, occasionally causing heavy peak-days. Incidentally, appointments are cancelled on the day of the appointment for reasons such as patient fear and the inability to lie still in the scan. For speed diagnostics on gynecology and head/neck several planning slots are reserved. As a consequence of clustering the mamma examinations on the MRI-scan, slots are reserved for those examinations as well.

Preparation: Before the examination can start, the MRI-scanner has to be prepared for the specific examination to take place. Different examinations require different coils (configuration of the examination table), for example for an MRI head/neck exam the heaviest coil of 18 kilos is installed on the table. For this reason, mamma examinations are already clustered, and in the near future the head/neck examinations will be clustered too. Patients do not need preparation at home for the examinations, they only need to pass the checklist and physically fit in the MRI-scan. This is verified upon scheduling the patient. Sometimes contrast fluid or other medication is administered to a patient intravenously during the exam. The drip needle is placed by the technician before or during the MRI-scan.

Examination: Duration of the examination varies significantly, depending on the type of examination. Sometimes a patient undergoes more than one examination at a time. Some examinations take 20 minutes, others 60 minutes. Deviations from the planned examination duration are mostly caused by examinations that (partly) failed and have to be repeated. Repeating a part of the examination takes approximately 1-7 minutes. This causes disturbances in the process.

Ultrasound patients that combine their appointment with this modality: 5,81% of all ultrasound patients combines the appointment with an appointment for a MRI-scan (and possibly other appointments).

2.3.3 Mammography

Capacity: Two mammography examination rooms are currently available for performing mammography examinations. In practice, mostly one room is used. The other room is used in case of a very full program. Generally, during mammapoli mornings two technicians staff the mammography, on other days only one.

Scheduling: Many of the mammography examinations are periodic and therefore scheduled far in advance. This results in many cancellations because patients forget their appointment, and rescheduling requests of patients at the radiology desk. Sometimes rescheduling of patients is necessary because of unforeseen absence of the treating specialist. The 'mammapoli' trail, one of the speed diagnostics trails of the radiology department, includes a mammography examination. In the schedule, time is reserved for this trail on Monday and Thursday mornings. The waiting time for mammography examinations is low: often no waiting time is involved.

Preparation: No preparation is needed for a mammography examination.

Examination: For a normal mammography examination a planning slot of 10 minutes is reserved. When more specific mammography is also needed, e.g. spot mammography, more time is reserved. Some examinations take less than 10 minutes, but others delay. This is caused by, for example, repetition of some examinations when one fails, consultation of the radiologist about the quality of the examination or the presumption of the technologist that further examination might be needed. Next to this, some breasts are easy to examine, others difficult, thus taking more time.

Ultrasound patients that combine their appointment with this modality: 8,45% of all ultrasound patients combines the appointment with an appointment for a mammography (and possibly other appointments).

2.3.4 R/F and intervention

Capacity: During R/F examinations patients are examined under an X-ray fluoroscopy device. The radiology department owns two R/F examination rooms. One room is sterile, in this room most interventions take place. The other room is not sterile and often used for examination of intestines. Sometime R/F examinations are only performed for diagnostics. An R/F examination becomes an intervention when, with help of R/F diagnostics, a medical intervention takes place, e.g. placing a drain or explorer. The R/F schedule covers not all days: Monday afternoon and Thursday morning only emergency patients are admitted. On these mornings the modality is closed. Sometimes, this modality is closed on other moments as well, e.g. because of radiologist shortage or efficiency reasons.

Scheduling: This modality is not included in any speed diagnostics trail.

Preparation: Most patients do not need preparation at home before the examination, however some patients need empty the intestines for the examination. Two technicians prepare the patient for the examination. Some patients need a drip needle or drain for applying contrast fluid.

Examination: When the patient is ready for the examination, the radiologist is called and performs the requested research. When necessary, an intervention or further exams are done. Sometimes the radiologist consults the treating specialist during the examination. These factors cause high variety in examination duration, together with other insecurities, such as the speed of the contrast fluid to disperse in the body of the patient and how easily a drain or explorer is placed. The schedule of R/F is a bit loose in order to cope with the variances in examination duration and the emergency requests for examination.

Ultrasound patients that combine their appointment with this modality: 0,71% of all ultrasound patients combines the appointment with an R/F and/or intervention appointment.

2.3.5 Bucky

Capacity: There is one bucky examination room, mostly crewed by two technologists.

Scheduling: The bucky (X-ray) is currently the only modality at the radiology department which is directly accessible. However, some patients are still scheduled: when patients need bucky examination next to other radiology examinations, the bucky examination is also scheduled. In this way, the patient does not forget to visit the bucky, and is assured of short waiting time for the bucky. Patients who need a bucky examination report at the radiology desk and are simply scheduled on the first planning slot available and invited to take place in the waiting room immediately. Depending on the flow of patients at the bucky, a patient is helped immediately or has to wait for an expected maximum of half an hour. During specific time periods, patient flow is very low. This is caused by the consulting hours of the outpatient clinic. During these hours the bucky sometimes remains idle.

Preparation: No preparation is needed for a bucky examination.

Examination: Bucky examinations are relatively simple and short. Variety in examination duration differs depending on the sort of bucky examination. For example, for bucky examination of thorax the examination duration is relatively constant, while for bone structure examinations variety is higher. Patients do not need preparation. Examination of inpatients generally takes more time than outpatient examinations.

Ultrasound patients that combine their appointment with this modality: 18,22% of all ultrasound patients combines the appointment with a bucky appointment (and possibly other appointments).

Appendix C-c gives an overview of probabilities for various combinations of other examinations patients need to undergo next to ultrasound examination.

2.4 Conclusions current performance

Analyzing the current ultrasound process at the radiology department we conclude:

- The radiologist is the bottleneck in the process. Therefore, radiologist capacity determines the capacity of the ultrasound modality.

- Currently, the schedule of ultrasound is “loose”: each planning slot contains a buffer of on average 3 minutes. Empirically this seems to provide scheduling flexibility to cope with emergency patients and requests for same day examinations.

- Figure 14 summarizes the current performance of the ultrasound modality.

Current performance							
Patient waiting time (minutes)		*mean (stdev)*	**No of examinations performed**				
days	*other day inp + outp*	7,16		*emergency / same day*		*other day*	
	other day inpatients	2,25	*inpatients*	489	10,2%	91	1,9%
	other day outpatients	7,31	*outpatients*	671	14,0%	3551	73,9%
minutes	*other day outpatients*	8,25 (17)	**Resources used**				
	same day outpatients	57,64 (71)	*Examination rooms*				2
Utilization rate			*Radiologists*				1
Utilization of planning slots		157%	*Technicians*				1-2
Radiologist utilization		110%	**Effort needed to schedule a patient**				
Overtime (minutes)			*regular request*	minimal			
average work in overtime per day		30	*emergency request*	consultation of radiologist/technician			
average work during regular hours per day		153		by responsible desk employee			
% during overtime		16,4%					

Figure 14 – Current performance of ultrasound

- Concerning other radiology modalities we conclude (Figure 15):

Other modalities					
	CT-scanner	*MRI-scanner*	*Mammography*	*R/F and intervention*	*Bucky*
Capacity	2 CT-scanners, shared Full-time use of a CT-scanner.	1 MRI-scanner, full-time used.	2 mammography examination rooms, only 1 mostly used.	2 examination rooms. No full-time schedule, closed i.c.o. shortage.	1 examination room
Scheduling	Waiting time 2-3 weeks Emergency patients cause disturbances	Waiting time ±2 weeks. Emergency patients can cause peak-days.	No waiting time. Many rescheduling and no-shows.		Open access, but some examinations are scheduled.
Preparation	Patients prepare at home for all abdomen examinations.	Preparation of examination table for specific examinations.	No preparation is needed.	Some patient follow diet in advance.	No preparation is needed.
Examination	10-20min duration, varying by possible radiologist consultation	Duration varies (10-60 min). Disturbances by failed examinations.	Duration normally ±10 min. Little variance.	High variety in examination duration, loose schedule.	Short and simple examinations. Low variety in duration.
Relation with ultrasound	8,37% of ultrasound patients	5,81% of ultrasound patients	8,45% of ultrasound patients	0,71% of ultrasound patients	18,22% of ultrasound patients

Figure 15 – Other radiology modalities

3 Literature review

Our strive for offering more same day ultrasound examinations, corresponds with the 'open access' concept as described by Murray and Berwick (Section 3.1). However, to develop a scheduling system which is efficient and flexible and therefore facilitates same day access, we first need to consider some classic literature on operations research and scheduling (Section 3.2). In our study, we use simulation to evaluate different scheduling policies. Section 3.3 discusses some issues encountered while using simulation as a tool for analyzing healthcare processes.

3.1 Open access

The *open access* (or *advanced access*) concept as described by Murray (2003) is a strive for *"Doing today's work today"*. They describe the concept of open access for primary care purposes. Offer all patients an appointment on the same day as their request, thereby reducing backlog appointments and minimizing waiting time. Another goal of this concept is to offer patients an appointment with their own physician, but this is of less relevance in this study. Patients still get an appointment: mostly on the same day as their request, but if they request for an appointment on another day, this can be scheduled as well (Murray 2003). Figure 16 sums up the tips of Murray for adopting an open access policy, but to realize open access we also need to consider other constraints.

Hans (2006) distinguished three levels of hospital planning and control: strategic, tactical and operational level. Strategic decisions comprise choices for hospital layout and how much capacity to use. At tactical level decisions are made on the allocation of capacity to different specialties (or modalities). Operational decisions concern scheduling of patients and planning of workforce. To realize open access, overall capacity should meet overall demand (*strategic*), and capacity should be balanced such that each radiology modality can meet its specific demand (*tactical*). Next, the scheduling system should facilitate an efficient schedule, leading to possibilities for flexibility, such as coping with emergency patients and same day demand (*operational*) (Hans 2006). Chapter 2 shows that the utilization using the current schedule for ultrasound is >100%. Providing more same day appointments using the current schedule possibly causes problems: extra capacity might be needed, risk of idle time may increase, or the number of patients being examined may decrease. To create planning space in order to facilitate open access we reconsider the capacity as well as the scheduling system of the ultrasound modality.

Advanced access tips

1. *Move toward advanced access by working down your backlog of appointments.*
2. *Roll out the new system by showing, not telling, patients how it works. When we try to explain our systems, we often make them overly complicated.*
3. *Begin offering every patient an appointment on the day they call your office, regardless of the reason for the visit.*
4. *If patients do not want to be seen on the day they call, schedule an appointment of their choosing. Do not tell them to call back on the day they want to be seen.*
5. *Allow physicians to pre-schedule patients when it is clinically necessary ("good backlog").*
6. *Reduce the complexity of your scheduling system to just three kinds of appointments (personal, team and unestablished) and one standard length of time.*
7. *Make sure each physician has a panel size that is manageable, based on his or her scope of practice, patient mix and time spent in the office.*
8. *Encourage efficiency and continuity by protecting physicians' schedules from their colleagues' overflow.*
9. *Develop plans for how your practice will handle times of extreme demand or physician absence.*
10. *Reduce future demand by maximizing today's visit.*

Figure 16 – Tips for adopting an open access policy (Murray 2000)

3.2 Scheduling systems

Cayirli (2003) provides a literature review on outpatient scheduling in healthcare, with a framework for designing appointment systems (Figure 17).

Appointment system design		
Appointment rule	Block size	*individual, multiple, variable*
	Appointment interval	*fixed, variable*
	Initial block	*with, without*
Patient classification	None	*all patients homogenous*
	Use patient classification	*sequence patients at time of booking*
		adjust appointment intervals to match service time characteristics of patient groups
		any combination of the above
Adjustments	For no-shows	*none, overbooking, decrease appointment intervals*
	For walk-ins	*none, underbooking, increase appointment intervals*
	Any combination of the above	

Figure 17 – Framework for appointment system design (Cayirli 2003)

Appointment rule

Designing an appointment system, one first has to determine the appropriate *block size*. The block size is the number of patients scheduled in a certain block (different blocks can have different sizes). Block size is 1 when each patient is called individually, but can be >1 or even variable in size as well. One can choose to work with a different *initial block* at the beginning of each session: a number of patients receive an identical appointment time at the beginning of each session. Working with an initial block should prevent the system from being idle. The *appointment interval* is the time between two successive blocks. The interval can be fixed or variable, depending on the service time characteristics (see Patient classification).

Combining the three elements mentioned above leads to several different appointment rules. Famous is Bailey's rule (Bailey 1952): when the specialist starts examining patients, a number of patients is already in the waiting room. This is an example of an *Individual-block/Fixed interval rule with an initial block*. Patients are individually scheduled on a fixed interval (size of the interval is based on service time): each session starts with an initial block (for example 2 patients scheduled at the same time, length of block is two times average consultation time). The initial block prevents the system from being idle. Another appointment rule is block-booking: schedule a number of patients (e.g. 8) at the same time on an interval of the block size (e.g. 8) times the mean service time. This method is more suitable when service times are relatively short, otherwise waiting times tend to be high (Cayirli 2003). *Variable intervals* can be used to improve performance (Ho 1994). Ho et al. find that increasing the appointment intervals towards the end of a session leads to little doctor idle time and acceptable patient waiting times. By shortening the appointment intervals at the beginning of each session, patient 'inventory' is created to reduce the risk of idle time.

Patient classification

Classifying patients allows to discern scheduling rules used for each patient group. For example, when certain patient groups take more consultation time than others, variable scheduling intervals for each patient group can be used. Using prioritization of patients provides another basis for patient classification. Urgent patients get high priority and are therefore scheduled earlier (less waiting time), while other patients do not have medical need to be examined as soon as possible (Cayirli 2003). Some systems reserve slots for patients with certain characteristics. An example of this is the 'mammapoli' at the radiology department.

Adjustments

No-shows, walk-ins, urgent patients or emergencies can disturb the system and therefore it is wise to account for them while designing an appointment system. In literature different ways to do so are described.

Rising (1973) performed a case study of an outpatient clinic where they adapt the appointment schedule for expected walk-ins: *"By scheduling more appointment periods during the periods of low walk-in demand, the appointment patients would smooth the load on physicians and facilities."* First, they smooth patient arrivals by day. For each weekday they estimate the number of walk-in patients to be expected, resulting in different numbers of appointment slots per day in the schedule. The next step is to schedule physicians and appointments. Rising et al. first intuitively determine a set of appointment periods that roughly complement the hourly arrivals of walk-in patients. With this appointment pattern they vary the physician capacity across various hours of the day to determine the best physician schedule. Next they rearrange the appointment periods in order to make further improvements. Implementing their newly developed appointment schedule increased the number of patients seen by a physician by 13,4% while decreasing the number of physician hours with 5,1%. Waiting time for walk-in patients decreased, but waiting time for appointment patients increased, resulting in an overall average waiting time that remained the same (Rising 1973).

Both walk-ins and no-shows can disturb the system. In some studies these disturbances are said to cancel out each other. Fetter (1966) believes that scheduling systems should separate the phenomenon of walk-ins and no-shows, while walk-ins and no-shows seem to concentrate on particular clinic hours. They determine a realistic load factor (the number of appointment slots to fill with appointments) of the system based on historical no-show rates and walk-ins. They perform several experiments in which they evaluate patient waiting time and doctor idle time for different load factors (Fetter 1966).

3.3 Simulation of healthcare processes

During recent years, the application of Operations Research (OR) techniques in healthcare has emerged. In the Netherlands, the project *'Sneller Beter'* was the reason for the Dutch postal company *TPG* to perform a study about applying logistic principles to healthcare settings in 2004. The conclusions of this study are promising: applying logistic principles to different aspects of healthcare delivery could substantially cut down costs (TPG 2004). However, applying logistic principles to healthcare systems is not as easy as one might think.

Healthcare processes differ from industrial processes in a number of ways. First, industry of manufacturing organizations are more profit-oriented than healthcare providers. Healthcare providers focus on cost-control, and price-performance interaction between provider and customer is relatively low. Secondly, while healthcare providers are mostly service providers, their product ('care') cannot be stocked. Also, patient flow is more important than material flow in a hospital, while in industrial organizations material flow is of main concern. Third, many production control approaches assume that end products are pre-specified, while in healthcare end products are often vague and subjective. Finally, there are many, often highly trained, stakeholders within healthcare organizations that have (partly) opposite interests. For example, management is focused on cost control, while medical specialists focus more on delivery of high quality care (Bertrand 2005).

Despite the differences described above, simulation is a widely used tool for analyzing healthcare systems. The pressure to control costs stimulates the usage of OR techniques in hospitals and the often complex and highly stochastic nature of healthcare processes makes simulation an appropriate tool to use in this context (Lowery 1996). Many applications of simulation in healthcare are described in the literature, but only few is written on the specific issues encountered while using simulation in healthcare. Carter (2004) does name the challenges they experienced using simulation in healthcare. The problem of data collection is one that keeps on returning. Often, data are not present or not available in the right form. For example, patient systems are built to support clinical processes instead of administrative processes, charting of patients is not done at the actual times, or data are simply not available and need to be measured manually. This last point brings us to the next problem often encountered while performing simulation studies in healthcare: performing the study in the projected time frame. Data collection is a time-consuming step, next to validation of the model. The actual model building takes relatively little time. The authors conclude that the different interests of stakeholders involved during analysis of the healthcare system and possible implementation of outcomes, ask for a good understanding of the different languages of clinicians and analysts to succeed in using simulation in healthcare (Carter 2004).

Some of the steps in simulation studies need extra attention when applying it to a healthcare system. Next to data collection, it is important to set assumptions about the process and to document all steps in a proper way. These two things should lead to keeping the model simple, which is very important. Lowery (1998) states the following rule of thumb: *"develop as simple a model as possible that you think will meet the project's immediate objectives"*. Model verification and validation are also of great importance. This is not an easy step but very important: if the model is not an accurate representation of the system in practice, experimenting with the model is useless (Lowery 1996; Lowery 1998). Chapter 4 describes how to model the current system and the main steps in this simulation study.

3.4 Conclusions literature study

Open access

- The concept of open access is trying to meet the patient's demand on the same day as the request.
- To realize open access, capacity should meet demand; capacity should be balanced on different modalities; and an efficient schedule should be used.

Scheduling systems

- An appointment rule consists of a certain *block size*, with or without an *initial block*, with fixed or variable *appointment intervals*. Patients can be *homogenous* or divided into specific *patient groups* for scheduling purposes. Adjustments can be made for disturbances such as *no-shows* and *walk-ins*.
- To prevent the system from being idle, variable intervals and/or an initial block can be used.
- By adjusting the schedule for expected walk-ins the work load can be smoothened.

Simulation of healthcare processes

- Healthcare processes differ from industrial processes: they are focused on cost-control, their product can not be stocked, end products are not pre-specified, and many (powerful) stakeholders are involved.
- For modeling complex processes, such as healthcare systems, simulation is an appropriate tool. Simulation in healthcare can be time-consuming, especially data collection. It is important to keep the model as simple as possible.

4 Experiment approach

This chapter describes the basics of modeling a system (Section 4.1), the scenarios we evaluate in the simulation study (Section 4.2) and some specific settings for the simulation (Section 4.3).

4.1 Modeling steps

While experimenting with the actual system is not cost-effective and disrupts the ongoing process of the system, we use a mathematical model to represent the system. A model is a simplified representation of a system. The process of the radiology department is complex, therefore we use a simulation study to model the process. Discrete-event (system) simulation is *"the modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time"* (Law & Kelton 2000). Figure 18 displays the main steps in a simulation study.

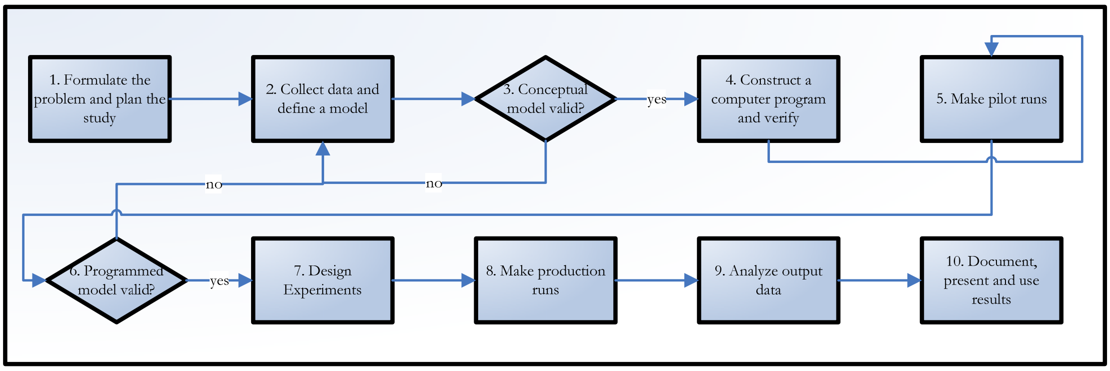

Figure 18 – Steps in a simulation study (Law & Kelton 2000)

4.2 Scenarios

We divide the simulation study in two parts: 1) anticipate the current same day demand, and 2) facilitate open access. Section 4.2.1 describes the scenarios to anticipate current same day demand and their foundations. Section 4.2.2 describes the scenarios which we use to evaluate in case we strive for open access: schedule all patients on the same day.

During the study, we compare the results of each scenario with the zero measurement. The zero measurement is the representation of the current practice at the radiology department. Figure 19 shows the current schedule, used in the zero measurement. The red slots indicate that the modality is closed, no patients are allowed on these slots. On green slots all patient categories are allowed. On yellow slots, only emergency and same day patients are allowed. Blue slots are only open for emergency patients. In the simulation model, in the zero measurement same day and emergency patients are scheduled differently than in the scenarios: the zero measurement first searches for an available green slot, then consecutively for a yellow, blue or echo2 slot. In the scenarios, same day and emergency patients are scheduled on the first slot available in the schedule where the patient is allowed. Chapter 5 describes this in detail.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	3	3	3	3	3	3
Thursday	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule zero measurement

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 19 – The current schedule for ultrasound

When the results of a scenario are promising, we attempt to optimize the schedule by analyzing it more in detail. Scenarios with non promising results are not further optimized.

4.2.1 Anticipate current same day demand

Currently, the peaks in same day demand occur generally between 9 AM and 10 AM, around 11 AM, and at the beginning of the afternoon program (around 1-2 PM). Figure 20 shows this for Tuesday. Based on the literature from Chapter 3 we develop three base schedules.

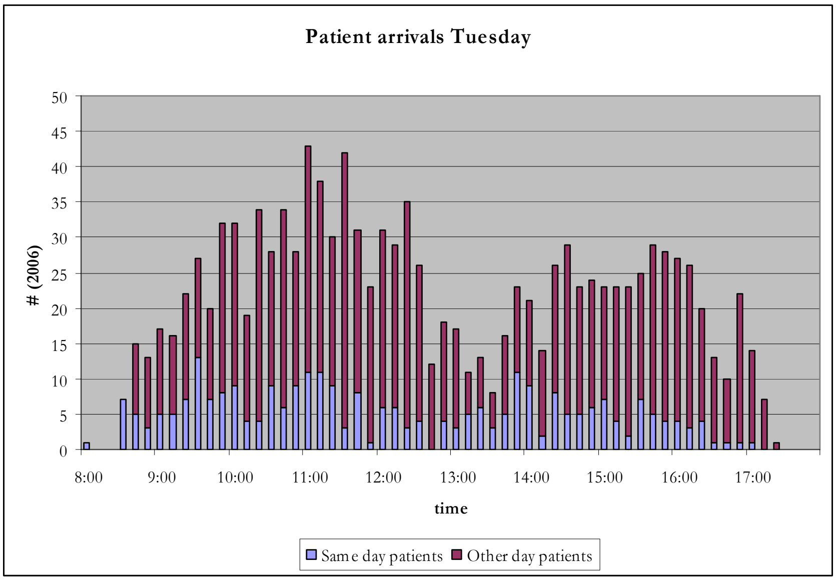

Figure 20 – Total number of patient arrivals per time slot in 2006 for Tuesday (all patient types)

Schedule 1: adapt the schedule for expected walk-ins

Schedule One is based on the literature of Rising (Chapter 3). By analyzing the arrivals of same day patients (in RIS) we spread slots reserved for same day demand over the day. Because of variance in the arrival of same day and emergency patients, it is difficult to choose the proper number of slots to reserve. Reserving too many slots may result in idle time, while reserving too few slots may result in waiting times for same day and emergency patients. Figure 21 shows the schedule.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule 1

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 21 – Schedule 1: adapt for expected walk-ins

Schedule 2: reserve block(s) to handle same day demand

This schedule reserves a block of planning slots (at the end of each day part) in stead of spreading the slots over the day (Schedule 1) to serve same day and emergency patients. The size of the time interval to reserve depends on the number of same day and emergency patients expected during the day part. RIS data analysis shows averages on the amount of same day demand to expect during each day part. During the morning and afternoon all same day demand is 'collected' and processed during the same day blocks. For this reason, the mammapoli mornings in Schedule 2 are closed, except for the same day blocks. However, the number of same day and emergency patients may vary on each day. The possibility for patients to wait for their examination to take place in the predefined time intervals provides clarity for the patients, but may lead to relatively long waiting times for same day and emergency patients on the other hand. Figure 22 shows the schedule.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3

Schedule 2

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 22 – Schedule 2: reserve blocks to handle same day demand

Schedule 3: combine Schedule 1 and Schedule 2

Schedule 3 reserves a minimal amount of planning slots for same day and emergency patients in the schedule, to minimize the risk of idle time. To handle the same day demand that exceeds the amount of reserved slots, a time block at the end of the day is reserved. In this way we strive for an optimum in terms of idle time and patient waiting time. Mammapoli mornings are only open during the reserved yellow blocks. Figure 23 shows Schedule 3.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3

Schedule 3

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 23 – Schedule 3: combine Schedules 1 and 2

4.2.2 Facilitate open access

To improve the accessibility of the ultrasound modality we evaluate how performance changes when we strive to examine all patients at the same day as their request. In these scenarios the slot colors are of less importance, but more important are the opening times of the ultrasound modality (thus, the red slots). We face two main problems when striving for open access: the mammapoli mornings and Wednesday afternoon, and the lunch breaks.

We use the schedule in Figure 24 as a starting point of this part of the simulation study. By analyzing the results, we consecutively evaluate solutions to cope with the problem of the mammapoli mornings, and that of lunch breaks.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3

Open access 1

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 24 – Schedule Open access 1, used as starting point to facilitate open access

The simulation study provides insight in the consequences of capacity choices, such as opening the modality during mammapoli mornings, on the performance of the ultrasound modality. We introduce a new performance measure that indicates the quality of the open access scenario evaluated: the *average percentage of converted patients per day*. A same day patient is converted to the category 'other day outpatient' when the patient can not be scheduled on the current day. This occurs in two situations: when a patient requests for an examination after 5 PM (the modality is already closed) and when the schedule is full on the current day.

Next to changing capacity, balancing the patient flow from the outpatient clinic to the available capacity at the radiology department can solve the problem of the mammapoli mornings and lunch breaks. Therefore, we evaluate the performance of the department using schedule Open access 1 with a patient arrival pattern that ideally fits this schedule. The total average number of patients per week is equally divided over the hours the modality is available. Table 13 shows the mean number of patients that arrive in each hour of the week in the scenario Open access 6.

Arrival pattern Balanced Demand					
hour	*Monday*	*Tuesday*	*Wednesday*	*Thursday*	*Friday*
8	0	0	0	0	0
9	0	3,48	3,48	0	3,48
10	0	3,48	3,48	0	3,48
11	0	3,48	3,48	0	3,48
12	0	3,48	3,48	0	3,48
13	3,48	0	0	3,48	0
14	3,48	3,48	0	3,48	3,48
15	3,48	3,48	0	3,48	3,48
16	3,48	3,48	0	3,48	3,48
17	0	0	0	0	0
total	*13,92*	*24,36*	*13,92*	*13,92*	*24,36*

Table 13 – The mean number of arrivals per hour in the scenario Open access 6: balanced demand

Figure 25 shows an overview of the various scenarios we evaluate in this part of the study.

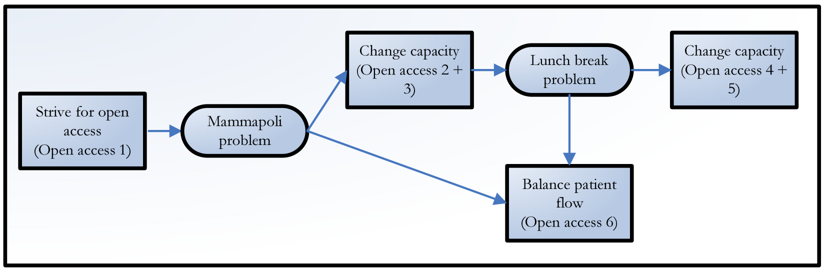

Figure 25 – Overview of scenarios to facilitate open access

4.3 Simulation settings

4.3.1 Initial settings for the system

To evaluate scenarios to anticipate the current same day demand, we start the simulation run with an initial group of 100 patients already scheduled for a planning horizon of 15 days. The size of this group is determined analyzing RIS data; the number of patients already scheduled on the first 15 days of 2006. This initial patient group is also used in the zero measurement (the model of the current situation).

Chapter 3 describes that for Open access to work, the backlog of appointments should be minimal. When evaluating the Open access scenarios, we therefore start with an empty system.

4.3.2 Run length

To construct reliable averages for the output of the simulation model, we determine the run length using the formula from Figure 26 (Law & Kelton 2000). The run length is the number of independent replications (in this case: days) needed to construct a 95% confidence interval for each mean, with a relative error of 10%. The computed run length is 1000 days. Appendix E shows the calculations.

$$n^* = \min\left\{ i \geq n : \frac{1.96\sqrt{S_n^2 / i}}{\bar{X}} \leq \gamma' \right\}$$

Figure 26 – Formula to determine the run length (Law & Kelton 2000)

5 Simulation model

This chapter describes the simulation model constructed for the radiology department. Figure 27 depicts a screenshot of the simulation model. Section 5.1 describes for each component in the model the relevant details and algorithms. Section 5.2 describes the input, output and the assumptions made while modeling. Section 5.3 describes how we implement the scenarios in the model. Section 5.3 discusses the validation of the model. For a detailed description of the model we refer to Appendix D.

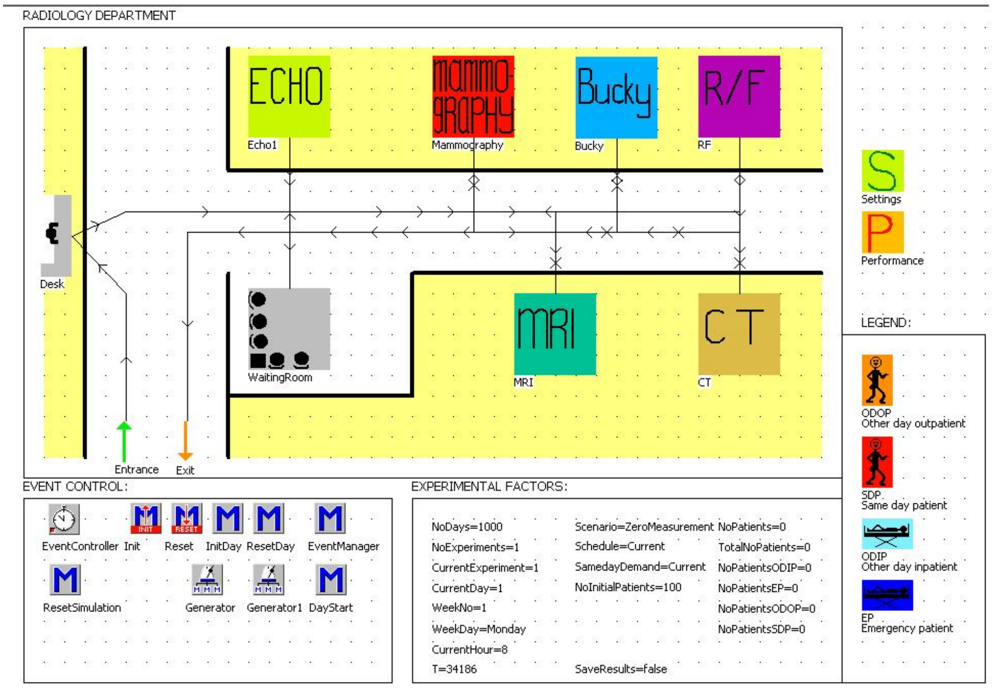

Figure 27 – Screenshot of the simulation model

5.1 The radiology department

Figure 28 shows an overview of the components in the model. Consecutively the entrance of the radiology department, the radiology desk, the waiting room, the different modalities of the radiology department and the exit of the department. This section describes each component.

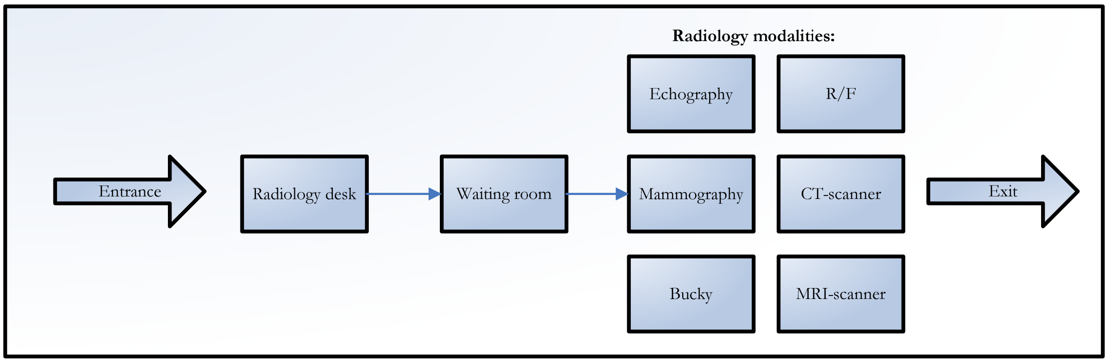

Figure 28 – Overview of system components

5.1.1 Entity: the patient

Patients flow through the system. When entering the system, the following characteristics are assigned to a patient: Category, OnlyEcho and LongProc. Patients are divided in the four categories used throughout the study: other day outpatients, other day inpatients, same day patients and emergency patients. OnlyEcho indicates whether a patient needs any other examinations next to ultrasound examination. LongProc indicates whether the length of the examination is expected to be 'regular' (a planning slot of 10 minutes is reserved, 88% of all examinations), or 'long' (two planning slots of 10 minutes are reserved, 12% of all examinations).

5.1.2 Entrance

At the entrance of the model, patients arrive at the department. Each patient is assigned with patient characteristics (e.g. patient type, 'OnlyEcho' and 'LongProc') by drawing a random number. If any other examinations are needed, they are assigned with (a combination of) other examinations. Depending on the 'Longproc' characteristic, the duration of the examination is assigned to the patient according to the statistical distribution determined (Section 5.2.1.).

Other day inpatients and other day outpatients are 'stored' in this component until they return to the department for their appointment(s).

5.1.3 Radiology desk

Patients reporting at the desk 1) return to the department for their appointment scheduled earlier or 2) request for an examination.

For patients who return for their appointment at the desk the arrival time is registered. The patient takes place in the waiting room.

Patients who need an examination are scheduled at the radiology desk. Depending on the patient category the algorithm 'Other day', 'Emergency' or 'Same day' is used to schedule the patient. The 'Emergency' and 'Same day' algorithm are different for the zero measurement and the scenarios. Other day inpatients and outpatients are only allowed on green slots. While the day the appointment is scheduled in practice depends on different factors (e.g. patient preferences, appointments at the outpatient clinic and the schedule of ultrasound), we draw the number of days between the request and the appointment using the distribution of the waiting time in days from the RIS. On the determined day, the algorithm searches for the first green slot available. When no green slot is found, a new day is drawn. Figure 29 visualizes the 'Other day algorithm'.

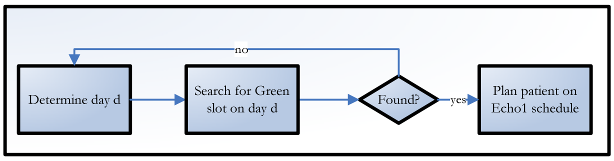

Figure 29 – 'Other day' algorithm

In the zero measurement, same day patients and emergency patients are scheduled on the same day, when possible. Emergency patients are allowed on green, yellow, blue and echo2 slots. While same day patients are allowed on green, yellow and echo2 slots, this algorithm is almost the same as the 'Emergency' algorithm. When a same day or emergency patient enters the system the algorithm first searches for a green slot available on the current day. When not found, the algorithm consecutively searches for a yellow, (blue) or echo2 slot available. On echo2, a maximum of four patients per day are scheduled. Emergency patients are always allowed on echo2. When no available slot is found on the current day, or when the program is already finished at arrival of the patient, the patient is scheduled as soon as possible on the next day. The algorithm is also little different (Section 5.3). Figure 30 shows the flow chart for the 'Emergency' algorithm.

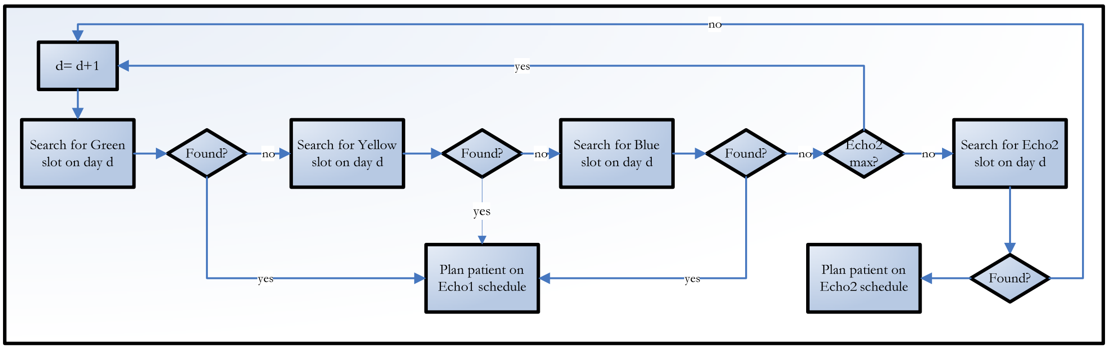

Figure 30 – 'Emergency' algorithm for the zero measurement

After scheduling the appointment, same day and emergency patients enter the waiting room. Other day (in)(out)patients leave the department and are 'stored' in the entrance until the day of the appointment. Other day outpatients arrive before or after the appointment time. This deviation is assigned to the patient when scheduling the appointment. Other day outpatients arrive just before the appointment time.

In the scenarios, the scheduling algorithm for emergency and same day patients is different. Echo2 schedule is not used in this scenarios, and the input schedules are designed in such a way that the slots are yellow (or blue) when same day demand is expected. Thus, the same day algorithm searches for the first slot available. If this slot is green or yellow (or blue for emergency patients), the patient is scheduled on that slot. When a same day appointment is not possible, the patient is converted to other day patient and scheduled using the other day algorithm (not on the next day, but on a drawn day!). Figure 31 visualizes the algorithm. The 'Other day' algorithm is the same in the scenarios.

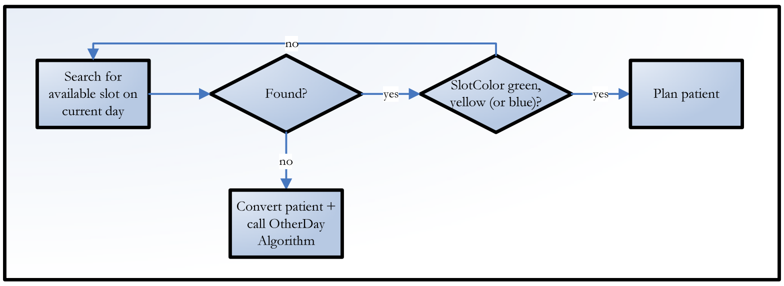

Figure 31 – 'Emergency' algorithm used in the scenarios

5.1.4 Waiting room

The waiting room is sorted on the appointment time of the patients in this room. When the ultrasound modality is available and open, the first patient leaves the waiting room to enter the examination room.

5.1.5 Ultrasound

Only one examination room is used in the model, while the radiologist capacity in stead of the number of examination rooms determines the capacity of the ultrasound modality (Section 2.1.2). The duration of the examination is assigned to the patient at the entrance. When the examination is finished, the patient is directed to any of the other modalities the patient needs to visit, or to the exit of the department.

5.1.6 Other modalities

The other modalities are only shown in the model, but not completely modeled. Patients that need other examinations besides ultrasound examination only visit these modalities. These visits are registered.

5.1.7 Exit

Before the patient is destroyed in the exit of the department, the relevant data on the patient are stored. Section 5.2.2 describes the output of the model.

5.2 Input, output and assumptions

5.2.1 Input

Input is needed to construct a valid model of the radiology department. Appendix C shows details on the various inputs and how they fit a statistical distribution when appropriate.

We deduct the arrival of patients at the department from RIS data. For each hour of each day of the week the number of patients that arrive at the department to request for an ultrasound examination is analyzed (Appendix C-a).

Patient characteristics are assigned to the patient according to the probabilities extracted from RIS data (Appendix C-b). Patients that need other examinations besides ultrasound examination, are assigned with the (number of) other modality(ies) to visit at the entrance of the department. Probabilities for combinations of other modalities that ultrasound patients have to visit are extracted from RIS data (Appendix C-c). Of all ultrasound patients, 39% combines an ultrasound appointment with an other radiology appointment.

For other day inpatients and other day outpatients, an appointment is scheduled on a certain day. While the day on which the appointment is scheduled depends on different factors in practice (e.g. patient preferences, appointments at the outpatient clinic and the schedule of ultrasound), we determine the number of days between the request and the appointment using the distribution of the waiting time in days (Appendix C-d). In Chapter 2 we use the waiting time in days as a measure of performance, in the simulation model this is not possible.

As section 2.1.4 describes, patients' arrival times deviate from the appointment time. In the model, other day outpatients arrive according to a deviation, represented by a normal distribution (Appendix C-e).

The duration of the examination is assigned to each patient according to two statistical distributions, determined by analyzing RIS data. One for 'regular' examination duration and one for 'longproc' examinations (Appendix C-f).

The schedule, working hours, break times and same day demand vary according to the various scenarios from Section 4.2. Table 14 shows an overview of the inputs.

Input	
input	*modeled by:*
Arrival of patients	avg. no. patients per hour per day
Patient characteristics	probabilities extracted from RIS
Other examinations	probabilities extracted from RIS
Waiting time in days	probabilities extracted from RIS
Arrival time deviation	normal distribution: μ=-15, σ=14 *(minutes)*
Examination duration	
regular	Weibull distribution: α=1,8, β=11,7 *(minutes)*
longproc	Weibull distribution: α=1,45, β=19,12 *(minutes)*

Table 14 – Input for the simulation model

5.2.2 Output

Outputs of the simulation model are the measures determined in Chapter 2 in dialogue with the stakeholders.

Per category the number of patients served is registered. Patients that request for a same day appointment but can not be scheduled on the same day, are converted to other day patients. We introduce the number of converted patients as a new performance measure in the model.

As Section 5.2.1 discusses, waiting time in days is not used as a measure of performance in the simulation model, while it is input for the model. The waiting time in minutes is determined using the formulas from Figure 32. The arrival time of other day outpatients deviates from the appointment time with a mean of minus 15 minutes (Appendix C-e). Therefore, we can assume that the average time an other day patient actually waits in the waiting room is the average waiting time plus 15 minutes patient induced waiting time (Actual waiting time).

Other day outpatients:
IF arrival time < appointment time THEN
Waiting time = start time – appointment time
ELSE
Waiting time = start time – arrival time

Actual waiting time = Waiting time + 15 minutes

Same day patients:
Waiting time = start time – plan time

Actual waiting time = Waiting time

Figure 32 – Formulas used to determine the waiting time in minutes for other day outpatients and same day patients

In the model, utilization is expressed by idle time. Although RIS data do not show idle time, we compare idle time of the zero measurement and each scenario in the model. We define idle time as the time the radiologist is not working during the regular program (excluding breaks). The regular program is defined as the time between the radiologist start time and the time the overtime starts, minus the total break time.

Overtime is divided in work performed during breaks and work performed outside the regular program. Work during breaks is delay of examinations into the break time. When the coffee break starts later then the planned break time, the break is postponed a few minutes. Work performed outside the regular program is defined as work performed after the start of the overtime (4.10 PM in all scenarios) or before the program starts (e.g. during mammapoli mornings). In Chapter 6 we evaluate the work performed outside the program, and neglect the work performed during breaks. This is because the break is only postponed in the simulation model.

For all other radiology modalities the average number of examinations per day combined with an ultrasound examination are output of the model. Table 15 shows an overview of the output generated by the simulation model.

Output		
output		*output*
No. of patients served		**Utilization**
other day outpatient		*idle time*
same day patient		**Overtime**
other day inpatient		*work during breaks*
emergency patient		*after closure time*
Waiting time		**Claim on other modalities**
minutes	*other day outpatients*	*avg no examinations per modality*
	same day patients	

Table 15 - Output of the simulation model

5.2.3 Assumptions

When constructing the model, we assume that:

- Mammapoli patients are excluded from the model. The mammapoli mornings on Monday and Thursday are (in the zero measurement) considered to be yellow slots in the schedule: only open for same day and emergency patients.

- While the number of no-shows is low (Section 2.1.4), these are neglected in the model.

- We assume the arrival pattern of patients at the radiology department to be fixed. Growth is not considered. The patient flow from the outpatient clinic to the radiology department can not be influenced.

- The data used to construct a distribution for the examination duration represent the examination duration for the *patient*, not the *radiologist* time. RIS does not register accurate data on radiologist time. Therefore, the processing times in the model are slightly longer than in practice.

- While there is no information on patient preferences concerning acceptable waiting times available, we assume that patients are willing to wait for the examination as it is scheduled. The lack of insight in the different factors that determine the number of days between requesting and scheduling the appointment leads to the assumption that the waiting time in days is represented by the distribution extracted from RIS.

- The slots in the schedule that are currently reserved for special examinations such as ‘sentinel node’ are considered as green slots in the model, while these slots are not always filled and then become available as green slots.

- The planning horizon of the schedule in the model is 21 days (15 work days). This simplifies the model.

- We assume, for the zero measurement and the evaluation of scenarios that anticipate the current same day demand, the initial number of patients already scheduled on the planning horizon of three weeks is 100. For the scenarios that evaluate facilitating open access, we assume the initial system to be empty.

5.3 Model validation

To ensure the constructed model is a correct and valid representation of the radiology department, we validate the simulation model. First, we present the constructed model to the stakeholders. We discuss the assumptions made, and the algorithms used to model human behavior.

While the peaks in same day demand are important when modeling the system, we evaluate the ratios same day demand / total demand for all hours of each day. In some cases RIS data show a peak in same day demand, while the model does not. Therefore, we correct the same day demand ratios in the model for same day peak hours. For example, for Monday Figure 33 shows the ratios from RIS, for the model without correction and for the model after correction of same day peaks at 1 PM and 2 PM.

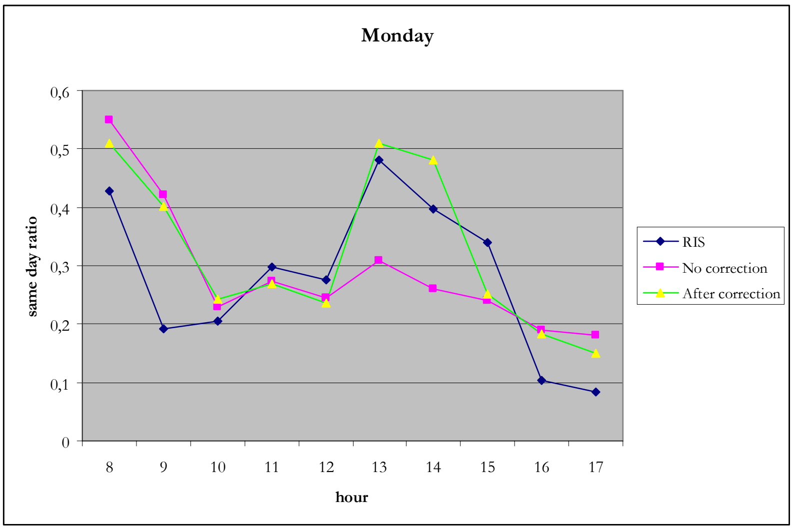

Figure 33 – Comparison of same day demand ratios from RIS, the model without correction and the model after correction for same day peaks

Table 16 shows the results of comparing model output with the results from Chapter 2. The number of same day patients and the number of other day inpatients are higher in the model. This is explained by the same day peak correction described above. Obviously, during the same day peaks, the number of same day patients is higher (which is common sense) as well as the number of other day inpatients. The means and standard deviations of the waiting time in minutes are comparable with the RIS data for both other day outpatients as well as same day patients. The total amount of overtime is slightly higher in the model (32,13 minutes in stead of 30,00 minutes in the RIS).

Model validation		
	RIS	*zero measurement*
measure	*2006*	*year (254 days)*
No. of patients	4802	4925
Other day outpatient	3551	3340
Same day patient	671	829
Other day inpatient	91	174
Emergency patient	489	443
Waiting time (minutes)		
Other day outpatient	8,25 (σ =17)	7,56 (σ =13)
Same day patient	57,64 (σ =71)	64,73 (σ =61)
Overtime (minutes)		
Avg. total overtime per day	30,00	32,13

Table 16 – Compare output from RIS (2006) and model output for one year

6 Computational results

Chapter 6 presents the computational results of the simulation study. The study consists of two parts: 1) anticipate the current same day demand (Section 6.1), and 2) facilitate open access (Section 6.2). Section 6.3 describes the variance analysis of the computational results. Section 6.4 describes how much capacity of other radiology modalities is claimed on average by patients that visit the ultrasound modality. Appendix F gives an overview of all scenarios evaluated in the study, as well as the main computational results.

We compare the outcomes of the scenarios with the outcomes of the 'zero measurement'. The 'zero measurement' is the model of the current situation, using the current schedule (Figure 34). In the zero measurement, same day and emergency patients are preferably scheduled on green slots. In the scenarios, these patients are scheduled on the first slot available where the patient is allowed (Section 5.1.3 describes the different algorithms).

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Tuesday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3
Wednesday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3
Thursday	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Friday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule zero measurement
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 34 – Current schedule for ultrasound, used in the zero measurement

6.1 Anticipate current same day demand

To cope with the current same day demand (emergency patients and same day outpatients), three schedules are developed (Section 4.2). Table 17 (Section 6.1.4) gives an overview of the computational results of all schedules evaluated.

6.1.1 Schedule 1: adapt the schedule for expected walk-ins

In Schedule 1 (Figure 35) planning slots are reserved for same day and emergency patients on expected same day peaks spread over the day.

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Thursday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule 1
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 35 – Schedule 1: reserve planning slots when same day demand is expected

Using Schedule 1, average waiting times decrease compared to the zero measurement. For other day outpatients (73,9% of all patients) the average waiting time changes from 7,56 minutes to 4,33 minutes. We mention that the *actual* waiting time for other day outpatients is 15 minutes longer on average, because patients show up 15 minutes early for their appointment on average (Section 5.2.1). This is patient-induced waiting time and therefore not a performance measure for the department. For same day patients (13,0% of all patients) the average waiting time changes from 64,73 minutes to 58,98 minutes.

Average overtime per day increases a little using Schedule 1: in the zero measurement the average overtime per day is 22,08 minutes, while Schedule 1 gives an average overtime of 26,88 minutes per day. The average idle time per day decreases from 42,10 minutes (zero measurement) to 30,62 minutes (Schedule 1) per day. Generally, the idle time is expected to increase when reserving slots for same day demand. When the reserved slots cannot be filled as a result of a lack of same day demand, this results in idle time. The decrease in idle time in this case can be explained by the use of another scheduling algorithm. In the current situation, same day patients are preferably scheduled on green slots, while using a schedule that anticipates for same day demand, the patient is scheduled as soon as possible (on a green or yellow slot). In the current situation this leads to the risk of yellow slots (especially in the morning) that remain empty.

The results of Schedule 1 are positive, thus further improvement of this schedule is interesting. Using a local search technique, we search for the time slots reserved for same day demand that improves the computational results. We do so by moving the yellow slots one by one to a time slot earlier or later. When the results improve, we move the slot one further, until no improvement is achieved anymore. When no improvement is observed, we move the yellow slot back to its original position in Schedule 1. Next step is to add one or more yellow slots to the schedule and evaluate the results. This leads to *'Schedule1Improved'* (Figure 36). No more yellow slots can be added, while this causes problems scheduling other day patients.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	2	1	3	3	2	1	1	1	1	2	1	1	1	1	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	2	1	1	1	2	1	3	3	2	1	1	1	1	2	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	2	1	3	3	2	1	1	1	1	2	1	1	1	1	3	3	3	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule 1 improved

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 36 – Schedule 1 improved: the improved variant of Schedule 1

Using Schedule1Improved the average waiting time in minutes decreases to an average of 3,00 minutes for other day outpatients (73,8% of all patients) and 50,50 minutes for same day patients (13,0% of all patients).

Overtime reduces slightly compared to Schedule 1: from an average of 26,88 minutes per day (Schedule 1) to 25,25 minutes in the improved schedule. Idle time decreases from 30,62 minutes (Schedule 1) to an average of 27,95 minutes per day.

Compared to the zero measurement, *Schedule1Improved* leads to shorter waiting times, less idle time per day, but an increase in average overtime per day.

For these schedules to work in practice, it is important that the yellow slots are filled *during* the peaks in same day demand, and not in advance. To avoid idle time, the desk employee might tend to schedule a patient who does not explicitly ask for a same day appointment on a yellow slot. This results in yellow slots reserved for same day demand during peak hours but already filled with other patients when the same day patients arrive at the desk. This (still) leads to excessive waiting times for same day patients.

6.1.2 Schedule 2: reserve blocks to handle same day demand

Schedule 2 (Figure 37) reserves a block of planning slots at the end of each day part to serve same day and emergency patients. The same day blocks provide clarity for the patients, but waiting times for same day patients are expected to increase using Schedule 2. Advantage for the department is that the regular program is not interrupted by (a lack of) same day demand.

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3

Schedule 2
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 37 – Schedule 2: reserve two blocks to handle same day demand

Computational results show that the average waiting time for same day patients (13,3% of all patients) increases significantly, as expected: from 64,73 minutes (zero measurement) to 86,43 minutes. Longer waiting times are the result of the same day blocks: patients who arrive at the beginning of a day part have to wait until the start of the same day block. The average waiting time for other day outpatients (73,6% of all patients) also increases, from 7,56 minutes (zero measurement) to 10,56 minutes. This increase is explained by the concentration of green slots, which leads to no slack.

The average overtime per day increases from 22,08 minutes to 28,30 minutes compared to the zero measurement. The average idle time decreases from 42,10 minutes to 28,12 minutes.

Compared to the zero measurement, Schedule 2 leads, as expected, to longer waiting times for other day outpatients and same day patients, decreased idle time, but increased overtime. Because the results for Schedule 2 are not very promising, we do not further improve this schedule.

6.1.3 Schedule 3: combine Schedule 1 and Schedule 2

Schedule 3 (Figure 38) reserves a minimal amount of same day slots during the day in order to reduce the risk of idle time. Each day finishes with a same day block to handle same day and emergency patients that exceed the number of planning slots reserved during the day.

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3

Schedule 3
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 38 – Schedule 3: minimal amount of same day slots during the day, same day block at the end of the day

Computational results for Schedule 3 show that the average waiting time for same day patients (13,3% of all patients) is comparable with that of Schedule 2: average waiting time in minutes is 81,02 minutes for Schedule 3, against 86,43 minutes in Schedule 2. To evaluate whether this relatively high waiting time is caused by the closed mammapoli mornings, we analyzed this schedule also with yellow mammapoli mornings, just as in the zero measurement and Schedule 1. This results in the same waiting time for same day patients, thus we can conclude that the relatively high waiting time for same day patients in this schedule is not caused by the closed mammapoli mornings. The average waiting time for other day outpatients (73,3% of all patients) is almost the same as that of Schedule 2: 9,85 minutes for Schedule 3 and 10,56 minutes in Schedule 2.

Though the average overtime per day is 27,23 minutes, which is comparable to that of the other schedules, the average idle time per day is 25,63 minutes, which is the least compared to the other schedules. This matches the goal of this schedule: minimize the risk of idle time.

Compared to the zero measurement Schedule 3 leads to longer waiting times for both patient groups, less idle time, but increased overtime. Further improvement of Schedule 3 is not interesting.

6.1.4 Summary of results 'Anticipate current same day demand'

Table 17 provides an overview of the computational results for the first part of the simulation study. Comparing the zero measurement and the four schedules evaluated, *Schedule1Improved* performs best in terms of average waiting times for other day and same day patients.

In the zero measurement, the amount of same day patients is higher than in the scenarios. In the scenarios, more patients are converted to other day patients, because the schedule for the current day is full. In the zero measurement, *Echo2schedule* is used for same day and emergency patients that do not fit *Echo1Schedule*, leading to less converted patients.

Average overtime per day is higher in all scenarios than in the zero measurement. A difference in the scheduling algorithm causes this: in the zero measurement some same day patients are converted to other day patients when they arrive after the regular program is finished. This rule does not apply in the algorithms for the scenarios, leading to more patients scheduled between 4.10 PM and 5 PM, and thus a higher overtime. Between the various schedules the differences in average overtime per day are minimal. In terms of average idle time per day Schedule 3 performs best, although the differences between the scenarios are minimal.

Computational results Anticipate current same day demand								
	Other day patients			**Same day patients**				
	Ratios		Waiting time	Ratios		Waiting time	Avg overtime	Avg idle time
Scenario	*%ODIP*	*%ODOP*	*ODOP (minutes)*	*%EP*	*%SDP*	*SDP (minutes)*	*per day (minutes)*	*per day (minutes)*
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	22,08	42,10
Schedule 1	2,9%	73,9%	4,33	10,3%	13,0%	58,98	26,88	30,62
Schedule1Improved	2,8%	73,8%	3,00	10,3%	13,0%	50,50	25,25	27,95
Schedule 2	2,8%	73,6%	10,56	10,3%	13,3%	86,43	28,30	28,12
Schedule 3	2,7%	73,6%	9,85	10,5%	13,3%	81,02	27,23	25,63

Table 17 – Overview of computational results 'Anticipate same day access' (run length = 1000 days)

6.2 Facilitate open access

To gain insight in the consequences of striving for open access at the ultrasound modality, we evaluate a number of possible schedules. If possible, we schedule all patients who arrive at the radiology desk on the same day. Section 6.2.1 starts with a base schedule. Based on what we learn from the simulation, we create a new schedule and evaluate this schedule. Table 18 (Section 6.2.7) gives an overview of the computational results for all schedules evaluated in this part of the study.

6.2.1 Open access 1: mammapolis blocked, regular break times

The schedule used in scenario Open access 1 (Figure 39) is the starting point for this part of the study. Ideally, the mammapoli mornings are blocked for all patients other than mammapoli patients, the break times are the same as in the current situation, and Wednesday afternoon is blocked for all patients other than emergency patients.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3

Open access 1
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 39 – Schedule Open access 1: used as starting point to facilitate same day access

Computational results for scenario Open access 1 show that the average waiting time for same day patients (60,1% of all patients) is high compared to the zero measurement: 105,62 minutes, against 64,73 minutes in the zero measurement. Blocking the mammapoli mornings causes high waiting times for same day patients. For other day outpatients (28,2% of all patients) the average waiting time is 2,46 minutes, which is relatively low compared to the zero measurement. The *actual* waiting time for other day outpatients is 15 minutes longer on average, because patients show up 15 minutes early for their appointment on average (Section 5.2.1). This is patient-induced waiting time and therefore not a performance measure for the department. When comparing waiting times for other day outpatients and same day patients it is relevant to consider the *actual* waiting time.

Of all patients that report at the desk to schedule an ultrasound appointment, an average of 31,4% per day is converted to other day outpatient because the patient can not be scheduled on the same day. Of all patients, 69,1% is scheduled on the same day as the request for examination. In the zero measurement, 26,8 of all patients is examined on the same day.

Average overtime per day increases from 22,08 minutes (zero measurement) to 38,97 minutes. Average idle time per day increases slightly: from 42,10 minutes in the zero measurement to 46,57 minutes in scenario Open access 1.

Analyzing the day results shows that excessive waiting times occur on Mondays and Thursdays (mammapoli days). We learn from this scenario that the mammapoli mornings are the main bottleneck in striving for same day access for all patients. The mammapoli trail (speed diagnostics) leads to less planning flexibility for other patients. Based on this schedule we evaluate scenarios Open access 2 (Section 6.2.2) and Open access 3 (Section 6.2.3), that evaluate two solutions for the mammapoli problem in terms of capacity choices. Section 6.2.6 evaluates an other solution for the mammapoli mornings: balancing the patient flow from the outpatient clinic to the available capacity at the radiology department (Open access 6).

6.2.2 Open access 2: mammapolis blocked, then flexible lunch break

To reduce waiting times that occur during mammapoli days, we open the ultrasound modality on these days during the lunch break in scenario Open access 2 (Figure 40).

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3

Open access 2

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 40 – Schedule Open access 2: mammapolis blocked, on mammapoli days flexible lunch break

Computational results show that the waiting time for same day patients (67,8% of all patients) decreases, as expected: from 105,62 minutes in scenario Open access 1 to 62,12 minutes in scenario Open access 2. The waiting time for other day outpatients (20,5% of all patients) decreases from 2,46 minutes to 1,37 minutes.

The average amount of converted patients per day reduces from 31,4% to 22,8% in scenario Open access 2. Of all patients, 77,8% is examined on the same day as their request, against 69,1% in scenario Open access 1.

Because the capacity is increased in scenario Open access 2, the reduce in average overtime from 38,97 minutes to 33,68 minutes per day (compared to Open access 1) is expected. Increase of average idle time per day is a negative result of this: from 46,57 minutes in scenario Open access 1 to 72,22 minutes in Open access 2.

Compared to scenario Open access 1, scenario Open access 2 leads to shorter waiting times, less converted patients, a decrease in average overtime, but increased average idle time per day.

6.2.3 Open access 3: mammapolis open, regular break times

In scenario Open access 3 (Schedule Open access 3a, Figure 41) we open the modality during mammapoli hours for all patients. In practice, both ultrasound rooms should be used simultaneously, crewed by 2 radiologists on Monday and Thursday mornings.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	3	3	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3

Open access 3a

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 41 – Schedule Open access 3a: mammapolis open, regular break times

Unblocking the mammapolis leads to significant shorter waiting times for same day patients (76,4% of all patients), compared to Open access 1. From 105,62 minutes in scenario Open access 1, it decreases to 36,40 minutes is Open access 3a. Excessive waiting times occur when the morning program is delayed by a long examination, causing many same day patients to wait until the lunch break is finished. Other day outpatients (11,8% of all patients) wait 0,65 minutes on average for their appointment, compared to 2,46 minutes in Open access 1.

The amount of patients examined on the same day as their request increases: per day, an average 12,5% of all patients that request for an appointment are converted to other day outpatients. This results in 86,6% of all patients examined on the same day, against 69,1% in scenario Open access 1.

As expected, idle time increases when enlarging the capacity. In Open access 1 the average idle time per day is 46,57 minutes, in Open access 3a 143,4 minutes. Enlarging the capacity causes average overtime per day to decrease compared to scenario Open access 1: from 38,97 minutes to 33,08 minutes.

We adapt this schedule by spreading the green slots over the day, such that the converted patients (other day outpatients) are scheduled more dispersed over the day and yellow slots for same day patients are available at any time. 'Stacking' the other day patients at the start of the day is now avoided. Figure 42 shows schedule Open access 3b.

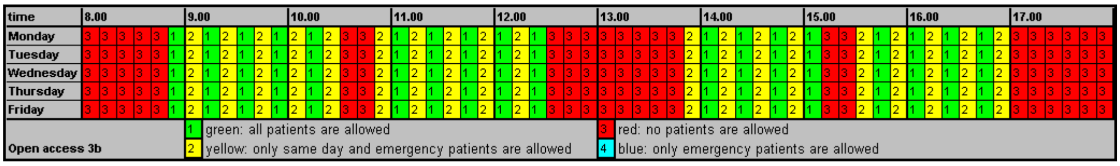

Figure 42 – Schedule Open access 3b: spread the green slots to avoid 'stacking' of other day patients

The results for Open access 3b are (almost) the same as these of the variant with all green slots Open access 3a), except that for other day outpatients the average waiting time becomes negative: minus 1,65 minutes. A negative waiting time occurs when an examination starts before the appointment time. While other day outpatients show up 15 minutes early on average, this is possible. The *actual* average waiting time of the other day outpatients is in this case 13,35 minutes. In the following scenarios we spread the green slots as in Schedule 3b while this leads to a (minor) improvement of the results.

Scenario Open access 3 leads to shorter waiting times, more same day and emergency patients, and less overtime per day, but an increase in idle time compared to scenario Open access 1. Analysis of day data shows that waiting times increase around the lunch break. For patients who arrive at the department between 11 AM and 3 PM, the lunch break may lead to excessive waiting times. Therefore, the next step is to evaluate two schedules: one with a shortened lunch break (Section 6.2.4), one with flexible lunch breaks (Section 6.2.5).

6.2.4 Open access 4: mammapolis open, shorten lunch break

In scenario Open access 4 (Figure 43) we shorten the lunch break to 40 minutes, but keep the same capacity as in scenario Open access 3 by closing the modality 40 minutes earlier (4.20 PM in stead of 5 PM). Scenario Open access 3 showed that spreading green slots gives better results, we also apply this in scenario Open access 4.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	3	3	1	2	1	2	1	2	1	2	1	2	3	3	3	3	2	1	2	1	2	1	2	1	2	1	2	1	3	3	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	3	3	1	2	1	2	1	2	1	2	1	2	3	3	3	3	2	1	2	1	2	1	2	1	2	1	2	1	3	3	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	3	3	1	2	1	2	1	2	1	2	1	2	3	3	3	3	2	1	2	1	2	1	2	1	2	1	2	1	3	3	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	3	3	1	2	1	2	1	2	1	2	1	2	3	3	3	3	2	1	2	1	2	1	2	1	2	1	2	1	3	3	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3
Friday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	3	3	1	2	1	2	1	2	1	2	1	2	3	3	3	3	2	1	2	1	2	1	2	1	2	1	2	1	3	3	2	1	2	1	2	3	3	3	3	3	3	3	3	3	3

Open access 4

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 43 – Schedule Open access 4: shorten lunch breaks, close 40 minutes earlier in the afternoon

Compared to scenario Open access 3b the waiting times decrease. For same day patients (70,2% of all patients) the average waiting time changes from 35,87 minutes to 23,36 minutes. For other day patients (18,1% of all patients) the waiting times changes from minus 1,65 minutes to minus 2,80 minutes. This indicates that many examinations start before the actual appointment time of the patient.

Closing the modality 40 minutes earlier leads to more patients converted to other day outpatients. In scenario Open access 3b an average 12,5% per day is converted, in scenario Open access 4 this is 20,7% on average. Of all patients, 79,5% is examined on the same day as the request for examination. In scenario Open access 3b this is 86,5%.

Overtime is low in this scenario, because the modality closes at 4.20 PM. Average overtime per day is 7,40 minutes. Idle time increases compared to scenario Open access 3b. This is because the regular program time is longer when shortening the lunch break. In scenario Open access 4 the average idle time per day is 167,6 minutes compared to 143,1 minutes in Open access 3b.

In scenario Open access 4 the waiting times decrease for same day and other day outpatients compared to scenario Open access 3. The average overtime is low, but idle time increases. Compared to Open access 3, more patients have to be converted to other day outpatients.

6.2.5 Open access 5: mammapolis open, flexible break times

In scenario Open access 5 (Schedule Open access 5a, Figure 44) the breaks are not scheduled. In practice, coffee and lunch breaks are flexible: when there are no (or a few) patients in the waiting room, personnel can take a break or do supporting tasks normally performed during the lunch break. When break times are flexible, it is hard to arrange meetings during break times. To concede this problem, it is wise to arrange meetings during the more quiet hours of a day, for example at the beginning or at the end of a day. Arranging interdisciplinary meetings could be a problem in this setting.

time	8.00						9.00						10.00						11.00						12.00						13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	3	3	3	3	3
Wednesday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	3	3	3	3	3
Friday	3	3	3	3	3	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	3	3	3	3	3	3

Open access 5a

1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Figure 44 – Schedule Open access 5a: mammapolis are open, breaks are flexible

The waiting time for same day patients (80,9% of all patients) decreases from 35,87 minutes in Open access 3b to an average of 12,12 minutes in scenario Open access 5a. The average waiting time for other day outpatients (7,3% of all patients) is minus 0,73 minutes. Comparing the *actual* waiting time of other day outpatients (14,27 minutes on average) with the waiting time for same day patients shows that same day patients and other day outpatients spend the same time in the waiting room on average.

Each day an average of 9,5% of all patients is converted to other day outpatient. More detailed analysis of the results shows that these patients arrive at the radiology desk between 5 PM and 6 PM when the modality is already closed, and are therefore scheduled on an other day. Of all patients, 91,6% is examined on the same day as the request.

Compared to scenario Open access 3b the average overtime per day decreases a little: from 32,95 minutes to 29,22 minutes per day. This is because the capacity is enlarged, and more patients are served within the regular program. From the idle time given by the simulation model we subtract the total break time (120 minutes). This leads to an average idle time per day comparable with that of scenario Open access 3b: 143,1 minutes (Open access 3b) against 148,9 minutes in this scenario. Relatively high idle times are caused by the enlarged capacity compared to scenario Open access 1.

To relieve the mammapoli mornings and the lunch time we adapt schedule Open access 5a. During the mammapoli mornings and lunch time only same day patients are allowed. Figure 45 shows the adapted schedule, schedule Open access 5b.

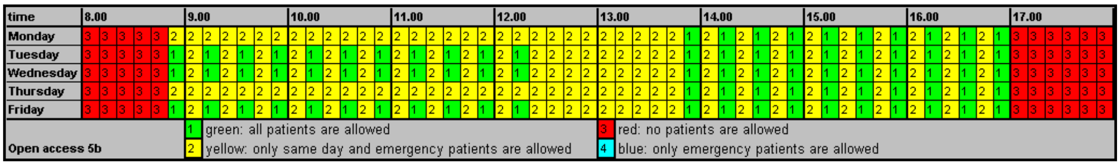

Figure 45 – Schedule Open access 5b: relieve the mammapoli mornings and lunch time

Computational results for schedule Open access 5b are the same as for schedule Open access 5a. Only, the waiting time for other day outpatients decreases from minus 0,73 minutes to minus 3,77 minutes. The amount of same day patients is the same as for Open access 5a: 91,6% of all patients are examined on the same day. While the amount of other day outpatients is only little (7,4% of all patients), applying this schedule leads to only a minor improvement compared to schedule Open access 5a.

Comparing scenario Open access 5 with scenario Open access 3, waiting times decrease, overtime decreases, but idle time increases. The amount of same day and emergency patients is high in scenario Open access 5.

6.2.6 Open access 6: balanced demand

Results from scenario Open access 1 show that the mammapoli mornings and lunch breaks lead to high waiting times for same day patients. In scenario Open access 2 to scenario Open access 5 we evaluate various solutions in terms of capacity: what is the effect when adapting the schedule during the mammapoli mornings and lunch breaks? Scenario Open access 6 evaluates an other solution to the problem of the mammapoli mornings and lunch breaks: what is the effect of balancing the patient flow from the outpatient clinic to the capacity of the radiology department?

In scenario Open access 6 we use the schedule of Open access 1 (Figure 39). The arrival of patients is balanced, such that the total amount of patients arriving at the department is evenly spread over the available hours. Before 9 AM, after 4 PM, during lunch time, during mammapoli mornings, and on Wednesday afternoon the arrival of patients is low.

Computational results show that balancing demand and capacity leads to significantly shorter waiting times for same day patients (75,6% of all patients). The average waiting time decreases from 105,62 minutes in Open access 1 to 41,58 minutes in Open access 6. For other day outpatients (12,4% of all patients) the waiting time decreases from an average of 2,46 minutes to 0,33 minutes.

When balancing demand, less patients are converted to other day patients. In Open access 1, 69,1% of all patients is examined on the same day, while in Open access 6 86,4% of all patients is examined on the same day. Per day an average of 13,9% of all patients is converted to other day outpatients.

The average overtime per day is comparable with that of scenario Open access 1: 39,30 minutes against 38,97 minutes in Open access 1. The average idle time per day decreases. In scenario Open access 1 this is 46,57 minutes, while in Open access 6 this reduces to 41,05 minutes.

Balancing demand to capacity leads to improved overall performance, compared to scenario Open access 1. More patients are scheduled on the same day, average waiting times decrease, and idle time decreases.

6.2.7 Summary of results 'Facilitate open access'

Table 18 shows an overview of the computational results for all scenarios evaluated in the second part of the study. Open access 1 shows that when striving for open access, the mammapoli mornings and lunch breaks lead to high waiting times.

Adapting the schedules in Open access 2-5 leads to shorter waiting times and more same day patients on the one hand, but increasing idle time on the other hand. Balancing demand in Open access 6 leads to better overall performance: more same day patients, decreased waiting times and decreased idle time.

In terms of waiting time and the amount of patients examined on the same day, scenario Open access 5 performs best. *Actual* waiting time of other day outpatients in this scenario is about the same as the average waiting time for same day patients.

Computational results Facilitate open access									
	Other day patients			**Same day patients**					
	Ratios		Waiting time	Ratios		Waiting time	Avg converted	Avg overtime	Avg idle time
Scenario	*%ODIP*	*%ODOP*	*ODOP (minutes)*	*%EP*	*%SDP*	*SDP (minutes)*	*per day (%)*	*per day (minutes)*	*per day (minutes)*
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Open Access 1	2,7%	28,2%	2,46	9,0%	60,1%	105,62	31,4%	38,97	46,57
Open Access 2	1,8%	20,5%	1,37	10,0%	67,8%	62,12	22,8%	33,68	72,22
Open Access 3a	1,6%	11,8%	0,65	10,2%	76,4%	36,40	12,4%	33,08	143,4
Open Access 3b	1,6%	12,0%	minus 1,65	10,2%	76,3%	35,87	12,5%	32,95	143,1
Open Access 4	2,5%	18,1%	minus 2,80	9,3%	70,2%	23,36	20,7%	7,40	167,6
Open Access 5a	1,1%	7,3%	minus 0,73	10,7%	80,9%	12,12	9,5%	29,22	148,9
Open Access 5b	1,1%	7,4%	minus 3,77	10,7%	80,9%	12,47	9,5%	29,28	148,9
Open access 6	1,2%	12,4%	0,33	10,8%	75,6%	41,58	13,9%	39,30	41,05

Table 18 – Overview of computational results 'Facilitate open access' (run length = 1000 days)

6.3 Variance in performance

Next to the averages of the performance measures, it is important to analyze the variance. We analyze the variance in waiting times and idle time for the most promising scenarios when anticipating current same day demand and when facilitating open access.

For *Schedule1Improved* (Section 6.1.1) the standard deviation of the waiting time in minutes for other day outpatients is 22 minutes, on an average of 3 minutes (n=13473). In the zero measurement the standard deviation is less: 13 minutes on an average of 7,56 minutes. For same day patients, the standard deviation is 66 minutes on an average of 59 minutes (n=2378), while in the zero measurement this is 61 minutes in an average of 64 minutes. This shows that for both patient groups, the waiting times vary substantially. On 49% of all days, idle time during the regular program is 0. The standard deviation of the idle time calculated over all days is 42 minutes, on an average of 28 minutes (n=1000).

Scenario Open access 5 (Section 6.2.5) shows a standard deviation of 24 minutes for the waiting time in minutes for same day patients, on an average of 12 minutes (n=14751). Figure 46 shows the average waiting time per hour of the day in case the radiologist starts at 8:50 AM (as in scenario Open access 5) and in case the radiologist starts at 8:30 AM. At the start of the day, waiting times are relatively high when the radiologist starts at 8.50 AM. This problem visibly decreases when the radiologist starts 20 minutes earlier. Average waiting time for this scenario slightly decreases to 11 minutes. In Open access 5, the idle time varies substantially: standard deviation is 107 minutes on an average of 148,9 minutes (n=1000).

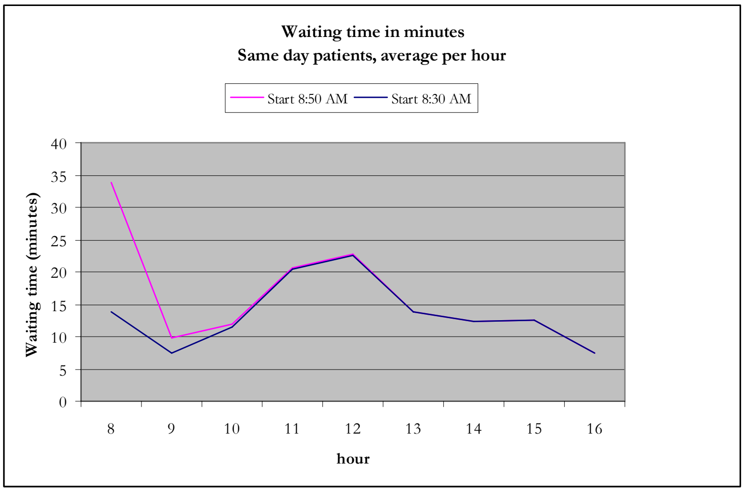

Figure 46 – Average waiting times per hour for same day patients in scenario Open access five, for program start 8:30 AM and 8:50 AM (n=14751, same day patients)

For the Open access scenarios, we expect a relation between waiting time in minutes and idle time. Analyzing the data confirms this. Figure 47 shows that when idle time on a day is high, the average waiting time for same day patients is generally low on that day.

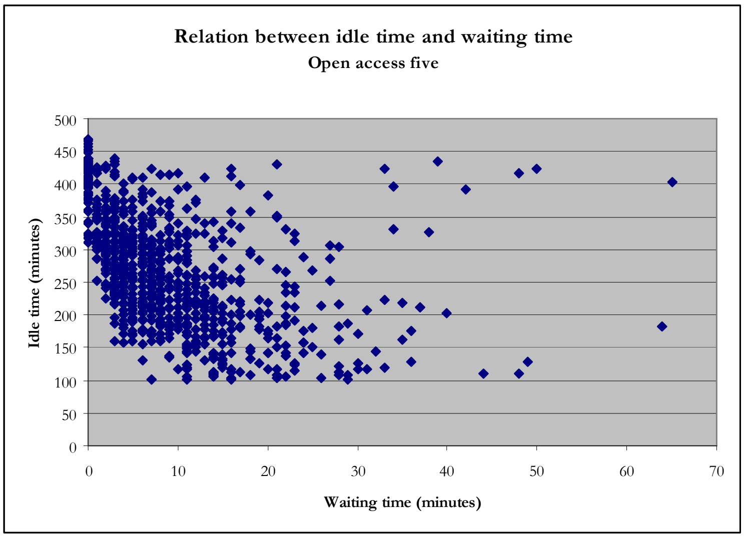

Figure 47 – Relation between the idle time on a day and the average waiting time for same day patients on that day in the scenario Open access 5 (n=1000 days)

6.4 Other examinations

To gain insight in the number of other examinations that patients need on the same day as the ultrasound examination, we register the other modalities visited by the patients in the model. The results are the same for all scenarios, while for each scenario patients are generated with similar characteristics. Table 19 shows the statistics: the average number of other modalities visited per day by ultrasound patients, the standard deviation for these observations, and the maximum number of visits per day observed during the simulation run.

Other examinations			
modality	*mean*	*st. deviation*	*maximum*
Bucky	3,5	2,53	16
Mammography	1,8	1,61	9
MRI	1,2	1,19	6
CT	1,7	1,49	8
R / F	1,6	0,41	3

Table 19 – Statistics on the other modalities visited by ultrasound patients

7 Discussion, conclusion and recommendations

Section 7.1 discusses the results of the study. Section 7.2 describes the main conclusions of this study. Section 7.3 gives some practical recommendations, as well as some suggestions for further research.

7.1 Discussion

Based on the three research questions (Section 1.4) we discuss the results. Section 7.1.4 evaluates the research approach.

7.1.1 Current performance

Although the RIS provides many data on the current process, for some performance measures in Chapter 2, a lack of appropriate data from the RIS asks for a critical view on the results.

Determining the utilization (Section 2.2.2), we encounter several problems. Because switching between examination rooms leads to overlap in the examinations of different patients, adding up the examination durations gives an incorrect number for the total production on the ultrasound modality. Reliable data on radiologist time would have solved this problem. The current schedule that is used, is (in a way) already adapted for possible disturbances (Section 2.1.2 describes this). Therefore it is hard to determine the actual capacity in terms of 'number of available slots in the regular program'. It is unclear whether the two numbers calculated for the utilization, indeed indicate undercapacity. No accurate data on idle time can be extracted from the RIS data.

Section 2.2.3 analyzes work performed outside the regular program (overtime). The overtime found is an approach of the actual work in overtime. Especially the determination of the work performed during breaks is an estimation: in practice breaks might only be postponed when the program is delayed, in stead of skipped.

7.1.2 Developed scenarios

For the development of the schedules to anticipate current same day demand, RIS data on patient arrivals in 2006 are the basis for the specific slots to reserve for same day demand. The arrival of patients at the radiology department depends on the program of the outpatient clinic. When this program changes, the specific slots to reserve for same day demand also change.

From analysis of patient arrivals in 2006 it follows that both the *number of patients*, as well as the *number of same day requests* vary per week for each hour of each weekday at the radiology department. The mean number of (same day) patients arriving per hour of each day of the week in 2006 are the basis for designing the various schedules. This results in more than average idle time and shorter waiting times on quiet days; but also less idle time, overtime and longer waiting times compared to the average, on peak days. In the simulation model the variance in patient arrivals is the same as in the current situation, thus the variance in the results of the scenarios is comparable with that of the zero measurement.

In the schedule currently used for the ultrasound modality, various slots are reserved for special examinations, such as 'sentinel node' or speed diagnostics. In the developed scenarios we assume these slots to be green (available for all patient types), possibly leading to distorted results.

7.1.3 Performance in scenarios

We use a simulation model to evaluate the performance of the various scenarios. While the constructed model is a simplified representation of the current system (assumptions in Section 5.2.3), some assumptions ask for a critical view on the results. First, we make some general comments. Next, we discuss the results separately for both parts of the simulation study.

As Section 7.1.1 describes, RIS provides only data on the examination duration for patients. The statistical distribution we use in the simulation model is based on these data. In practice, the examination duration might be shorter (the measurements for radiologist time in Section 2.1.3 show this). Concerning the simulation study, shorter examination durations lead to less waiting time, but more idle time on the other hand. Shorter examination durations may also influence the design of the various schedules.

It is risky to focus on averages for the computational results of the study. Section 6.3 shows that the computational results for the various measures vary for each patient or day.

The computational results on waiting time for other day outpatients show the waiting time from the appointment time to the start of the examination. As in the current situation, other day outpatients' arrival time deviates from the appointment time, with a mean of 15 minutes *before* the appointment time (Section 2.1.5). For the performance of the radiology department the registered waiting time is relevant, but for the waiting time experienced by the patient we consider the *actual* waiting time. The actual waiting time is the mean registered waiting time minus the average deviation of 15 minutes (Section 5.2.2). The standard deviation of the actual waiting time is the same as for the registered waiting time.

Anticipate current same day demand

Evaluation of the three schedules designed to cope with the current same day demand shows that reserving slots when same day demand is expected (Schedule 1) leads to the best computational results. Though, the choice for the schedule to implement at the radiology department depends on more than the computational results only.

Although reserving two same day blocks (Schedule 2) performs not well in terms of waiting times for both patient types, the advantage of this scenario is that it provides clarity for the patient and for the personnel at the ultrasound modality. The regular program is not disturbed by (a lack of) same day demand.

In practice, when reserving a minimal amount of same day slots in combination with one same day block at the end of the day (Schedule 3), it is possible to anticipate the amount of same day demand on a specific day. When the same day block is still empty at the end of the afternoon, then a same day appointment can be offered to some other day patients. This may reduce the risk of idle time even more. This strategy also applies when two same day blocks are used (Schedule 2).

When specific slots are reserved for same day demand (Schedule 1 and Schedule 3), it is important to fill the reserved yellow slots *during* the same day peaks. When patients that in fact have no same day indication are scheduled on the yellow slots (e.g. with the intention to avoid idle time), this results in even higher waiting times for same day patients, because then they are examined after the regular program. Clear arrangements with the radiology desk and the outpatient clinic on the conditions for same day patients are important, especially in this case.

Facilitate open access

The computational results for the second part of the study show that when we increase the capacity (Open access 2 to 5), the waiting time for same day patients, as well as the amount of patients examined on the same day improve. On the other hand, idle time then increases. Balancing demand (scenario Open access 6) improves overall performance of the ultrasound modality, including the idle time. This gives reason for discussion.

The mammapoli mornings on Monday and Thursday lead to advantages for mammapoli patients, but on the other hand to less planning flexibility for scheduling other patients. The overall strategy of the hospital plays a role in the decision to reserve capacity for one or more large patient groups, or not. Reserving capacity for one or more large patient groups improves the patient flow of these groups on the one hand, but less planning flexibility for other patients may lead to worse patient flow for the relatively small, highly specialized patient groups. Is the strategic focus of the Antoni van Leeuwenhoek hospital more on quickly serving a few big patient groups (e.g. breast cancer, lung/throat cancer), or on serving all various cancer patient groups with its highly specialized knowledge?

In practice, adapting the program of the outpatient clinic in such a way that demand is balanced to the capacity of the radiology department is complex. The utilization of the outpatient clinic is high, providing only little flexibility. The results for Open access 6 show that, though it is hard, putting some effort in balancing demand may lead to better results for the radiology department. Combining partly balancing the demand and limited increase of capacity may lead to acceptable waiting time *and* idle time.

For patients that need (an) other examination(s) next to ultrasound examination, same day access is less interesting when the other modalities can not be visited on the same day. Though, when striving for open access, it is important to maximize the number of patients scheduled on the same day. In this way, the idle time on the current day is reduced, and slots on other days remain available to serve the same day patients quickly.

The waiting time in minutes for other day outpatients is negative in some Open access scenarios (Open access 3, 4 and 5). In this case, many examinations start before the actual appointment time. We mention that the *actual* waiting time of these patients is around 15 minutes on average, caused by the arrival time deviation (Section 2.1.4).

Considering possible implementation of the open access policy, few challenges arise. First, the current backlog of patients should be minimized. Second, flexible coffee and lunch breaks ask for acceptance of personnel for the new policy to work. On some days, much idle time may occur. Substitute tasks for both the radiologist and the technicians are useful for these days.

7.1.4 Evaluation of research approach

Although we started the research in the luxurious position of having many accurate data available on the ultrasound process, some data were still missing or not relevant. This forced us to make assumptions, that may have lead to less reliable results.

Developing an accurate simulation model is a time consuming practice, but a simulation study does provide accurate insight on the quantitative effects of various possible decisions on the performance of the echography modality. Simulation does not provide insight in qualitative aspects, such as user-friendliness of the decision or practical matters concerning the implementation.

While a same day appointment for ultrasound examination is less interesting for patients who need other examinations besides an ultrasound examination, it is important to analyze the department as a whole. In stead of executing a simulation study for only the ultrasound modality, we could have started to analyze the balance in demand and capacity for all modalities of the radiology department. The next step then, would be a simulation study for the various modalities of the radiology department, to gain insight in the effect of different decisions on same day access.

7.2 Conclusions

The goal of the research (Chapter 1), is to *determine the performance of the ultrasound modality in different scenarios to improve same day access in the radiology department*. Based on the three research questions, Section 7.2 presents the conclusions.

7.2.1 Current performance

Currently, same day and emergency patients are scheduled on a green slot (when available), or else on a yellow slot (which indicated that the slot is not available), or slot in *echo2 schedule*.

Analysis of RIS data concerning 2006 shows that other day outpatients (73,9% of all patients) wait an average of 7,31 days for an ultrasound appointment. Other day inpatients (1,9% of all patients) wait 2,25 days on average. The mean waiting time in minutes is for other day outpatients 7,21 minutes, for same day patients (14,0% of all patients) 57,64 minutes. Waiting time in minutes varies substantially for same day patients: the standard deviation is 71 minutes.

Utilization is hard to determine because of lack of data on radiologist time. The determined measures for utilization indicate that generally more patients are examined than the regular capacity allows.

Per day 30 minutes of work is performed outside the regular program. This can be during break time, or after the finish of the regular program. Of all work, 16,4% is performed in overtime.

7.2.2 Developed scenarios

To anticipate current same day demand, three schedules were developed. Schedule 1 is based on the literature of Rising (1973). Slots are reserved in the ultrasound schedule when same day demand can be expected.

Schedule 2 reserves a block of same day slots at the end of each day part. Longer waiting times can be expected, but clarity for patients and personnel is the advantage of this schedule.

Schedule 3 combines both schedules 1 and 2. During the day a minimal amount of slots is reserved when same day demand is expected, to reduce the risk of idle time. When the number of same day patients exceeds the number of slots, these patients are scheduled at the end of the day in a same day block.

Facilitating same day access for all patients, we adapt the capacity of the schedule in various scenarios, and evaluate a scenario that balances demand with the capacity of the ultrasound modality.

7.2.3 Performance in scenarios

To evaluate the performance of various scenarios, the simulation study consists of two parts: 1) anticipate current same day demand and 2) facilitate open access.

Anticipate current same day demand

The improved Schedule 1, *Schedule1Improved*, leads to the best computational results when anticipating same day demand. Slots are reserved on specific time slots when same day demand is expected. Waiting time for same day patients (13,0% of all patients) reduces from 65 minutes on average in the zero measurement, to 50 minutes on average using *Schedule1Improved*. For other day outpatients (73,8% of all patients), the waiting time also reduces: from an average of 7,6 minutes to 3,0 minutes. Average overtime per day is around 27 minutes for all scenarios, compared to 22 minutes in the zero measurement. The computational results show that average idle time per day varies little between the scenarios, from 25,6 minutes using Schedule 3, to 30,6 minutes using Schedule 1. Compared to the zero measurement (42,1 minutes idle time on average), in all scenarios idle time is reduced.

Reserving specific time slots when same day demand is expected (as in Schedule 1 and Schedule 3), only works when in practice the same day slots are actually assigned to same day and emergency patients *during* the expected same day peaks.

When two same day blocks are used (Schedule 2), and when a minimal amount of reserved slots during the day is combined with a same day block at the end of the day (Schedule 3), waiting times increase compared to the zero measurement. These schedules also have advantages: for both schedules, in practice the risk of idle time can be reduced by anticipating on the amount of same day demand of that day. When the amount of same day demand is low, to some other day outpatients a same day appointment can be offered to avoid idle time. Using two same day blocks (Schedule 2) provides clarity for patients, and less disturbances for personnel of the ultrasound modality.

For all scenarios, the variance in the number of (same day) patients requesting for an (same day) appointment leads to variance in waiting time, overtime and idle time.

Overview of main computational results									
	Other day patients			Same day patients					
	Ratios		Waiting time	Ratios		Waiting time	Avg converted	Avg overtime	Avg idle time
Scenario	*%inpatient*	*%outpatient*	*outpatient(minutes)*	*%inpatient*	*%outpatient*	*SDP (minutes)*	*per day (%)*	*per day (minutes)*	*per day (minutes)*
Anticipate current same day demand									
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Schedule 1	2,8%	73,8%	3,00	10,3%	13,0%	50,50	-	25,25	27,95
Schedule 2	2,8%	73,6%	10,56	10,3%	13,3%	86,43	-	28,30	28,12
Schedule 3	2,7%	73,6%	9,85	10,5%	13,3%	81,02	-	27,23	25,63

Table 20 – Overview of main results when anticipating for current same day demand

Facilitate open access

When striving for open access, computational results show that the reserved mammapoli mornings on Monday and Thursday, the closed modality on Wednesday afternoon, and the lunch break lead to excessive waiting times for same day patients.

Expanding the capacity to challenge these problems leads to shorter waiting times and more patients served on the same day as the request for examination, but also increased idle time. When daily opening the ultrasound modality between 8.50 AM and 5 PM with personnel taking flexible breaks during quiet hours, 91,6% of all patients is served on the same day, with an average waiting time of 12 minutes. Average idle time per day in this scenario is 149 minutes.

Balancing demand to the available capacity of the ultrasound modality leads to better overall performance. Comparing the current arrival pattern and the balanced arrival pattern of patients using the base schedule (with reserved mammapolis, Wednesday afternoon closed and regular lunch breaks), the average waiting time for same day patients reduces more than an hour (from 105 minutes to 42 minutes). The amount of patients served on the same day increases from 69,1% to 86,4%, and the average idle time per day decreases from 46,6 minutes to 41,1 minutes.

For all scenarios the variance in the number of patients requesting for an appointment leads to variance in waiting time, overtime and idle time.

Overview of main computational results									
	Other day patients			Same day patients					
	Ratios		Waiting time	Ratios		Waiting time	Avg converted	Avg overtime	Avg idle time
Scenario	*%inpatient*	*%outpatient*	*outpatient(minutes)*	*%inpatient*	*%outpatient*	*SDP (minutes)*	*per day (%)*	*per day (minutes)*	*per day (minutes)*
Facilitate open access									
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Open access	2,7%	28,2%	2,46	9,0%	60,1%	105,62	31,4%	38,97	46,57
Increase capacity	1,1%	7,3%	minus 0,73	10,7%	80,9%	12,12	9,5%	29,22	148,90
Balance demand	1,2%	12,4%	0,33	10,8%	75,6%	41,58	13,9%	39,30	41,05

Table 21 – Overview of main results when facilitating open access

Challenges that arise when striving for open access, are to work down the current backlog of patients, to gain acceptance under personnel and to cope with the increased idle time.

For patients who need other examinations next to ultrasound examination (36,6% of all patients), same day access is less interesting, unless the other appointments are also on the same day.

7.3 Recommendations

During the study, we experience the routines of the radiology department and analyze the current process. Based on this experience and the results of the study we give some practical recommendations. During the study new questions arise, on which we base recommendations for further research.

7.3.1 Practical recommendations

Although the Radiology Information System (RIS) provides much information on the processes of the radiology department, this information can be improved when next to patient time (statuses START and KLAAR), also the start and finish of the actual examination is registered (radiologist or examination time) for each modality. Definition and registration of 'emergency patients' (the current 'CTRL+Q'-patients) in the RIS provides more insight in the number of emergency requests and when these requests generally can be expected.

When both ultrasound examination rooms are equipped with two dressing-rooms, the current switching between two examination rooms is not necessary anymore. In this way, it is possible for two radiologists two work simultaneously without efficiency loss.

Considering the whole radiology department, flexible exchange of personnel between modalities to cope with peaks can reduce disturbances caused by peaks, and can possibly reduce the occupation of personnel at the radiology department. For example, a 'circulation radiologist' (e.g. the radiologist assigned to the R/F modality) can assist on the various modalities when needed.

Scheduling other day outpatients on the quiet hours of the ultrasound modality gives more room for flexibility, thus to cope with same day demand and disturbances, during peak hours. Avoid the scheduling of other day outpatients between 11 and 12 AM and between 1 and 3 PM. More stringent scheduling of patients may first lead to less patient satisfaction, but eventually leads to improved patient satisfaction because more patients can be examined on the same day, and waiting times are limited.

When anticipating the current same day demand, it is important to make arrangements with the radiology desk and the outpatient clinic: which patients may claim a same day appointment and how to schedule these patients? This reduces the work pressure for the radiology desk as well as frustrations for personnel and patient. Only admit same day and emergency patients to the reserved slots in the schedule.

Before striving for open access, try to balance the arrival of patients from the outpatient clinic to the capacity of the radiology department. Try to minimize the arrival of patients during mammapoli mornings. When necessary, enlarge capacity, for example by using a second radiologist during the mammapoli mornings, or flexible break times.

Implementation of open access can be done in steps: start with the Tuesday and / or Friday. On these days many patients request for an ultrasound examination, and no problems are caused by the mammapoli trail. Avoid scheduling other day outpatients on these days, but when necessary, schedule them as early as possible on the day.

When striving for open access, schedule as many patients as possible on the same day. When a patient nevertheless prefers an other day appointment, schedule the patient on quiet hours (as early as possible on the day).

7.3.2 Recommendations for further research

While the possibility for same day access should improve patient satisfaction, it is important to gain more insight in patient preferences. How long is a patient willing to wait for *one* same day appointment? How does this willingness change when *all* examinations are offered in the same day? Does a patient prefer clarity about when the examination will take place, or is waiting time more important?

Analyzing the influence of the program of the outpatient clinic on the arrival of patients at the radiology department gives more insight in the arrival pattern of patients and their specific needs. Adjustment of the program of the outpatient clinic, or the capacity of the radiology department, might smoothen work pressure at the radiology department.

The next step is to extend this study for the radiology department as a whole. We suggest two possible approaches:

- Model the patient flow from the outpatient clinic to the radiology department. Analyze the specific demand for combinations of radiology examinations per day. Verify if capacity and demand per day per modality are in balance. Focus on the tactical level in the planning framework of Hans (2006): can each radiology modality meet the specific demand on each day? Waiting times are of less relevance, first focus on the balance between capacity and demand.

- Extend the simulation model constructed for this study. It can be considered to do this in two steps, to reduce complexity. When involving other modalities, the problem becomes a job shop problem: a patient needs to visit various radiology modalities (with or without precedence relations) before (s)he leaves the system.

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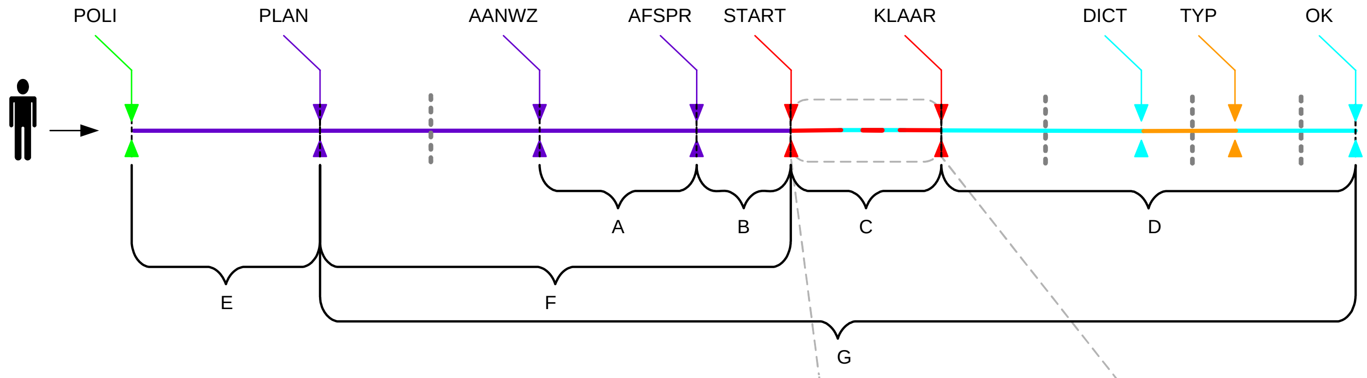
Appendices

Appendices

Appendix A Patient flow model



Legend

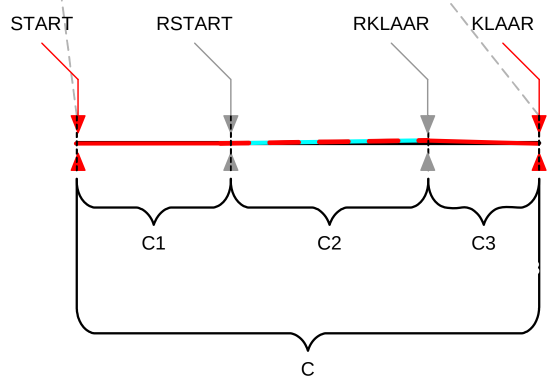
- Possible day border
- Patient time
- Technologist time
- Radiologist time
- Radiologist/technologist time
- Secretary time
- Entered by out-patient clinic
- Entered by radiology desk
- Entered by technologist
- Entered by Maarten
- Entered by secretary
- Entered by radiologist

Times

POLI	*Time of appointment at out-patient clinic*[1]
PLAN	*Radiology desk employee enters appointment*
AANWZ	*Patient enters waiting room*[2, 3]
AFSPR	*Appointment time*[3]
START	*Patient enters examination room*[3]
RSTART	*Radiologist starts examination*[4]
RKLAAR	*Radiologist ends examination*[4]
KLAAR	*Patient leaves examination room*
DICT	*Radiologist finishes recording*
TYP	*Secretary finishes transcribing*[5]
OK	*Authorised report available*

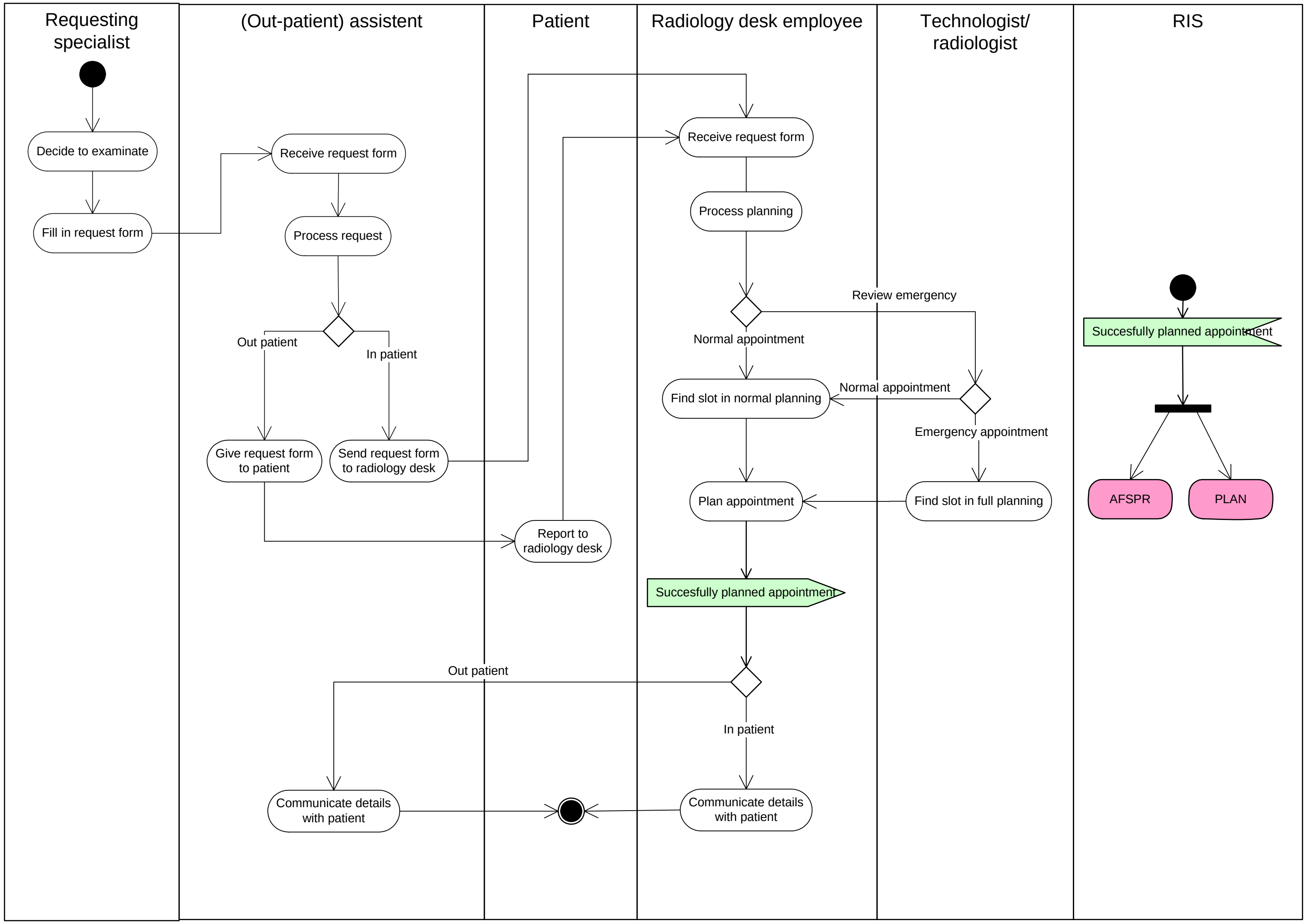
Durations

A	*Patient lateness for appointment*[3]
B	*Radiology department induced waiting time*
C	*Bruto examination duration (total patient time)*
C1	*Patient handling before*
C2	*Netto examination duration*
C3	*Patient handling after*
D	*Duration authorized report available*
E	*Time from start outpatient appointment to planning radiology appointment*
F	*Outpatient+radiology induced waiting time*
G	*Turn-around time complete examination*



[1] POLI is not available for inpatients
[2] AANWZ is not available for inpatients
[3] AANWZ, START and AFSPR can occur in every order
[4] RSTART, RKLAAR are manual measurements
[5] TYP is not available with online interpretation

Appendix B Process flow: request for examination



Appendix C Input distributions

For the simulation model we use different input distributions. This appendix contains an overview of probabilities and statistical distributions used, and when necessary the calculations performed on data.

a. Arrival of patients

For the arrival of patients we analyzed the number of patients that arrive at the radiology desk to plan an appointment (times of statuses PLAN in RIS). This results in an average number of patients per hour of each weekday. Table C1 shows these data as well as the conversion of these data to mean interarrival times in seconds. We use these data in the simulation model.

Example: Monday morning between 10 and 11 AM every 2255 seconds (≈ 37 minutes) a patient arrives at the desk to plan an echography appointment (sometimes in combination with other radiology appointments). The first patient arrives at 10.37 AM, the next 37 minutes later (around 11.14 AM). At 11 AM the interarrival time changes to 1510 (≈ 25 minutes). Thus, the 3rd patient arrives at 11.25 AM.

Arrival process data										
	Monday		*Tuesday*		*Wednesday*		*Thursday*		*Friday*	
hour	*no.events*	*interarr. time*	*no.events*	*interarr. time*	*no.events*	*interarr. time*	*no.events*	*interarr. time*	*no.events*	*interarr. time*
8	0,27	13371	0,69	5200,00	0,48	7488	0,42	8509	0,67	5349
9	1,31	2753	2,60	1386,67	1,85	1950	1,58	2283	1,85	1950
10	1,60	2255	3,42	1051,69	2,63	1366	1,71	2103	2,75	1309
11	2,38	1510	3,96	908,74	2,77	1300	2,60	1387	2,81	1282
12	1,58	2283	2,90	1239,74	1,92	1872	1,58	2283	2,23	1614
13	1,90	1891	1,69	2127,27	1,08	3343	1,38	2600	1,58	2283
14	2,58	1397	2,65	1356,52	1,42	2530	2,00	1800	2,96	1216
15	1,87	1930	2,85	1264,86	1,48	2431	1,92	1872	2,77	1300
16	1,48	2431	2,25	1600,00	1,15	3120	1,38	2600	2,31	1560
17	0,21	17018	0,42	8509,09	0,06	62400	0,13	26743	0,31	11700

Table C1 – Mean number of events per hour and interarrival times per hour (extracted from RIS, 2006)

b. Patient characteristics

At the entrance of the radiology department, patients are assigned with characteristics: Category, OnlyEcho and LongProc. Patients are divided in the four categories used throughout the study: other day outpatients, other day inpatients, same day patients and emergency patients. OnlyEcho indicates whether a patient needs any other examinations next to echography examination. LongProc indicates whether the length of the examination is expected to be 'regular' (a planning slot of 10 minutes is reserved), or 'long' (two planning slots of 10 minutes are reserved). These characteristics result in 16 patient types.

An excel pivot table provides insight in the probabilities for each of the patient types to occur. We distinguish four inputs for patient characteristics: current patient characteristics, patient characteristics for same day demand A, patient characteristics for same day demand B and patient characteristics for same day demand C (Section 4.3.2). Some same day or emergency patients arrive at the end of the day, when the program already finished. These patients are served as soon as possible on the next day. The category of this patient is then changed to other day (in)(out)patient. The next other day patient that arrives at the department changes to a same day or emergency patient. This ensures that the ratios for the categories stay the same. Table C2 shows all patient types and their probabilities for the current situation.

Patient groups & probabilities							
Type	*Category*	*LongProc*	*OnlyEcho*	*Probability*			
				Current	*A*	*B*	*C*
1	Other day inpatient	false	true	0,0119	0,0019	0,0004	0,0000
2	Other day inpatient	false	false	0,0040	0,0012	0,0004	0,0000
3	Other day inpatient	true	true	0,0023	0,0000	0,0000	0,0000
4	Other day inpatient	true	false	0,0008	0,0002	0,0000	0,0000
5	Other day outpatient	false	true	0,4075	0,2897	0,1579	0,0000
6	Other day outpatient	false	false	0,2387	0,1985	0,1412	0,0000
7	Other day outpatient	true	true	0,0546	0,0400	0,0194	0,0000
8	Other day outpatient	true	false	0,0387	0,0331	0,0204	0,0000
9	Emergency patient	false	true	0,0700	0,0800	0,0814	0,0752
10	Emergency patient	false	false	0,0248	0,0275	0,0283	0,0354
11	Emergency patient	true	true	0,0052	0,0075	0,0075	0,0060
12	Emergency patient	true	false	0,0019	0,0025	0,0027	0,0042
13	Sameday patient	false	true	0,0735	0,1914	0,3232	0,4661
14	Sameday patient	false	false	0,0481	0,0883	0,1456	0,3017
15	Sameday patient	true	true	0,0085	0,0231	0,0437	0,0606
16	Sameday patient	true	false	0,0096	0,0152	0,0279	0,0508

Table C2 – Division of patient groups: input probabilities for each same day demand scenario (Current, A: all patients within 3 days, B: all patients within 7 days, C: all patients, extracted from RIS, 2006, n=4802)

c. Other examinations

Patients assigned with characteristic 'OnlyEcho=false' visit next to the echography modality one or more other radiology modalities. The probabilities for each combination of other examinations to undergo are extracted from RIS (Table C3). Of all patients, 39% combines an ultrasound examination with an appointment on one or more other radiology modalities.

Combinations of other examinations					
	Probability	*Combination*		*Probability*	*Combination*
1	0,3426	Bucky	*16*	0,0352	Bucky-MRI
2	0,0830	Bucky-CT	*17*	0,1107	CT
3	0,0006	Bucky-CT-RF	*18*	0,0006	CT-RF
4	0,0006	Bucky-CT-RF-MRI	*19*	0,0012	CT-Echo-MRI
5	0,0023	Bucky-CT-Echo	*20*	0,0029	CT-Mammo
6	0,0006	Bucky-CT-Echo-MRI	*21*	0,0006	CT-Mammo-MRI
7	0,0006	Bucky-CT-Mammo	*22*	0,0104	CT-MRI
8	0,0006	Bucky-CT-Mammo-MRI	*23*	0,0144	RF
9	0,0133	Bucky-CT-MRI	*24*	0,0277	Echo
10	0,0035	Bucky-RF	*25*	0,0052	Echo-Mammo
11	0,0069	Bucky-Echo	*26*	0,0012	Echo-MRI
12	0,0006	Bucky-Echo-Mammo	*27*	0,2249	Mammo
13	0,0012	Bucky-Echo-MRI	*28*	0,0075	Mammo, MRI
14	0,0127	Bucky-Mammo	*29*	0,0882	MRI
15	0,0006	Bucky-Mammo-MRI			

Table C3 – Probabilities for all (combinations of) other modalities to visit next to echography (extracted from RIS, 2006, n=1883)

d. Waiting time in days

While the day on which an other day patient is planned depends on several factors (e.g. patient preferences, requests from the outpatient clinic and the schedule), the distribution of the waiting time in days from RIS serves as input for the simulation model. We distinguish two distributions: for inpatients (generally scheduled within 3 days) and outpatients. Figure C1 and C2 show the distributions for the waiting time in days for a planning horizon of 21 days for respectively (other day) inpatients and outpatients. Table C4 shows the probabilities that follow from these distributions for both patient groups. All inpatients are scheduled within .. days. Of all outpatients, 88% is scheduled within 21 days.

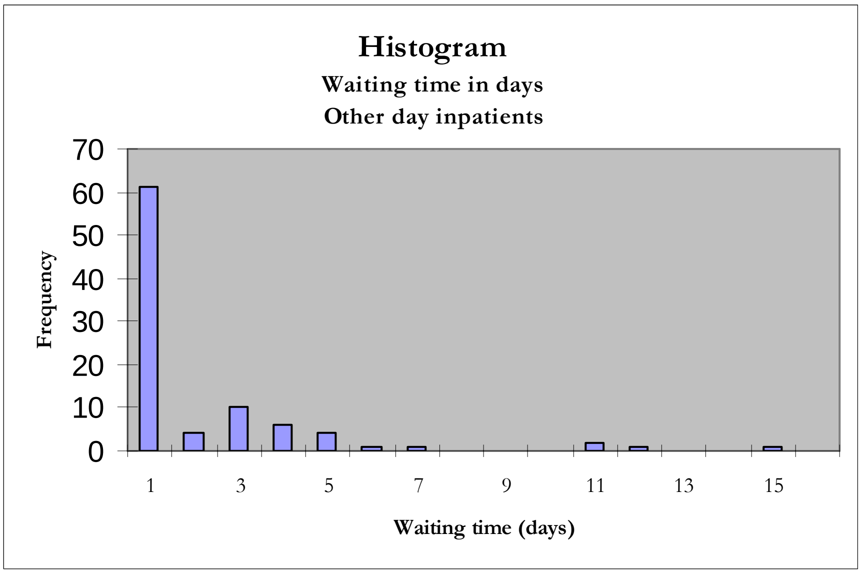


Figure C1 – Waiting time in days for inpatients (extracted from RIS, 2006, n=91, all other day inpatients)

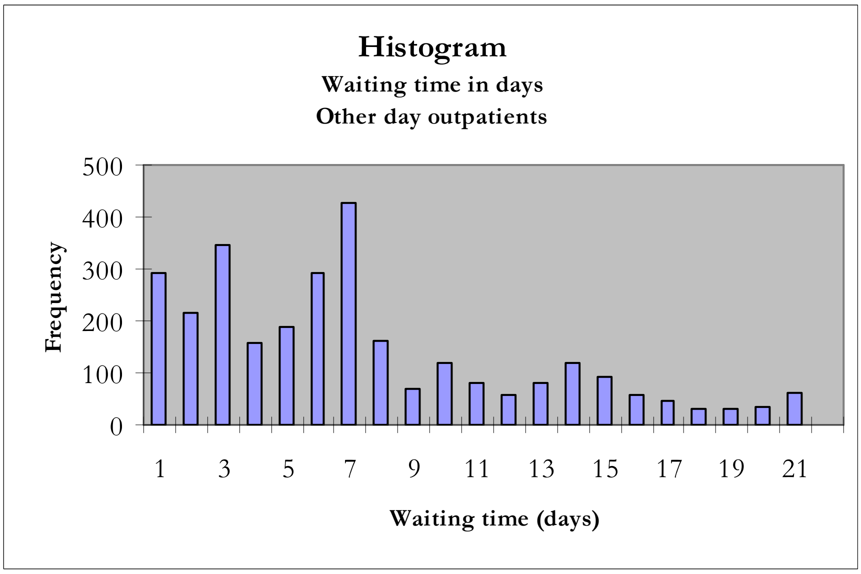


Figure C2 – Waiting time in days for outpatients (extracted from RIS, 2006, n=2962, other day outpatients planned within 21 days)

Distribution of waiting time days					
Days	*Inpatients*	*Outpatients*	*Days*	*Inpatients*	*Outpatients*
1	0,6703	0,0993	12	0,0110	0,0196
2	0,0440	0,0726	13	0,0000	0,0267
3	0,1099	0,1172	14	0,0000	0,0398
4	0,0659	0,0527	15	0,0110	0,0311
5	0,0440	0,0641	16	0,0000	0,0189
6	0,0110	0,0993	17	0,0000	0,0159
7	0,0110	0,1445	18	0,0000	0,0098
8	0,0000	0,0544	19	0,0000	0,0101
9	0,0000	0,0240	20	0,0000	0,0118
10	0,0000	0,0402	21	0,0000	0,0213
11	0,0220	0,0270			

Table C4 – Probabilities for the number of days between 'PLAN' and 'AFSPR' separated for other day inpatients and other day outpatients (extracted from RIS, 2006, other day inpatients (n=91), other day outpatients (n=3053))

e. Arrival time deviation

As Section 2.1.4 describes, patients tend to arrive early or late for their appointment. We determined the statistical distribution for the deviation of the arrival time from the appointment time based on RIS data concerning arrival times and appointment times. We smoothen the peak around 0 minutes. This peak is caused by patients that neglect to report at the radiology desk before the appointment, and therefore a measurement error. We only consider deviations between -99 minutes and 99 minutes. Outliers are excluded from the analysis. Figure C3 shows how the arrival time deviation follows a normal distribution with parameters μ=-15 and σ=14. The Excel add-in XLStat is used to fit the correct distribution on empirical data from RIS.

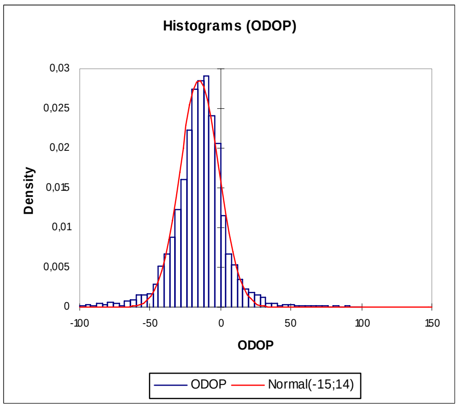


Figure C3 – Normal (μ=-15, σ=14) distribution fits the empirical data from RIS on deviation of arrival time from appointment time for other day outpatients (extracted from RIS, 2006, other day outpatients, n=3463).

f. Examination duration

We distinguish two distributions for the examination duration (ProcTime): for regular examinations (one 10 minute slot reserved) and for 'longproc' examinations (one or more 10 minute slots reserved). Figure C4 shows that for regular examinations, a Weibull (α= 1.8, β=11.7) distribution fits the empirical data. Figure C5 shows that for 'longproc' examinations, a Weibull (α= 1.5, β=19.1) distribution fits the empirical data. The Excel add-in XLStat is used to fit the correct distribution on empirical data from RIS.

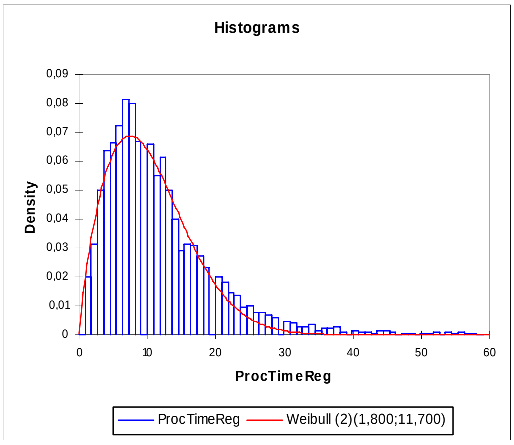


Figure C4 - Weibull (α= 1.8, β=11.7) distribution fits the empirical data on examination durations from RIS (extracted from RIS, 2006, all patients for which one slot is reserved, n=4195)

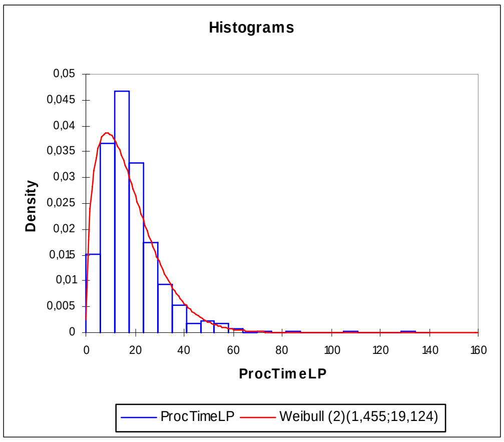


Figure C5 - Weibull (α= 1.5, β=19.1) distribution fits the empirical data on examination durations from RIS (extracted from RIS, 2006, all patients for which two or more slots are reserved, n=584)

Appendix D Detailed description of simulation model

This appendix contains a detailed description of the constructed simulation model. First, the entity 'Patient' is described, which moves through the system (Section D-a). Second, we describe all components of the radiology department (Section D-b). Performance measurement (Section D-c), simulation settings (Section D-d), experimental factors (Section D-e) and event control (Section D-f) are supporting components of the simulation model. Figure D1 shows a screenshot of the simulation model, where each component is visualized.

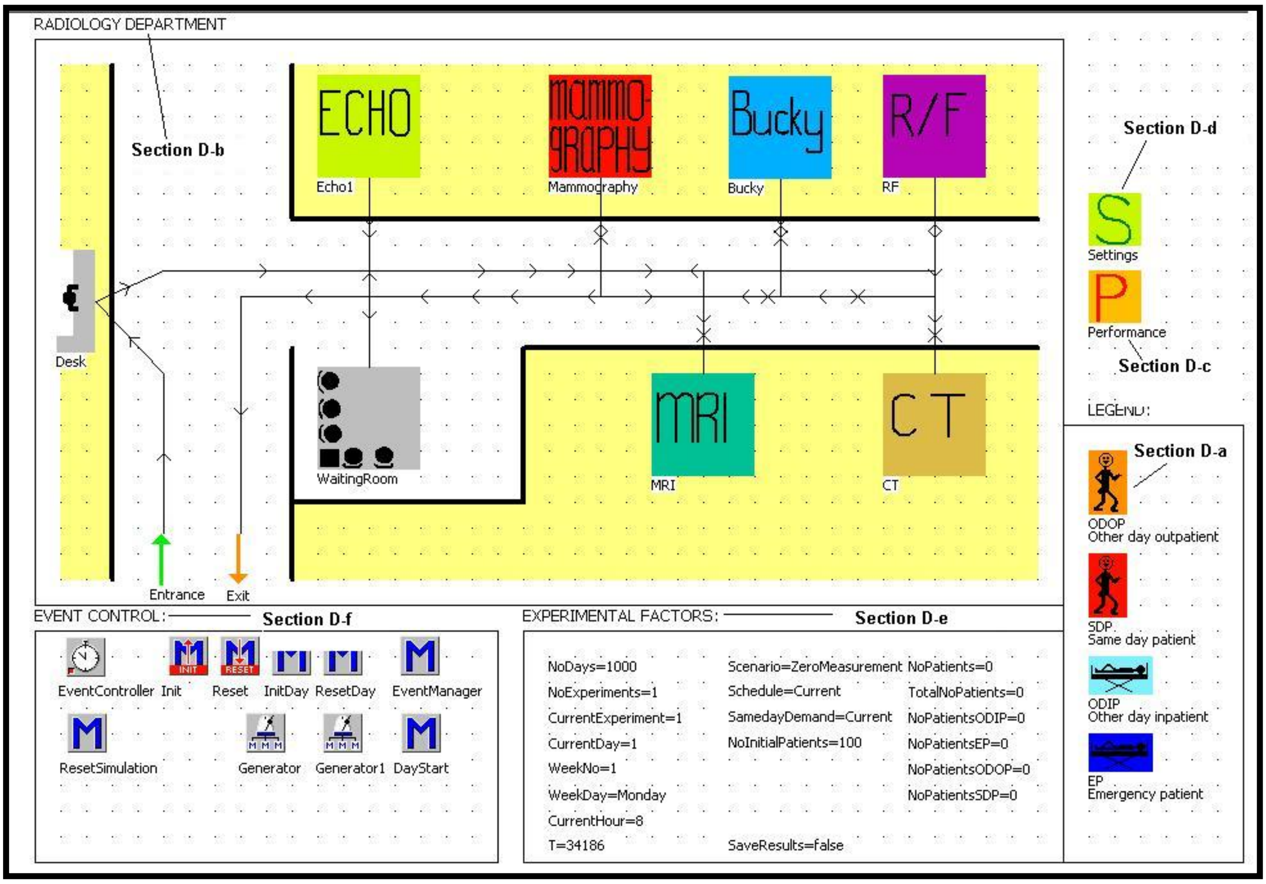


Figure D1 – Screenshot of the simulation model

a. The patient

Patients flow through the system. When entering the system, the following characteristics are assigned to a patient: Category, OnlyEcho and LongProc. Patients are divided in the four categories used throughout the study: other day outpatients, other day inpatients, same day patients and emergency patients. OnlyEcho indicates whether a patient needs any other examinations next to echography examination. LongProc indicates whether the length of the examination is expected to be 'regular' (a planning slot of 10 minutes is reserved, 88% of all examinations), or 'long' (two planning slots of 10 minutes are reserved, 12% of all examinations). From these characteristics 16 patient types, each occurring with a certain probability (Appendix C-b, Table C2), follow. A patient types is assigned to a patient by drawing a random number between 0 and 1.

In the model, various attributes are used for the patient. Figure D2 provides an overview and description of the attributes. Some attributes are only for modeling purposes, others for registration of performance.

Attributes of 'patient'		
Attribute	*Format*	*Description*
IdNo	*integer*	*unique id no of the patient*
PatientType	*integer*	*patient type 1..16*
Category	*string*	*category 'ODOP', 'SDP', 'ODIP', 'EP'*
Colour	*string*	*colour corresponds with certain icon for category*
LongProc	*boolean*	*regular (false), longproc (true)*
ProcTime	*time*	*duration of examination, determined from distribution*
OnlyEcho	*boolean*	*only echo (true) or also other examinations (false)*
OtherBucky	*integer*	*1 if bucky is needed next to echography, 0 if not*
OtherCT	*integer*	*1 if CT is needed next to echography, 0 if not*
OtherEcho	*integer*	*1 if another echo is needed next to echography, 0 if not*
OtherMammography	*integer*	*1 if mammography is needed next to echography, 0 if not*
OtherMRI	*integer*	*1 if MRI is needed next to echography, 0 if not*
OtherRF	*integer*	*1 if R/F is needed next to echography, 0 if not*
PatientStatus	*string*	*current status of the patient 'PLAN', 'AANWZ'*
PlanTime	*time*	*time of scheduling the appointment at the desk*
PlanHOUR	*integer*	*hour of scheduling the appointment at the desk*
PlanWEEKDAY	*string*	*weekday of scheduling the appointment at the desk*
PlanWeekNo	*integer*	*week no of scheduling the appointment at the desk*
AfsprTime	*time*	*appointment time*
PlannedSlot	*integer*	*slot on which patient is scheduled 480, 490 .. 1070*
SlotColor	*string*	*color of the slot on which patient is scheduled 'green', 'yellow', 'blue', 'echo2'*
FromHomeTime	*time*	*time assigned to patient to arrive on day of appointment*
AanwzTime	*time*	*time the patient reports at desk on day of appointment*
StartTime	*time*	*start time of the examination*
KlaarTime	*time*	*the time the examination finishes*
FinishTime	*time*	*hulp variable finish time of the examination*
ServiceTime	*time*	*hulp variable duration of the examination*
WaitingTimeDays	*integer*	*patient waiting time in days*
WaitingTimeMin	*time*	*patient waiting time in minutes*

Figure D2 – Attributes of entity 'Patient'

b. The radiology department

Figure D3 shows an overview of the components in the model. Consecutively the entrance of the radiology department, the radiology desk, the waiting room, the different modalities of the radiology department and the exit of the department. This section describes each component.

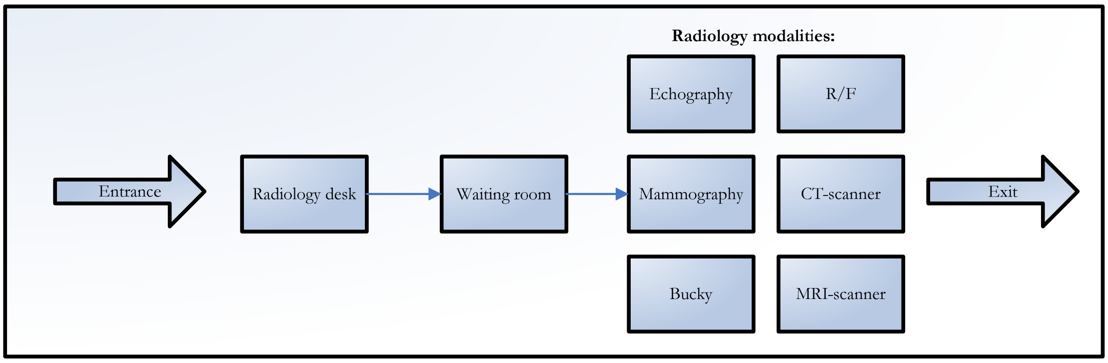


Figure D3 – Overview of system components

Entrance

At the entrance of the model, patients are created in the *Source*. Figure D4 shows the content of the component 'Entrance'. The method *ArrivalRate* determines each hour a new interarrival time. Interarrival times are negative exponential distributed, the parameter changes for every hour (Appendix C-a). The method *Arrive* assigns each patient with a patient type, by drawing a random number. Next, the patient is assigned with the characteristics matching the drawn patient type. If any other examinations are needed, the patient is assigned with (a combination of) other examinations. Depending on the 'Longproc' characteristic, the duration of the examination is assigned to the patient according to the statistical distribution determined (Appendix C-f). Newly created patients flow directly through the *OutputBuffer* to the next component: the radiology desk.

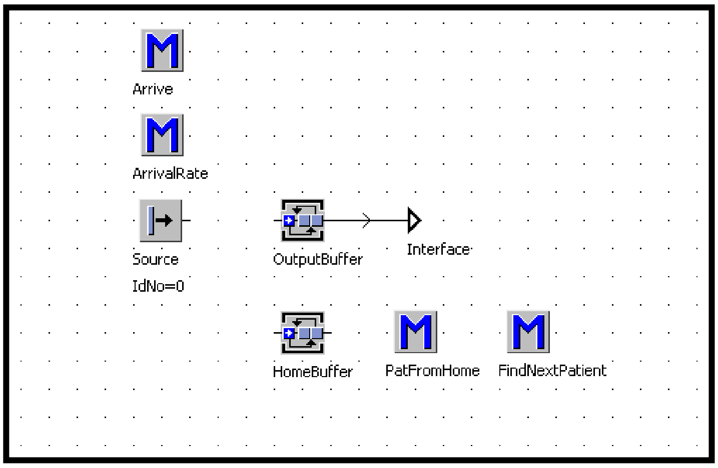


Figure D4 – The component 'Entrance'

Other day inpatients and other day outpatients are 'stored' in the *HomeBuffer* until they return to the department for their appointment(s). The method *PatFromHome* picks the first patient from the *HomeBuffer* on the FromHomeTime of that patient. The method *FindNextPatient* checks the FromHomeTime of the first patient in the *HomeBuffer* and calls the method *PatFromHome* on the FromHomeTime.

Radiology desk

Patients reporting at the desk are 1) patients who return to the department for their appointment scheduled earlier or 2) patients that need an examination. Figure D5 shows the content of component *Desk*.

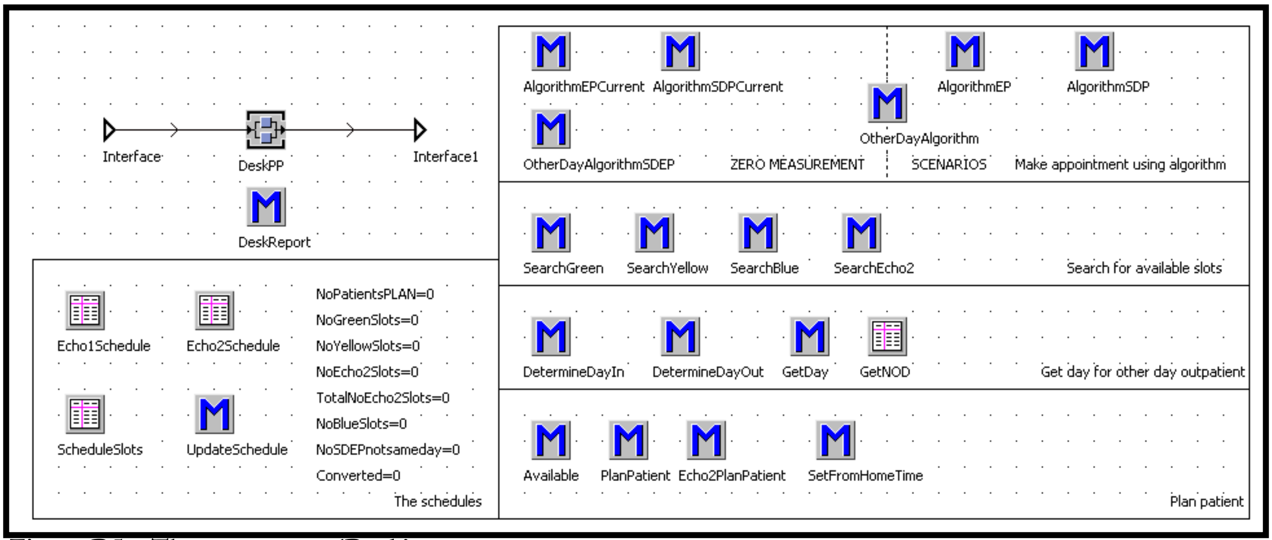


Figure D5 – The component 'Desk'

The method *DeskReport* checks the current status of the patient. If the status of the patient is PLAN, then the appointment is already scheduled. The arrival time is registered and the patient is directed to the component *WaitingRoom*. When the current status is not PLAN, an appointment is scheduled for the patient, using the appropriate algorithm.

Patients are scheduled on *Echo1Schedule* or (only in zero measurement) on *Echo2Schedule*. The planning horizon in the model is 3 weeks: 15 work days. The TableFile *ScheduleSlots* contains the slot colors of *Echo1Schedule* for the planning horizon of the schedule. Slot colors are represented by integer numbers: 1 corresponds with green, 2 with yellow, 3 with red and 4 with blue slots. All schedules are updated at the start of a new day: all columns move one left, the first column is deleted and a new last column is copied from *InitSchedule* (Section D-d). Variables count the number of slots filled during a simulation run, as well as the number of patients that cannot be scheduled on the current day (*NoSDEPnotsameday* and *Converted*).

In the zero measurement, emergency patients (EP) are scheduled using the method *AlgorithmEPCurrent*, same day patients (SDP) are scheduled using the method *AlgorithmSDPCurrent*, and other day inpatients and outpatients are scheduled with method *OtherDayAlgorithm*. For EP and SDP who cannot be scheduled on the current day, the algorithm *OtherDayAlgorithmSDEP* is used. In the scenarios, EP are scheduled with method *AlgorithmEP* and SDP are scheduled with *AlgorithmSDP*. Other day inpatients and outpatients are scheduled with the same *OtherDayAlgorithm* as in the zero measurement. This difference is because for the new schedules to work, EP and SDP should be scheduled as soon as possible on yellow *or* green slots, in stead of preferably on a green slot, otherwise on yellow (zero measurement).

The method *OtherDayAlgorithm* first determines the day on which to schedule the patient. If the category is other day inpatient (ODIP), this is performed by method *DetermineDayIn*, when category is other day outpatient (ODOP), method *DetermineDayOut* is called. While patients cannot be scheduled in weekends, the TableFile *GetNOD* checks this. As long as the determined day is in a weekend, a new day is determined by the method. When a day is found, *OtherDayAlgorithm* searches for the first green slot available on that day. The method *Available* checks whether the slot is available (*void*) in the *Echo1Schedule* or *Echo2Schedule*. When no slot is found, a new day is determined. When an available slot is found, the method *PlanPatient* or *Echo2PlanPatient* schedules the patient and assigns the appointment time to the patient. Next, the FromHomeTime is assigned by the method *SetFromHomeTime*. For SDP the FromHomeTime is the PlanTime. For EP and ODIP, the FromHomeTime is just before the appointment (waiting time in minutes is not considered relevant for these groups during the study). For ODOP, the FromHomeTime deviates from the appointment time (AfsprTime) following the distribution from Section C-e. Figure D6 shows a simplified flow chart of the *OtherDayAlgorithm*.

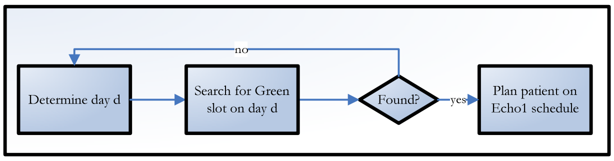


Figure D6 – Flow chart of 'OtherDayAlgorithm'

In the zero measurement, SDP and EP are scheduled on the same day, when possible. EP are allowed on green, yellow, blue and echo2 slots. While same day patients are allowed on green, yellow and echo2 slots, *AlgorithmSDPCurrent* is almost the same as *AlgorithmEPCurrent*. For EP and SDP, first the slot to start the search from is determined. That is the start time of the first slot from the current time. When the start time of the search is after the start of the Overtime, and the radiologist is not working anymore, *OtherDayAlgorithmSDEP* is called. This method schedules the patient as soon as possible on the next day: preferably on a green slot, otherwise on yellow (or blue or echo2). The variable *NoSDEPnotsameday* is updated by 1. The next other day patient entering the system will be changed into a same day patient. This is done to keep the ratios in patient groups as much as possible like the current ratios. When the program is not finished yet, the patient is scheduled on the current day. First, the algorithms search for an available green slot. When not found, the algorithm searches for a yellow slot. When not found, the *AlgorithmEPCurrent* searches for a blue slot, but *AlgorithmSDPCurrent* skips this step. When no available slot is found in *Echo1Schedule*, both algorithms search *Echo2Schedule* for an available slot. Finally, when the patient cannot be scheduled on *Echo2Schedule* as well, the patient is converted to an other day (in)(out)patient and the counter *Converted* is updated by 1. The patient is then scheduled using the *OtherDayAlgorithmSDEP*. Figure D7 shows a simplified flow chart of *AlgorithmEPCurrent*.

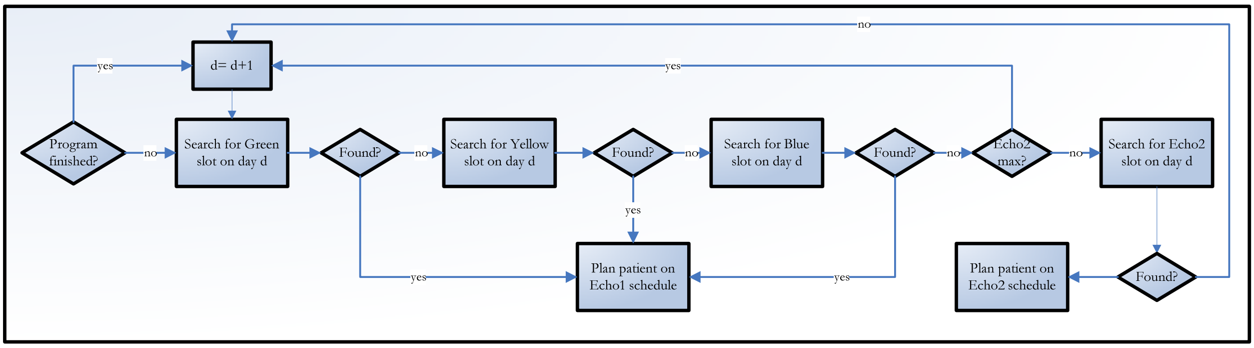


Figure D7 – Flow chart of 'AlgorithmEPCurrent'

In the scenarios, ODOP and ODIP are scheduled using the same *OtherDayAlgorithm* as in the zero measurement. SDP are scheduled using *AlgorithmSDP*, EP are scheduled using *AlgorithmEP*. *Echo2Schedule* is not used anymore: all patients should fit in *Echo1Schedule*. If the start time of the search is after the DayStop (*not* the Overtime start), the patient is scheduled using the OtherDayAlgorithm. Thus, *not* intrinsically on the next day! Counter NoSDEPnotsameday is updated by 1. The algorithms for SDP and EP are almost the same, except that EP are allowed on blue slots, and SDP not. From the starting point of the search, both algorithms search for an available (*void*) slot in Echo1Schedule. For the first available slot that is found, the color is checked in *ScheduleSlots*. If this color is green or yellow (or blue for EP), then the patient is scheduled on this slot (method *PlanPatient* is called). When the color of the slot does not allow to schedule the patient, the next available slot is searched. When finally, no appropriate slot is found on the current day, the patient is scheduled using *OtherDayAlgorithm*. The day to schedule the patient on is then determined using method *GetDay* (thus not necessarily on the next day). The patient is converted to an other day (in)(out)patient. Counter *Converted* is updated by 1. Figure D8 shows the flow chart for both algorithms.

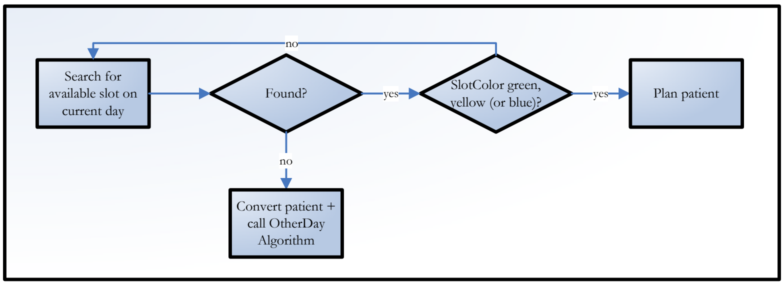


Figure D8 – Flow chart of 'AlgorithmEP' and 'AlgorithmSDP'

After scheduling the appointment, the method *DeskReport* changes the status of the patient into PLAN and directs SDP and EP to the waiting room. Other day (in)(out)patients leave the department and are 'stored' in the *Entrance* until the day of the appointment.

Waiting room

The *WaitingRoom* contains a *WaitSorter* that sorts the patients on appointment time (AfsprTime). When *Echo1* is empty and the entrance of Echo1 is unlocked, then the first patient in the *WaitSorter* is directed to *Echo1*. The method *SortWaitingRoom* orders the *WaitSorter* to sort its content. Figure D9 visualizes the content of the component *WaitingRoom*.

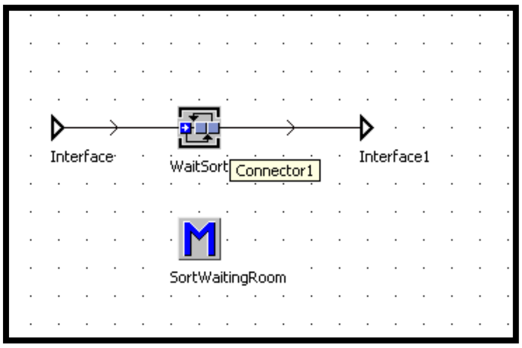


Figure D9 – The component 'WaitingRoom'

Echo1

The component *Echo1* represents the examination room. In the model, we only use one examination room. This is because only one radiologist is assigned to the echography modality, thus the radiologist determines the capacity in stead of the equipment. Figure D10 shows the content of component *Echo1*.

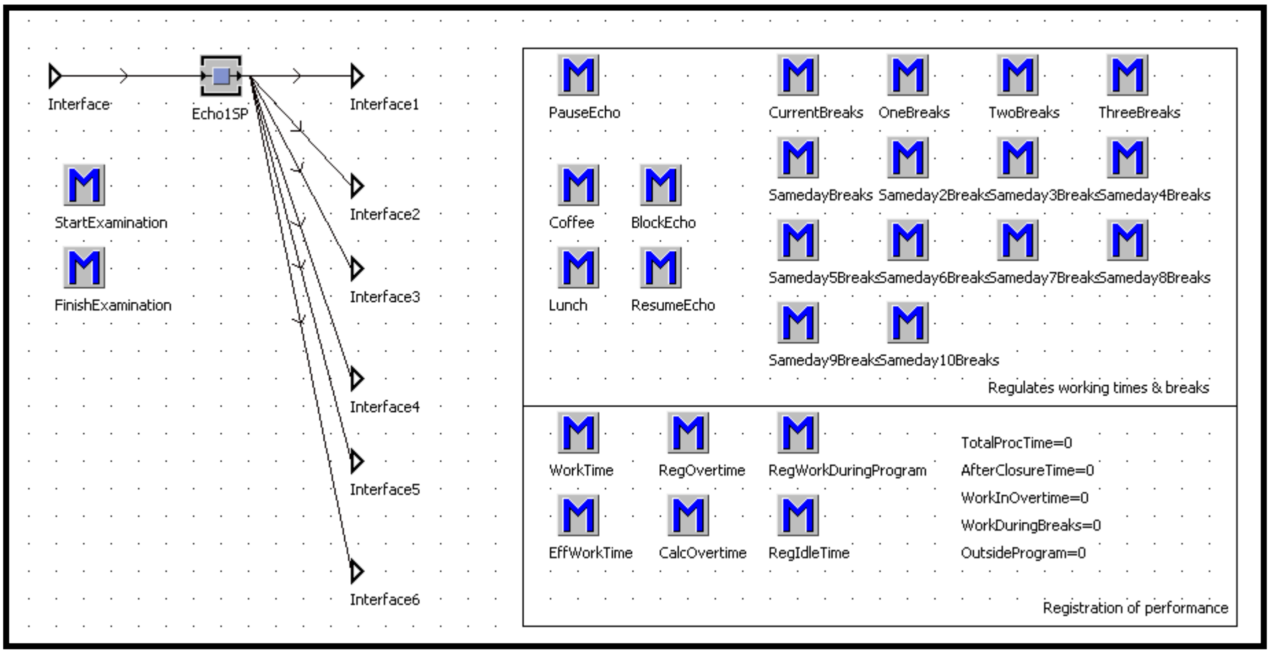


Figure D10 – The component 'Echo1'

Echo1 contains the SingleProc *Echo1SP*, which serves one patient at a time. The processing time is the ProcTime assigned to the patient at the *Entrance*. Before the examination starts, the method *StartExamination* registers the StartTime. When the examination finishes, method *FinishExamination* registers the finish time of the examination (KlaarTime) and updates the variable *TotalProcTime*. When the examination starts or finishes outside regular working hours, the method *RegOvertime* is called to register work in overtime. The method *FinishExamination* also registers the appropriate waiting times for the various categories. Figure D11 shows the formulas that determine the waiting time in minutes. When the patient needs any other examinations, the patient is directed to the next modality to visit. Otherwise, the patient is directed to the *Exit* of the department.

Other day outpatients:
IF arrival time < appointment time THEN
Waiting time = start time – appointment time
ELSE
Waiting time = start time – arrival time

Sameday patients:
Waiting time = start time – plan time

Figure D11 – Formulas used to determine the Waiting time in minutes

The entrance of the modality is blocked when the modality is closed: outside the program and during breaks. The method *PauseEcho* calls the appropriate method to regulate the working times, depending on the scenario. Appendix F provides an overview of the schedules and working times used in each scenario.

For the *Echo1* modality, various measures are registered, to calculate performance of the modality. To calculate the overtime, we distinguish work outside the regular program (*OutsideProgram*), and work performed during breaks (*WorkDuringBreaks*). For variable *OutsideProgram* we use two help variables: *AfterClosureTime* (work performed on wednesday afternoon if modality is closed) and *WorkInOvertime* (work performed before or after regular program). Figure D12 provides an overview of the formulas used to calculate overtime.

OutsideProgram = AfterClosureTime + WorkInOvertime
Total Overtime = OutsideProgram + WorkDuringBreaks

Figure D12 – Formulas used to determine Overtime

To calculate the idle time, we use the formulas from Figure D13. Variable *WorkTime* is the length of the regular program, *Effective WorkTime* is the duration of the actual work performed. *WorkDuringProgram* is the total amount of work performed within the regular program. The idle time is the time that the modality was idle *within the regular program*.

WorkTime = OvertimeStart – ProgramStart – TotalBreakTime + planned extra worktime
Effective WorkTime = WorkTime + Overtime
WorkDuringProgram = TotalProcTime – WorkDuringBreaks – OutsideProgram
IdleTime = WorkTime - WorkDuringProgram

Figure D13 - Formulas used to determine Idle Time

Other modalities

For the other radiology modalities (Mammography, Bucky, CT-scanner, MRI-scanner, R/F), the components are added in the model, but not modeled. The other modalities only visualize the patient flow through the modalities. Each *other modality* contains basically the same components. Figure D14 visualizes the *Mammography* modality. The SingleProc *MammoProc* processes patients with a standard processing time of 10 minutes (we chose this duration such that the moving units are visible while running the model). The method *FinishMammo* checks whether the patient needs to visit any other modality, and directs the patient to that modality. If no other examinations are needed, the patient is directed to the *Exit*.

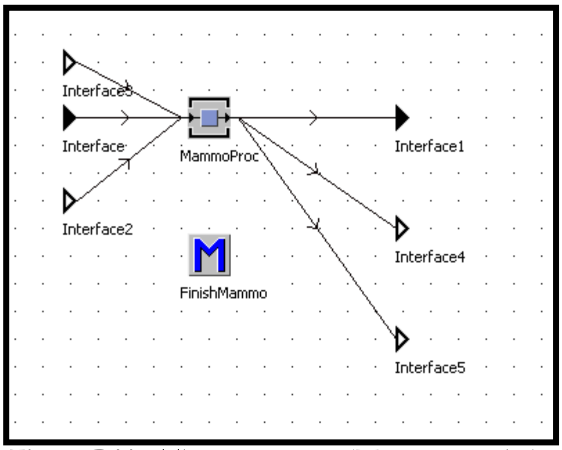


Figure D14 – The component 'Mammography'

Exit

In the *Exit* of the radiology department, the method *CollStatistics* saves the relevant data on the patient in the TableFile *PatientDataALL* (Section D-c). Next, the patient is destroyed in the *Drain*. Figure D15 shows the content of the component *Exit*.

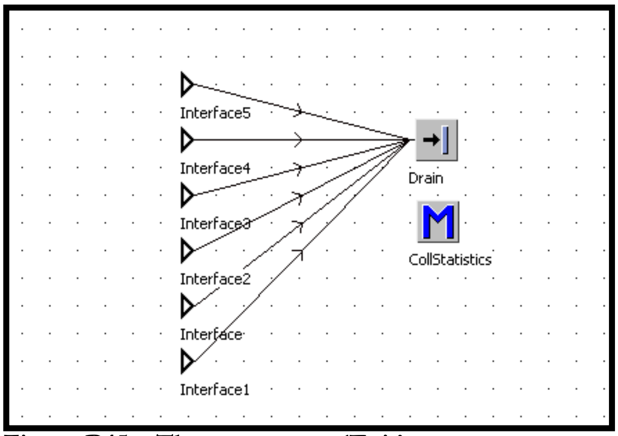


Figure D15 – The component 'Exit'

c. Performance measurement

The frame Performance contains TableFiles and Methods to save the relevant statistics during the simulation run. Figure D16 visualizes the frame. When a patient leaves the system (in the *Exit*), relevant statistics are saved in the TableFile *PatientDataALL*, and depending on the category of the patient, also in the corresponding TableFile. We separately save the statistics per patient group to compute averages per patient group at the end of the day. The TableFiles per patient group are emptied at the end of each day, the TableFile *PatientDataALL* is only emptied at the end of the experiment. At the end of the day, relevant day data are saved in the TableFile

DayData. At the end of the experiment, averages are computed for the various relevant measures, and stored in the TableFile *ExperimentData*.

Depending in the variable *SaveResults* at the main frame, the data are saved in excel at the end of each experiment.

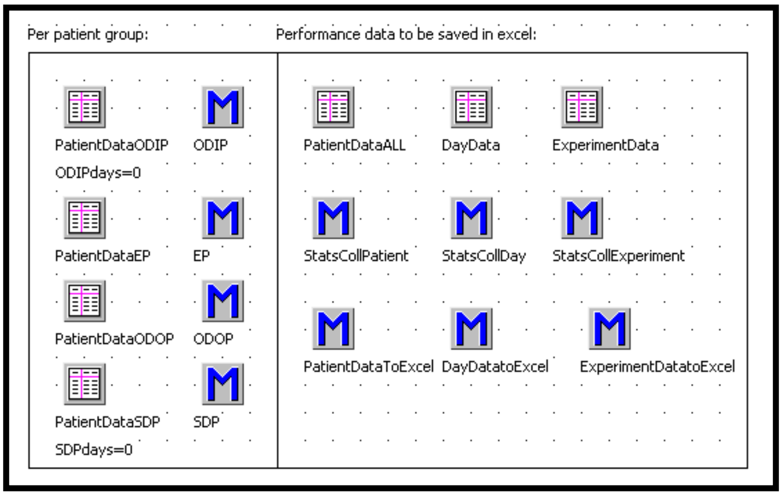


Figure D16 – The frame 'Performance'

d. Simulation settings

The frame *Settings* contains the settings for the simulation: the input for the various scenarios (the scenarios, schedules and work times) and the patient input. Figure D17 visualizes the content of the frame.

The TableFile *Scenarios* contains for each simulation run the scenarios, and the settings for the scenarios: name of the scenario, the schedule that is used, the amount of same day demand and the number of initial patients to start with. Depending on the scenario, at the start of an experiment, *InitSchedule* is set by the method *InitSchedule*. This method copies the content of the TableFile corresponding with the scenario to *InitSchedule*. The same is performed for the work times that correspond with that schedule: the content of the appropriate file is copied to *WorkTimes* by method *SetWorkTimes*.

The initial patient group (a group of patients that is already scheduled and in the system when the experiment starts) is generated by the methods in the section 'Make appointment for initial patient group'.

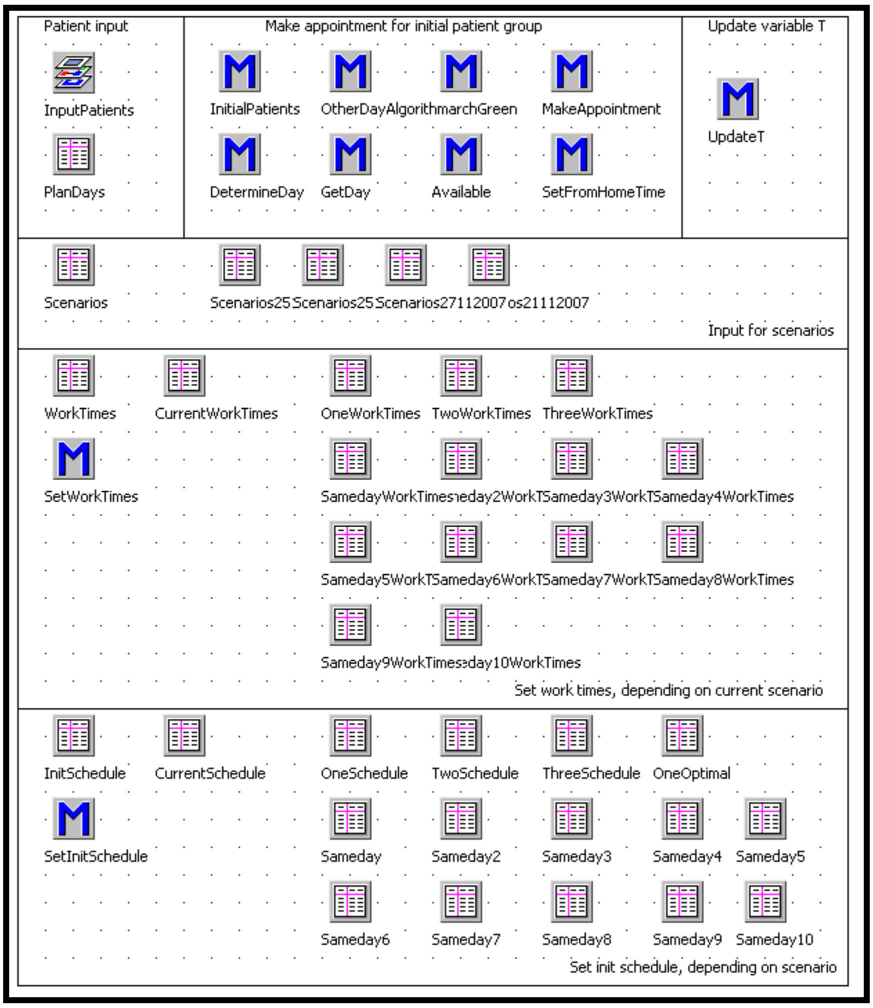


Figure D17 – The frame 'Settings'

Input for the patients is collected in the frame InputPatients (Figure D18). This frame contains a TableFile PatientArrivals with the parameters for the interarrival time of the patients. PatientCharacteristics contains the probabilities for each patient type to occur. Depending on the scenario, the method InitPatientCharacteristics initializes the TableFile PatientCharacteristics. When modeling current same day demand, we use different patient characteristics during the identified same day peak hours. At these hours, the probability for same day and emergency patients is higher compared to the other hours. When all demand is same day demand, the probabilities for other day inpatients and other day outpatients are 0. The TableFile OtherExaminations contains the probabilities for the various combinations of other examinations patients have to undergo next to ultrasound examination.

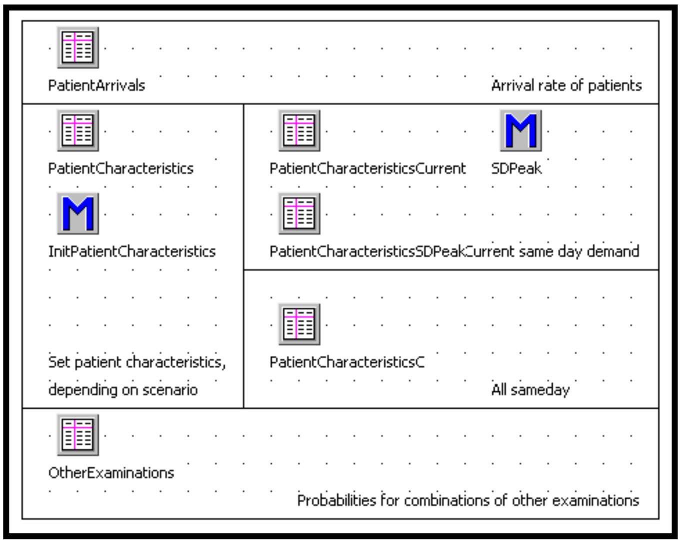


Figure D18 – Frame 'InputPatients'

e. Experimental factors

The section *Experimental factors* on the main frame contains various variables considering the simulation run and the experiment. Figure D19 shows these variables.

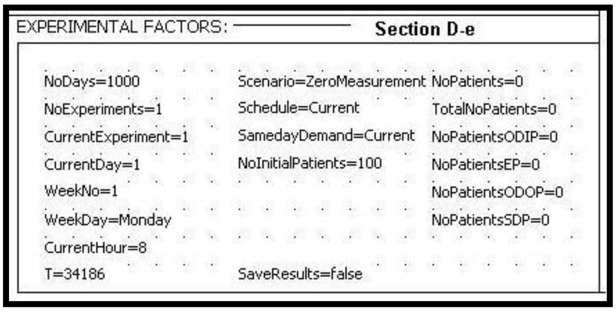


Figure D19 – Experimental factors

The left column contains variables regarding the time, and settings for the simulation. *NoDays* and *NoExperiments* indicate consecutively the run length and the number of experiments to perform in the simulation run. *CurrentExperiment*, *CurrentDay*, *WeekNo*, *WeekDay* and *CurrentHour* inidicate the current time in the current experiment. Variable *T* is updated when necessary, and gives the current time on the day in seconds (e.g. 9 AM = 9*60*60 = 32400).

The second column contains information on the current scenario: the name of the current scenario, the schedule, the amount of same day demand, and the number of initial patients for that scenario.

The third column contains counters for the number of patients. *NoPatients* counts the patients per day, the *TotalNoPatients* counts the patient for each experiment.

Variable SaveResults is true when at the end of each experiment the experiment data should be saved in excel.

f. Event control

The section Event control contains the EventController, various methods to init and reset the system, two generators, and the method EventManager. Figure D20 visualizes the section.

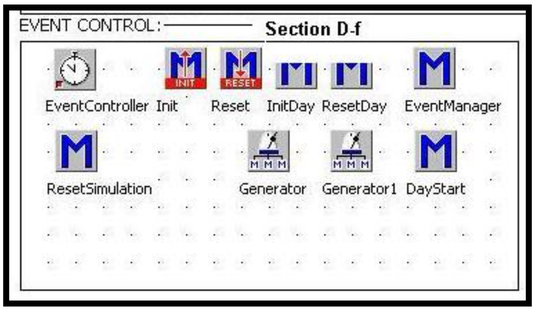


Figure D20 – Event control

The *event controller* is the user interface to start and stop the simulation. The two generators call a method at a predefined time (e.g. the method *FindNextPatient* and *PauseEcho*).

The method *ResetSimulation* should be executed before a simulation run starts. This method regulates if any more experiments should be performed or not. The methods *Init* and *Reset* are the methods that reset the system before each experiment: all counters are reset, the appropriate settings for the scenarios are initialized, and the methods *InitDay* and *ResetDay* are called. These methods regulate that the system is emptied at the end of the day, that relevant statistics are saved, and that all schedules are updated.

The method *EventManager* controls the number of days, and the number of experiments, and updates the variable *CurrentHour*.

Appendix E Calculation of simulation settings

Run length determination

The run length in days needed to construct a 95% confidence interval for the mean of each performance measure is calculated using the iterative method as described by Law & Kelton (Law & Kelton 2000).

We use a relative error γ of 0,10. This results in γ' (estimate of the actual relative error) of 1/(1-0,10) = 0,111.

The length of each run n^* is determined using the formula:

$$n^* = \min\left\{ i \geq n : \frac{1.96\sqrt{S_n^2 / i}}{\bar{X}} \leq \gamma' \right\}$$

Iterative steps performed to determine n^*:

1. Make n_0 replications ($n_0 \geq 2$), set $n=n_0$
2. Compute the mean(n) and delta with parameter t (student distribution):

$$\delta(n,\alpha) = t_{n-1,1-\alpha/2}\sqrt{S_n^2 / n}$$

3. If the statement is true, stop searching. The mean obtained by a run length of n is an accurate point estimate of the real mean. If the statement is not true, increase n and return to step 1.

$$\delta(n,\alpha) / \bar{X}_n \leq \gamma'$$

Table E1 shows the computations performed for 'Waiting time in minutes ODOP'. Iteratively, we found that a run length of 1000 days provides an accurate representation of the real mean.

To check whether the run length calculated on the measure 'Waiting time in minutes ODOP' is also sufficient for each of the other performance measures, we calculate step 2 and 3 for each of the measures. Table E2 shows the calculations. A run length of 1000 seems to be sufficient for all measures.

Conclusion: By using a run length of 1000 days for each experiment, a 95% confidence interval for the mean of each of the performance measures can be constructed.

Run length determination						
WaitingTimeODOP	*delta*	*delta/mean*	*γ '*	*t*	*variance*	*mean*
n=40	227,84152	0,49493	0,11111	2,0226909	507535,82	460,35
n=80	170,961	0,33593	0,11111	1,9904502	590175,9	508,9125
n=120	139,06808	0,27020	0,11111	1,9800999	591918,62	514,68333
n=160	103,02857	0,20489	0,11111	1,9749962	544268,02	502,8375
n=200	113,96797	0,24304	0,11111	1,9719565	534430,11	468,925
n=240	93,902697	0,20861	0,11111	1,9699394	545332,86	450,14167
n=300	87,381425	0,19666	0,11111	1,9679296	591480,43	444,32667
n=400	77,642233	0,16974	0,11111	1,9659272	623908,87	457,4075
n=500	67,674528	0,15475	0,11111	1,9647293	593218,98	437,308
n=600	61,027333	0,14164	0,11111	1,9639322	579358,08	430,85
n=800	56,855008	0,12502	0,11111	1,9629374	671142,18	454,755
n=900	53,432736	0,11677	0,11111	1,9626062	667100,08	457,58667
n=950	51,687188	0,11512	0,11111	1,9624668	658999,02	448,97368
n=980	51,315449	0,11199	0,11111	1,96239	670118,62	458,21429
n=990	50,905573	0,11152	0,11111	1,9623655	666202,19	456,45152
n=1000	50,447604	0,11065	0,11111	1,9623414	660894,22	455,932

Table E1 – Iterative calculations for the run length for performance measure 'Waiting time in minutes Other Day Outpatients'

Other performance measures						
n=1000	*delta*	*delta/mean*	*γ '*	*t*	*variance*	*mean*
WaitingTimeSDP	232,94344	0,06657	0,11111	1,9623414	14091325	3499,2233
AfterClosureTime	94,14293	0,07978	0,11111	1,9623414	2301581,1	1180,058
WorkDuringBreaks	41,468034	0,06392	0,11111	1,9623414	446557,88	648,747
IdleTime	125,10231	0,07199	0,11111	1,9623414	4064260,6	1737,668
Utilization	0,0183621	0,02366	0,11111	1,9623414	0,0875575	0,78

Table E2 – Check if n=1000 is sufficient for the other performance measures

Appendix F Overview of scenarios and results

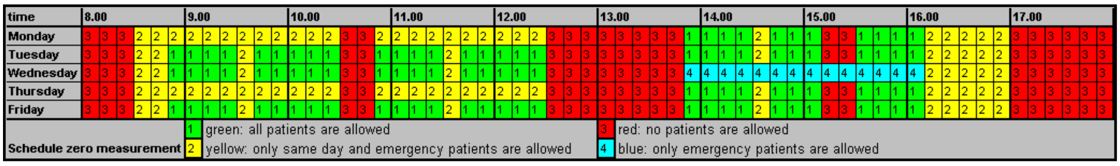


Figure F1 – Schedule used in the zero measurement

a. Anticipate current same day demand

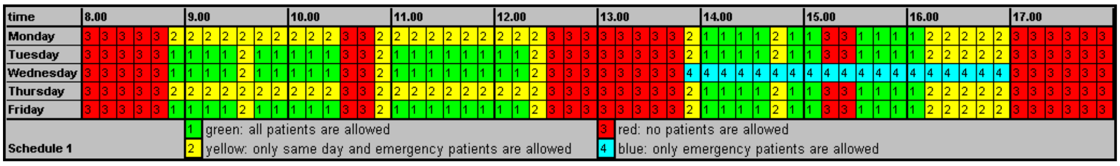


Figure F2 – Schedule 1: reserve planning slots when same day demand is expected

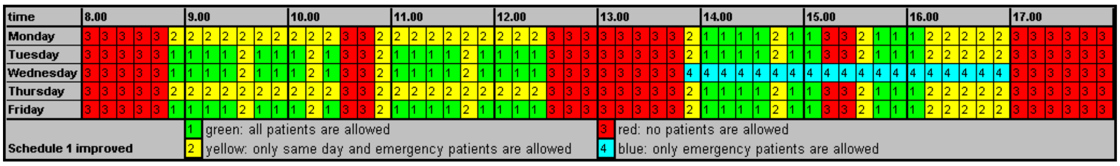


Figure F3 – Schedule 1 improved: the improved variant of Schedule 1

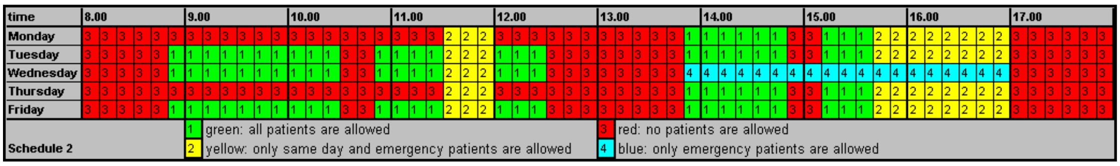


Figure F4 – Schedule 2: reserve two blocks to handle same day demand

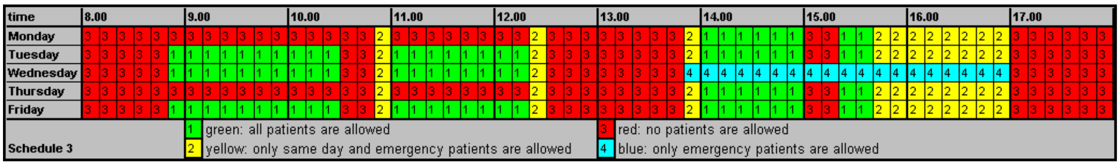


Figure F5 – Schedule 3: minimal amount of same day blocks during day, same day block at the end of the day

Computational results Anticipate same day access								
	Other day patients			Same day patients				
	Ratios		Waiting time	Ratios		Waiting time	Avg overtime	Avg idle time
Scenario	*%ODIP*	*%ODOP*	*ODOP (minutes)*	*%EP*	*%SDP*	*SDP (minutes)*	*per day (minutes)*	*per day (minutes)*
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	22,08	42,10
Schedule 1	2,9%	73,9%	4,33	10,3%	13,0%	58,98	26,88	30,62
Schedule1Improved	2,8%	73,8%	3,00	10,3%	13,0%	50,50	25,25	27,95
Schedule 2	2,8%	73,6%	10,56	10,3%	13,3%	86,43	28,30	28,12
Schedule 3	2,7%	73,6%	9,85	10,5%	13,3%	81,02	27,23	25,63

b. Facilitate open access

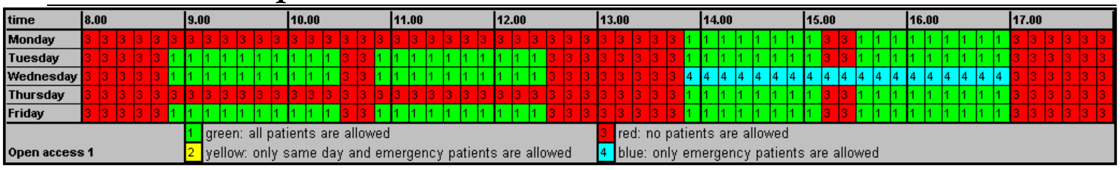


Figure F6 – Open access 1: current demand pattern; Open access 6: balanced demand

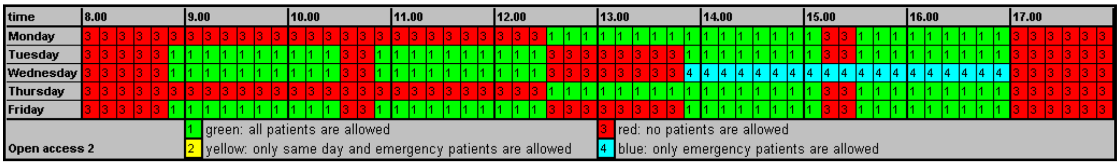


Figure F7 – Open access 2: mammapolis blocked, on mammapoli days flexible lunch break

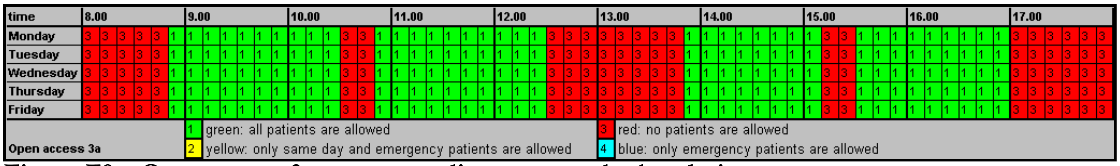


Figure F8 – Open access 3a: mammapolis open, regular break times

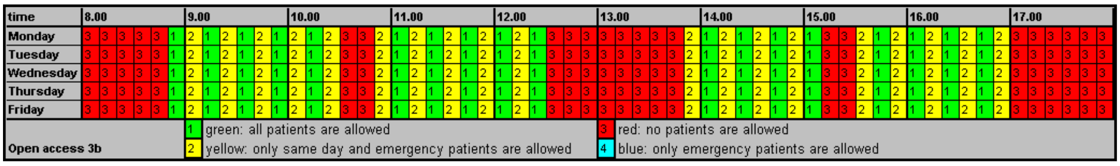


Figure F9 – Open access 3b: spread green slots to avoid 'stacking' of other day patients

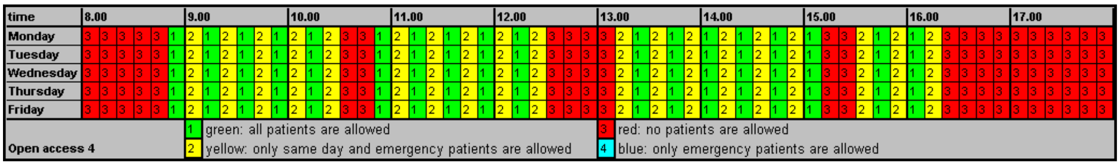


Figure F10 – Open access 4: shorten lunch breaks, close 40 minutes earlier in the afternoon

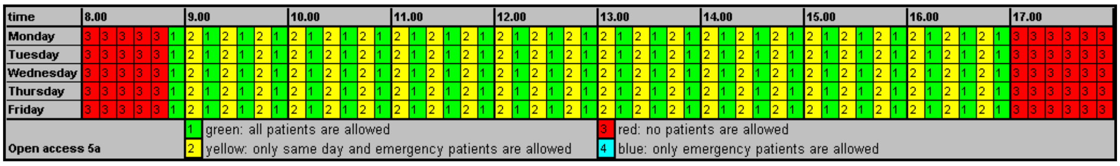


Figure F11 – Open access 5a: mammapolis are open, breaks are flexible

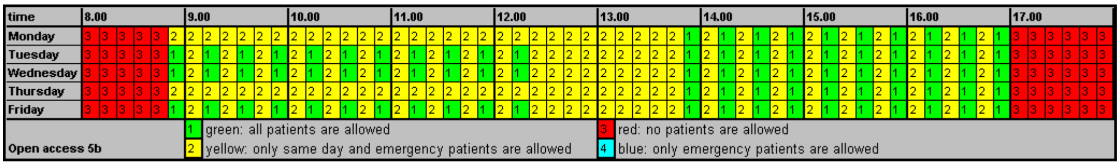


Figure F12 – Open access 5b: relieve the mammapolis and lunch time

Computational results Facilitate open access									
	Other day patients			Same day patients					
	Ratios		Waiting time	Ratios		Waiting time	Avg converted	Avg overtime	Avg idle time
Scenario	*%ODIP*	*%ODOP*	*ODOP (minutes)*	*%EP*	*%SDP*	*SDP (minutes)*	*per day (%)*	*per day (minutes)*	*per day (minutes)*
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Open Access 1	2,7%	28,2%	2,46	9,0%	60,1%	105,62	31,4%	38,97	46,57
Open Access 2	1,8%	20,5%	1,37	10,0%	67,8%	62,12	22,8%	33,68	72,22
Open Access 3a	1,6%	11,8%	0,65	10,2%	76,4%	36,40	12,4%	33,08	143,4
Open Access 3b	1,6%	12,0%	minus 1,65	10,2%	76,3%	35,87	12,5%	32,95	143,1
Open Access 4	2,5%	18,1%	minus 2,80	9,3%	70,2%	23,36	20,7%	7,40	167,6
Open Access 5a	1,1%	7,3%	minus 0,73	10,7%	80,9%	12,12	9,5%	29,22	148,9
Open Access 5b	1,1%	7,4%	minus 3,77	10,7%	80,9%	12,47	9,5%	29,28	148,9
Open access 6	1,2%	12,4%	0,33	10,8%	75,6%	41,58	13,9%	39,30	41,05

Glossary

Patient groups

Outpatient: a patient who visits the hospital, not admitted in the hospital

Inpatient: a patient who is admitted in the hospital

Other day outpatient (ODOP): an outpatient whose appointment is not on the same day as the prescription

Same day patient (SDP): an outpatient examined on the same day as the prescription

Other day inpatient (ODIP): an inpatient whose appointment is not on the same day as the prescription

Emergency patient (EP): an inpatient examined on the same day as the prescription

Mammapoli patient: an outpatient going through a trail of consultations and examinations to diagnose possible breast cancer in one day

Ultrasound examinations

Regular examination: an examination for which one planning slot of 10 minutes is reserved

Longproc examination: an examination for which two or more planning slots of 10 minutes are reserved

Other definitions

Radiology Information System (RIS): information system of the radiology department containing data on patients and patient flow

Same day demand: the request of any type of patient for an examination on the same day as the prescription

Same day access / Open access: the strive to offer all patients an appointment on the same day as the request for examination

Overview of scenarios and results

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Tuesday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3
Wednesday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3
Thursday	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Friday	3	3	3	2	2	1	1	1	1	2	1	1	1	1	1	3	3	1	1	1	1	2	1	1	1	1	1	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule zero measurement
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Schedule used in the zero measurement

a. Anticipate current same day demand

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Thursday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	1	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule 1
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Schedule 1: reserve planning slots when same day demand is expected

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	2	1	1	1	2	1	3	3	2	1	1	1	1	2	1	1	1	1	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	2	1	1	1	2	1	3	3	2	1	1	1	1	2	1	1	1	1	3	3	3
Thursday	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	3	3	3
Friday	3	3	3	3	3	1	1	1	1	2	1	1	1	2	1	3	3	2	1	1	1	1	2	1	1	1	1	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	2	1	1	1	1	2	1	1	3	3	2	1	1	1	2	2	2	2	2	3	3	3	3	3	3

Schedule 1 improved
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Schedule 1 improved: the improved variant of Schedule 1

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	1	1	1	1	2	2	2	1	1	1	3	3	3

time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	3	3	1	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3

Schedule 2
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

Schedule 2: reserve two blocks to handle same day demand

time	8.00						9.00						10.00						11.00						12.00					
Monday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3
Tuesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Wednesday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3
Thursday	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3
Friday	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	3	3	2	1	1	1	1	1	1	1	1	2	3	3	3

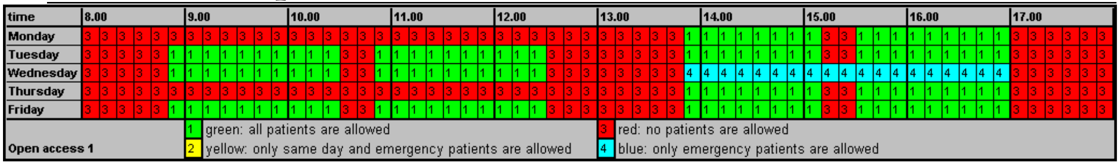
time	13.00						14.00						15.00						16.00						17.00					
Monday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Tuesday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Wednesday	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
Thursday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3
Friday	3	3	3	3	3	2	1	1	1	1	1	1	3	3	1	1	2	2	2	2	2	2	2	2	3	3	3	3	3	3

Schedule 3
1 green: all patients are allowed
2 yellow: only same day and emergency patients are allowed
3 red: no patients are allowed
4 blue: only emergency patients are allowed

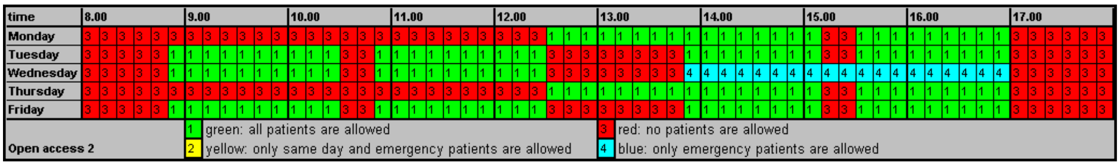
Schedule 3: minimal amount of same day blocks during day, same day block at the end of the day

Computational results Anticipate same day access								
	Other day patients			Same day patients				
	Ratios		Waiting time	Ratios		Waiting time	Avg overtime	Avg idle time
Scenario	*%ODIP*	*%ODOP*	*ODOP (minutes)*	*%EP*	*%SDP*	*SDP (minutes)*	*per day (minutes)*	*per day (minutes)*
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	22,08	42,10
Schedule 1	2,9%	73,9%	4,33	10,3%	13,0%	58,98	26,88	30,62
Schedule1Improved	2,8%	73,8%	3,00	10,3%	13,0%	50,50	25,25	27,95
Schedule 2	2,8%	73,6%	10,56	10,3%	13,3%	86,43	28,30	28,12
Schedule 3	2,7%	73,6%	9,85	10,5%	13,3%	81,02	27,23	25,63

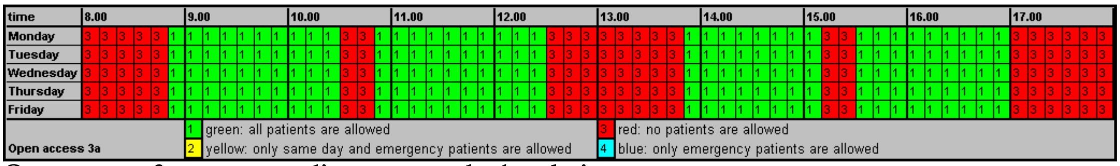
b. Facilitate open access



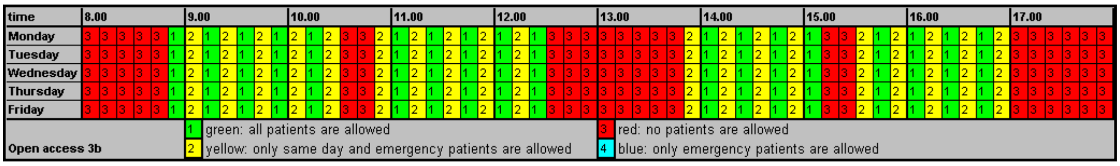
Open access 1: current demand pattern; Open access 6: balanced demand



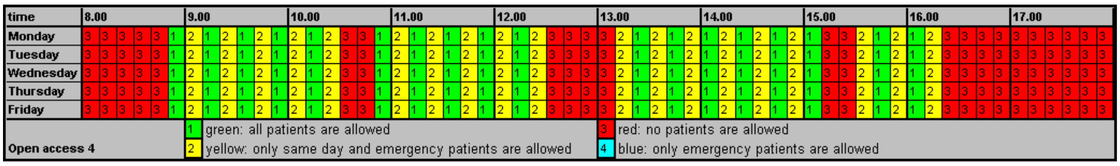
Open access 2: mammapolis blocked, on mammapoli days flexible lunch break



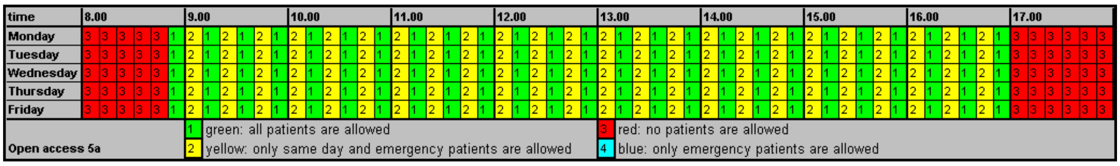
Open access 3a: mammapolis open, regular break times



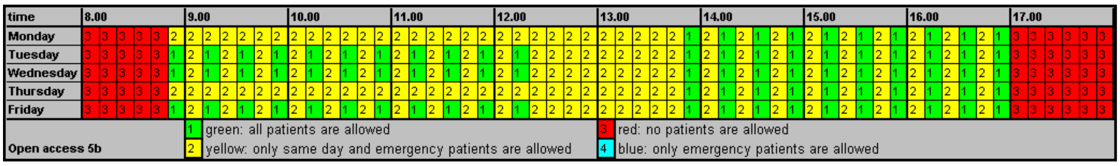
Open access 3b: spread green slots to avoid 'stacking' of other day patients



Open access 4: shorten lunch breaks, close 40 minutes earlier in the afternoon



Open access 5a: mammapolis are open, breaks are flexible



Open access 5b: relieve the mammapolis and lunch time

Computational results Facilitate open access									
	Other day patients			Same day patients					
	Ratios		Waiting time	Ratios		Waiting time	Avg converted	Avg overtime	Avg idle time
Scenario	*%ODIP*	*%ODOP*	*ODOP (minutes)*	*%EP*	*%SDP*	*SDP (minutes)*	*per day (%)*	*per day (minutes)*	*per day (minutes)*
Zero Measurement	3,6%	69,6%	7,56	9,5%	17,3%	64,73	-	22,08	42,10
Open Access 1	2,7%	28,2%	2,46	9,0%	60,1%	105,62	31,4%	38,97	46,57
Open Access 2	1,8%	20,5%	1,37	10,0%	67,8%	62,12	22,8%	33,68	72,22
Open Access 3a	1,6%	11,8%	0,65	10,2%	76,4%	36,40	12,4%	33,08	143,4
Open Access 3b	1,6%	12,0%	minus 1,65	10,2%	76,3%	35,87	12,5%	32,95	143,1
Open Access 4	2,5%	18,1%	minus 2,80	9,3%	70,2%	23,36	20,7%	7,40	167,6
Open Access 5a	1,1%	7,3%	minus 0,73	10,7%	80,9%	12,12	9,5%	29,22	148,9
Open Access 5b	1,1%	7,4%	minus 3,77	10,7%	80,9%	12,47	9,5%	29,28	148,9
Open access 6	1,2%	12,4%	0,33	10,8%	75,6%	41,58	13,9%	39,30	41,05