REDUCING THROUGHPUT TIME OF THE RADIODIAGNOSTIC TRACK

Master thesis

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Management Summary

In many hospitals, the diagnosis of breast cancer is organised in a 'one stop clinic': within one day, women are diagnosed for their treatment. However, what about the other patients, can we speed up the diagnosis of other types of cancer as well? This study aims to reduce the throughput time of the diagnostic track for all patients in the radiology department of the specialised cancer hospital, Antoni van Leeuwenhoek Hospital, using quantitative Operations Management techniques.

This goal of this study is to *decrease the throughput time of the diagnostic track (the outpatient visit with the radiology request(s), the radiology examination(s) and the outpatient visit to discuss the results) for all patients and translate these throughput times into service levels*. First, we determine the current performance of the diagnostic track for CT requests. Second, we determine the factors which have to be changed in order to improve the throughput time. Based on these factors we define different approaches, which improve the service levels for the throughput time of the diagnostic track. Third, we build a simulation model to evaluate the effect of these approaches on the organisational performance. We discuss the results of the model and recommend one of the approaches as basis for the implementation. Fourth, we base the implementation steps needed to improve the quality of service on both outcomes of the model and the results from a pilot on same day access on the ultrasound modality.

The current average throughput time of the diagnostic track for urgent requests is 6,96 working days and for short term (non-urgent) requests 16,90 working days. The throughput time of the diagnostic track is influenced by three factors: access time for the CT scanner, throughput time of the radiologist's report and access time for the second outpatient consult. The most important factor influencing the throughput time of the diagnostic track for urgent requests is the access time for the second outpatient consult (70,40% of the throughput time). For short term requests this factor is the access time of the CT scanner (72,66% of the throughput time).

To improve service levels we define four different approaches: (1) current situation, (2) throughput time for urgent requests a maximum of one week and short term requests a

maximum of two weeks, (3) throughput time for urgent and short term request a maximum of one week, (4) access time for all requests is maximum one day.

Computational results from the simulation model show that Approach 1 is not improving the service level for patients and Approach 4 does not increase the efficiency of the organisation. Both Approach 2 and 3 improve the service level for patients as well as the efficiency of the organisation in comparison with the current situation.

To recommend one of the two approaches, we have to balance the improvements in service levels with improvements in organisational performance (idle time and overtime). The improvement in service level in Approach 3 compared to Approach 2 is large (throughput time from two weeks to one week for short term requests) as the improvement in organisational performance in Approach 2 compared to Approach 3 is small (improvement of several minutes in averages and variation).

It is possible to further increase the performance of Approach 3 by lowering the throughput time of the radiologist's report from a maximum of two working days to a maximum of one working day (Approach 3B). As the increase in performance is not radical (improvement of several minutes in variation), implementation of this reduction in throughput time is only justified if it does not lead to a significance increase in the workload of radiologists.

We recommend implementing Approach 3B, which potentially reduces the throughput time of the diagnostic track (scan and report) for urgent and short term requests to a maximum of one week. This enables the following example: a physician requests a CT scan for a patient on Monday morning. During the week that follows, the patient is examined by the radiology department and the CT scan is reported by a radiologist. The physician is able to discuss the results of the examination during the same consultation hours (Monday morning) a week after the request.

To be able to implement this service level we have to decrease the current fluctuation in available CT capacity, due to maintenance and work meetings. We also have to implement a control mechanism to ensure that service levels are delivered, for example, checking at the end of every day if there are no radiologist's reports over due. We propose to draw up a service level agreement between the radiology department and outpatient department including the number of requests per month for which the service levels can be guaranteed. If we ensured availability of capacity and implemented the control mechanism of the process we can implement the new CT schedule.

After implementation of the service levels, we can change the planning process of the diagnostic track based on these levels. In the current situation, after the end of the consult with the physician at the outpatient department a patient first has to walk to the radiology desk to make a radiology appointment and then walk back to the outpatient department to schedule the second outpatient consult. In the new situation, the scan and report are always performed within five working days. Therefore, the outpatient desk is able to schedule the second outpatient consult before the scheduling of the radiology examination, reducing one step for the patient.

Parallel to the analysis and improvement of the diagnostic track we have successfully piloted the offering of same day access slots for the Ultrasound modality as recommended by Gilles (2007). The pilot offered 5 same day access slots for non-urgent request on Tuesdays during two months. The pilot was received with enthusiasm by both patients as well as a large part of the radiology department. The average utilisation of the five slots was 82,50% (expected: 83,53%) and the average waiting time for patients was 1:49 hour. The average throughput time of the diagnostic track was reduced from 11,91 working days to 4,61 working days. We recommend rolling out same day access (25 slots per week) to all weekdays in the Ultrasound schedule.

We conclude that we can substantially reduce the throughput time of the diagnostic track from an average of more than 3 weeks to a maximum of one week. We are able to achieve this reduction by changing division and dedication of CT capacity over the patient groups, improving maintenance management and defining service levels for maximum throughput times for the examination and the radiologist's report. These findings and conclusions can also be applied to other modalities. We recommend setting service levels for the throughput time of diagnostic tracks (examination and report) for all patient groups and modalities within the radiology department.

Next to the improvement of throughput times, we recommend focusing on another quality of service improvement: reducing the number of visits to the hospital. We have to group outpatient and radiology appointments on the same day. Same day access is one of the solutions to gain a reduction in visits, but further research to other possibilities and their implications is needed. Future work on this subject requires collaboration between outpatient and radiology department.

Management Samenvatting

In veel ziekenhuizen is de diagnose van borstkanker georganiseerd in een 'mammapoli': binnen een dag worden vrouwen gediagnosticeerd voor hun behandeling. Hoe zit het echter met de andere patiënten, kunnen we de diagnose voor andere typen van kanker ook versnellen? Dit onderzoek heeft als doel om de doorlooptijd van het diagnostisch traject te verkorten voor alle patiënten van de radiologie afdeling van het in kanker gespecialiseerde Antoni van Leeuwenhoek ziekenhuis. Dit proberen we te realiseren met behulp van kwantitatieve analyse methodes uit de Operations Management.

Het doel van ons onderzoek is om *de doorlooptijd van het diagnostisch traject (de poliklinische afspraak met de radiologieaanvraag, de radiologieonderzoek(en) en de poliklinische afspraak met de bespreking van de uitslag) voor alle patiënten te verkorten en deze vertalen in 'service levels'*. Eerst bepalen we de huidige prestatie van het diagnostische traject voor CT aanvragen. Vervolgens bepalen we de factoren die verandert kunnen worden om de doorlooptijd te verbeteren. Op basis van deze factoren definiëren we vier *approaches*, die elk staan voor een bepaald *service level* (maximale doorlooptijd van het traject) voor de verschillende patiëntgroepen. We evalueren het effect van deze *approaches* op de prestatie van de organisatie door middel van een simulatie model. Op basis van de uitkomsten van dit model adviseren we een van de *approaches*. Als laatste beschrijven we de implementatie stappen die nodig zijn om de *service levels* in te voeren.

De gemiddelde doorlooptijd van het diagnostisch traject voor urgente aanvragen is 6,96 werkdagen en voor korte termijn (niet-urgente) aanvragen is 16,90 werkdagen. De doorlooptijd wordt beïnvloed door drie factoren: de toegangstijd van de CT scanner, de doorlooptijd van het verslag van de radioloog en de toegangstijd van de tweede poliklinische aanvraag. Voor urgente aanvragen is de belangrijkste factor de toegangstijd van de tweede poliklinische aanvraag (70,40% van de doorlooptijd). Voor korte termijn aanvragen is dit de toegangstijd van de CT scanner (72,66% van de toegangstijd).

Om de *service levels* te verbeteren definiëren vier verschillende *approaches*: (1) de huidige situatie, (2) de maximale doorlooptijd voor urgente aanvragen is één week, voor korte termijn aanvragen twee weken, (3) de maximale doorlooptijd voor urgente en korte termijn aanvragen is één week, (4) de toegangstijd voor alle aanvragen is maximaal één dag.

De resultaten van het simulatiemodel laten zien dat Approach 1 de service naar de patiënt niet verbeterd en dat Approach 4 een verslechtering voor de prestatie van de organisatie betekent. Approach 2 and 3 verbeteren beide de service naar de patiënt als wel de efficiëntie van de organisatie in vergelijking met de huidige situatie.

Om een van de twee *approaches* aan te bevelen, moeten we de verbetering in service niveau naar de patiënt afzetten tegen de verbetering in prestatie van de organisatie ('idle time' en 'overtime'). De verbetering in service niveau van Approach 3 in vergelijking met Approach 2 is groot (doorlooptijd daalt van twee weken naar één week), terwijl de afname in prestatie relatief klein is (een stijging van een aantal minuten in gemiddelde en standaard deviatie van 'idle time' en 'overtime').

Om de prestatie van Approach 3 te verbeteren is het mogelijk om de doorlooptijd van het verslag van de radioloog te verkorten van maximaal twee naar maximaal één werkdag (Approach 3B). Deze verandering is echter alleen gerechtvaardigd als dit niet een extra belasting voor de radiologen betekent, aangezien de winst in prestatie gering is (enkele minuten in standaard deviatie van 'idle time' en 'overtime').

Onze eerste aanbeveling is om Approach 3B te implementeren, welke een mogelijk biedt om de doorlooptijd van het diagnostisch traject (CT scan en verslag) voor urgente en korte termijn aanvragen te verlagen tot maximaal één week. Hierdoor wordt het volgende voorbeeld mogelijk: een arts vraagt op maandagochtend een CT scan aan voor een patiënt. Gedurende de week die volgt wordt er een CT scan van de patiënt gemaakt en wordt deze scan verslagen door de radioloog. Vervolgens kan de arts een week later tijdens hetzelfde spreekuur (op maandagochtend) de uitslag van de CT scan met de patiënt bespreken.

Om dit serviceniveau in te kunnen voeren moeten we de fluctuatie in beschikbare capaciteit verlagen. Deze fluctuatie wordt veroorzaakt door o.a. onderhoud en werkoverleg. Ons voorstel is om een 'service level agreement' op te stellen om afspraken tussen de radiologieafdeling en de polikliniek vast te leggen over de *service levels* van de radiologie afdelingen en het maximaal aantal aanvragen per maand en jaar waarvoor deze *service levels* gegarandeerd kunnen worden. Zodra we deze afspraken hebben gemaakt en deze *service levels* kunnen aanbieden, voeren we het nieuwe CT schema in.

Nadat het nieuwe CT schema is ingevoerd kunnen we de planningsproces van het diagnostisch traject aanpakken. Op dit moment moet een patiënt na afloop van zijn bezoek aan de arts op de polikliniek eerst naar de radiologie balie lopen om een afspraak te maken voor een CT scan. Vervolgens moet deze patiënt weer terug naar de polikliniek balie lopen om de afspraak met de arts te maken om de uitslag te bespreken. In de nieuwe situatie kan de assistente in de polikliniek direct een afspraak met de arts maken, aangezien de scan en het verslag binnen vijf werkdagen beschikbaar zijn.

Tegelijkertijd met de analyse en verbetering van de doorlooptijd van het diagnostisch traject hebben we een succesvolle pilot uitgevoerd bij de echografie. Tijdens de pilot (juni en juli 2008) boden we vijf 'same day access' plekken aan op elke dinsdag voor niet-urgente echo aanvragen. Zowel patiënten als een groot deel van de radiologieafdeling waren enthousiast over de pilot. Gemiddeld werd 82,50% van de plekken opgevuld en was de gemiddelde wachttijd van de patiënt 1 uur en 49 minuten. De gemiddelde doorlooptijd van het diagnostisch traject was verkort van 11,91 werkdagen naar 4,61 werkdagen. Op basis van deze resultaten bevelen we aan om 'same day access' uit te rollen naar alle weekdagen (totaal 25 'same day access' plekken).

We concluderen dat het mogelijk is om de doorlooptijd van het diagnostisch traject te verkorten van een gemiddelde van meer dan 3 weken naar een maximum van 1 week. Het is mogelijk om dit te bereiken door de verdeling en toekenning van CT capaciteit over de patiëntgroepen aan te passen, het compenseren van 'verloren capaciteit' door o.a. onderhoud en het vastleggen van een maximale doorlooptijd van het diagnostisch traject in *service levels*. Deze bevindingen en conclusies kunnen ook op de doorlooptijden van andere modaliteiten worden toegepast. Ons voorstel is om voor alle modaliteiten en bijbehorende patiëntgroepen *service levels* te bepalen en vast te leggen.

Naast de verbetering in doorlooptijden kan de service naar de patiënt verder worden verbeterd door het aantal bezoeken aan het ziekenhuis te verlagen. Hiervoor moeten we poliklinische en radiologie afspraken op één dag combineren. Same day access is een van de mogelijkheden om dit te bereiken. Er is echter verder onderzoek nodig naar de andere mogelijkheden, vooral naar de implicaties voor de verschillende afdelingen. Bij dit onderzoek is een goede samenwerking tussen de radiologie afdeling en de polikliniek een vereiste.

Preface

I am proud to present my master thesis, completing my Master Industrial Engineering and Management at the University of Twente. I started my graduation project in February, in the Antoni van Leeuwenhoek Hospital. During this project there a lot of people who supported and assisted me inside and outside of the hospital to accomplish my personal goal: graduating by improving the quality of service and efficiency of the hospital.

At the start of my graduation project, Wineke van Lent assisted me with the formulation of my research goals. I thank Wineke for keeping me focused on these goals during the rest of the project. I thank Wim van Harten for the detailed questions and the constructive feedback during our frequent meetings. Especially the questions about how I would change the organisation triggered me to propose radical instead of incremental changes. Erwin Hans on his turn also triggered me to think 'out of the box' and proposed various valuable changes to the structure and writing style of my thesis. Most of all, he was able to increase my enthusiasm for my research every time I met him during the project. Thanks for the inspiration, Erwin!

Within the hospital there are several people I thank: Saar Muller for her analytical questions and feedback on my model and data analysis; Jelle Teertstra and Theo van Ooij for their feedback and support for the changes to increase the patient-centeredness of the organisation. I thank the ultrasound assistants, people from the radiology desk and especially Petra Haagsma for their assistance during the same day access pilot. Further, I thank Jorrita, Marianne, Julia, Arjan, Toni, Saskia and my lunch partners Relinde, Rozan, Wineke, Eva, Peter and Desiree.

I thank my parents and sister for their continuous support and interest in me during my study. Finally, I thank Vincent and my roommates, Maarten and Maarten, for keeping me smile during the writing of this thesis. Thanks guys!

Joost Deetman
Amsterdam, October 2008

Contents

1 Introduction

In many hospitals, the diagnosis of breast cancer is organised in a 'one stop clinic': within one day, women are diagnosed for their treatment. However, what about the other patients, can we speed up the diagnosis of other types of cancer as well? This study aims to reduce the throughput time of the diagnostic track for all patients in the specialised cancer hospital, Antoni van Leeuwenhoek Hospital, using quantitative Operations Management techniques.

The Netherlands Cancer Institute – Antoni van Leeuwenhoek Hospital (NKI-AVL) located in the west of Amsterdam has 180 beds (including 30 day treatment beds) and 26.397 new patient visits in 2007. The NKI-AvL is a combined hospital and research institute and treats all types of cancer. The case mix of patients, only cancer patients, is focused in comparison with other hospitals in The Netherlands. It is the only categorical cancer treatment centre in the Netherlands as other specialised cancer clinics are part of a hospital or care group. Another difference with other hospitals is the absence of an emergency department, this leads to a relatively small number of emergency admissions and treatments.

1.1 Problem description

As part of their mission NKI-AvL improves the quality of care together with the quality of service to their patients. One of the important aspects of the quality of service is waiting time. Waiting times (including access times) for patients should be as low as possible.

In previous work, Den Braber (2007) and Gilles (2007) present results of a simulation study of the ultrasound modality within the radiology department comparing different scenarios facilitating same day access. Their results suggest that providing open access on the ultrasound modality will reduce waiting time for patients and provide most of the examinations on the same day as the outpatient appointment. However this same day access strategy (instead of making appointments), will lead to idle time for radiologists. This is caused by the variance in demand of examinations, requested by physicians in the outpatient department (in the literature also known as *consultations department*).

Gilles (2007) recommends balancing the demand of radiology examinations with the available capacity on the radiology modalities, to improve same day access. To be able to balance demand and capacity we need to analyse the patient flow between the outpatient and radiology department. This analysis is the basis for our research. Since the outpatient and radiology department are part of the same hospital we can gather information about the patient flow between the two departments.

Figure 1 shows the diagnostic track from the perspective of the patient as well as the hospital. The diagnostic track involves two departments: the outpatient department (also described as consultation department) and the radiology department. These departments are controlled individually, without any formal management interaction. Part of the diagnostic track is considered and controlled as an integrated process: diagnostic speed trails for head/neck, gynaecology and breast cancer patients. However, for the remaining patients, the steps in the diagnostic track are controlled individually and not as an integrated process. In addition, the hospital can not easily measure the throughput time of the diagnostic track, because information has to be derived from two different information systems.

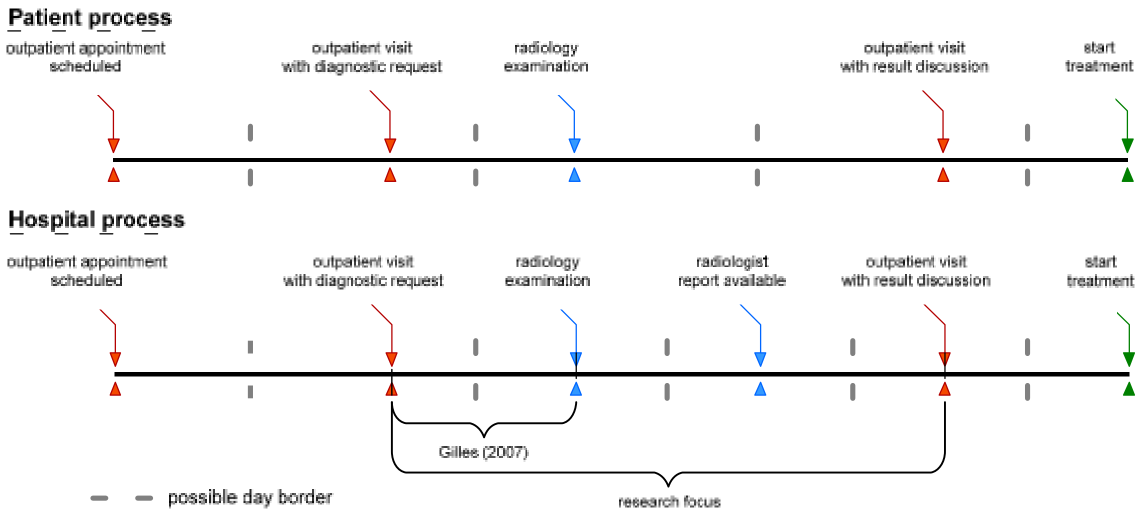

Figure 1. Pathway diagnostic track

Previous work within this hospital has focused on optimising parts of the diagnostic track. The study and recommendations of Gilles (2007) focus on the offering of ultrasound examinations on the same day as the outpatient appointment. Figure 1 shows these steps as the start of the diagnostic process. There are two additional steps in the hospital process of the diagnostic track: the throughput time of the radiologist's report and the outpatient consult with the result discussion.

Although the diagnostic track is not controlled as an integrated process, the throughput time of short term appointments is perceived as being too long by different stakeholders (outpatient and radiology department) and insight into the total diagnostic process is needed.

The central problem statement is:

> *The throughput time of the diagnostic track is perceived as being too long and there is no insight into the patient flows between the outpatient and radiology department.*

The problem described above lead to the central research question of this thesis:

> *How can we improve the throughput time of the diagnostic track (the outpatient visit with the radiology request(s), the radiology examination(s) and the outpatient visit to discuss the results) by aligning capacities and improving the planning method of the outpatient and radiology department?*

1.2 Research scope

To define the scope of our research we will use the framework for hospital planning and control (Figure 2) proposed by Van Houdenhoven et al. (2007). We will focus our study on the managerial area 'resource capacity planning'. The medical, material and financial planning of the diagnostic track influence the diagnostic track, but they are not part of our focus. We use the characteristics of these areas as input for our analysis.

Figure 2 shows the areas covered in this thesis in orange. As we consider case mix, number of radiology devices (e.g. CT and Ultrasound) and number of radiologists as fixed, we do not cover the strategic resource capacity planning. We study allocation of resource (CT, Ultrasound, radiologists) time over patient groups (tactical planning). After determining the capacity per patient group, we study how we can schedule requests in this capacity (operational offline scheduling). We will also discuss implementation issues and exception handling (operational online scheduling).

	Medical planning	**Resource capacity planning**	**Material coordination**	**Financial planning**
Strategic	Research and treatment methods	Case mix planning, layout planning, capacity dimensioning	Supply chain and warehouse design	Agreements with insurance companies, investment plans
Tactical	Definition of medical protocols	Allocation of time and resources to specialities, rostering	Supplier selection, tendering	Determining and allocating budgets, annual plans
Operational Offline	Diagnosis and planning of an individual treatment	Patient scheduling, workforce planning	Purchasing, determining order sizes	RNG billing
Operational online	Diagnosing emergencies and complications	Monitoring, emergency coordination	Rush ordering	Billing complications

Managerial areas

Hierarchical decomposition

Figure 2. Framework for hospital planning and control (van Houdenhoven et al., 2007)

As basis for our analysis we select a radiology modality based on the following criteria: a large number of requests for a large data set and an access time larger than one week indicating a possible capacity problem. We choose the CT scanner as basis for our analysis of the diagnostic track; it has a large number of requests and an access time of more than two weeks. The MRI and Mammography have a lower number of requests than the CT scanner; the Bucky (X-ray) already has open access and does not show a capacity problem.

Requests for the CT scanner can be categorised in three groups: (1) inpatient requests, (2) outpatient requests for speed trails (head/neck, breast cancer, gynaecology) and (3) other outpatient requests (research group: 'CT-general'). In our analysis of the diagnostic track we include patients from the last group. The diagnostic track is based on outpatient requests and not on requests from the clinical wards (the first group). The second group of the patients is already part of an integrated diagnostic track with a fixed access and throughput time and therefore left out.

The diagnostic track can be used for different types of diagnostics: diagnosis of cancer, calculation of the effect of the treatment (during treatment) and follow up checks. The pathway of the diagnostic track as described in the problem statement consists of three steps: (1) physician consult on the outpatient department or by phone, (2) radiology examination(s) and (3) another physician consult on the outpatient department or by phone.

The outpatient visits described above can be different types of appointments: follow-up consults (VE) and new patient consults. New patient consults consist of three different types of patients: new patient (NP), new specialty for a known patient (NS), second opinion patient (SO).

The problem of long throughput times is experienced in the short term appointments and not in the diagnostic tracks planned in advance (for quarterly and yearly follow-up patients). To study this group of requests we include the diagnostic tracks performed within 1 month. To create a consistent data set, we choose the access time for the radiology examination as limiting factor: a maximum of 20 working days.

Outpatient diagnostic tracks do not account for all requests for the CT scanner. There are several other patient groups demanding capacity of the CT scanner: inpatient requests, pre-surgery diagnosis and treatment related requests. These requests are not included in our analysis of the diagnostic track, but do influence the use and availability of CT capacity. Therefore, we analyse the performance of the CT scanner for all requests.

1.3 Research objective and questions

By answering the research questions below we are able to give alternative solutions to reach the objective of our research:

> *Decrease the throughput time of the diagnostic track for all patients and translate these throughput times into service levels.*

What is the process description of the diagnostic track, its control and its current performance?

Chapter 2 starts with a description of the process of the diagnostic track (2.1). Next, we describe the planning & control of the process, separated in two departments (2.2). We base the process descriptions on interviews and observations of the process. We define performance measurements (2.3), which we use to analyse and describe the current performance of the diagnostic track (2.4).

What are the factors that influence the throughput time of the diagnostic track?

Based on the findings in Paragraph 2.4 we will further analyse the radiology processes involved in the diagnostic track: access time of the CT scanner (2.5) and throughput time of the radiologist's report (2.6). We summarise the most important factors for each of the patient groups in Paragraph 2.7 and describe their characteristics.

What are suitable approaches to improve the throughput time?

Chapter 3 describes the possibilities to improve the different factors distinguished in Paragraph 2.7. These approaches have different effects on the organisation and the service level for the patient (length of the diagnostic track). To measure these effects we define the formal problem (3.2), choose a modelling technique (3.3), determine the settings and input for the model (3.4) and build the model (3.5).

What are the computational effects for the different approaches?

Chapter 4 presents the optimal configuration of the capacity for each approach (4.1). Based on the optimal configuration, we present the performance of the approaches (4.2). The results are discussed from both an organisation and a patient perspective and one of the approaches is recommended. We validate the input (data set) and the output (organisational performance) of the model (4.3). Finally, we describe the possibilities to further improve the quality of service, by reducing the number of visits to the hospital (4.4).

What are the required steps to implement the suggested approach?

Chapter 6 describes the steps (changes) needed to implement the recommended approach. To accomplish the research objective set above we have to alter several organisational processes. This chapter also discusses how we can monitor and control these changes in the organisation.

Parallel to the analysis of the diagnostic track, we will design and implement interventions to improve same day access for the Ultrasound modality based on Gilles (2007). Same day access shortens the access time for the Ultrasound modality and has influence on the throughput time of the diagnostic track. Results of the interventions will be used in combination with the analysis of the CT scanner. Chapter 5 describes these analysis, intervention, results and discussion for the ultrasound modality.

2 Process analysis

Based on the diagnostic track around outpatient CT requests, this chapter gives a process description (2.1), the control of the process (2.2), the performance measurements (2.3) and the current performance of the diagnostic track (2.4). After the analysis of the diagnostic track, we will analyse the individual steps within the track: the access time of the CT scanner (2.5) and the throughput time of the radiologist's report (2.6).

2.1 Process description

The diagnostic track starts with a visit to a physician in the outpatient department, who requests one or more radiology examinations on a paper request form. After the appointment, the patient transfers to the radiology desk with the request form, to arrange one or more appointments at the radiology department. The patient then walks back to the desk of the outpatient department, to arrange the follow-up appointment (in person or by phone) with the physician. Appendix B shows the planning process of the radiology examination and the second outpatient consult.

The next step in the diagnostic track is the CT scan or ultrasound examination. For some of the CT examinations (e.g. CT abdomen), the patient prepares the examination by drinking contrast fluid on the day before. The CT scan takes 10 (72,00% of the appointments) or 20 (27,63% of the appointments) minutes to perform, which includes preparation of the patient. The CT scanner is operated by radiology technicians, radiologists assist in rare or difficult situations (e.g. punctures).

After the examination, the radiologist reports his findings by dictating a letter to the physician. The reporting takes place in a different room than the examinations and is usually performed at a later time or day. The radiologist can dictate and authorise the letter simultaneous by using speech recognition (on-line reporting) or dictate first and authorise the letter typed out by the typist later (off-line reporting). The report is essential for the physician to be able to discuss the results of the examination with the patient.

The last step in the track consists of the consult with the physician to discuss the results of the examination, by visiting the outpatient department or receiving a phone call from the physician on an arranged time and date. The discussion of the results is the end of the diagnostic track. The pathway (e.g. treatment, discharge) after this step is not part of our research.

Currently, the four steps described above do not take place on the same day. For most patients there is more than one working day between every step. These waiting times lead to a long throughput time but also to a high number of visits to the hospital.

2.2 Planning & control

The planning and control of the diagnostic track is spread over two departments. The radiology department controls the process and planning of the radiology examination (2.2.1). The outpatient department controls the process and planning of the second outpatient consult (2.2.2)

2.2.1 Radiology department

The radiology department has two CT scanners in use: CT04 and PTCT06. The CT04 is completely in use by their department, the other (PET)CT scanner – PTCT06 – can be used one day per week (Monday). The nuclear medicine department uses the scanner for the remaining week. On Monday the radiology department uses the CT04 for special interventions (Radiofrequency ablation – RFA). During that day, they perform the general CT requests on the PTCT06.

Figure 3 shows the current opening hours and locations of the CT scanner for general CT requests. The regularly available slots are green. Yellow slots are used for urgent requests (within 1 week) if there is no suitable green slot available. These urgent requests have to be authorised by the head of the radiology desk or one of the CT scanner assistants. In a regular week, 199 green slots of 10 minutes are available (Figure 3). The radiology department reserves part of these green slots for special diagnosis (e.g. speed tracks).

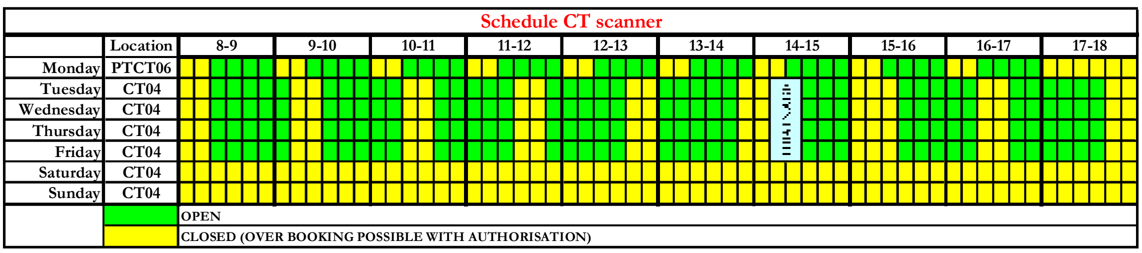

Figure 3. Current schedule of the CT scanner

2.2.2 Outpatient department

For short term appointments, one of the assistants of the outpatient department plans the second outpatient consult after the radiology examination is planned. For long term appointments, the procedure is the other way around; the outpatient consult is planned before the planning of the radiology examination.

In the ideal situation, the patient sees the physician five working days (current working standard for the throughput time of the radiologist's report) after the radiology examination. A lot of physician agendas are already fully booked months before. To overcome this problem, the assistant makes an overbooking in the physician's schedule. This is a manual task which requires some extra time and work with the current appointment planning software (CS-Agenda). In comparison long term appointments can be booked nearly automatically, because of enough empty slots in the agendas. Therefore long term appointments are easier to plan and less time consuming for assistants than short term appointments.

Most physicians have at least once per week consultation hours for a specific patient group. Patients discuss the result of their CT scan with the same physician who requested the scan, except for the head-neck specialty and pre-surgery patients. Next to the general consultation hours, physicians have the possibility to see patients with urgent needs on other times as well, in so called 'reserve spreekuren' (extra consultations).

2.3 Performance measurements

We want to reduce the throughput time of the diagnostic track, therefore the waiting times for the patient between the different steps are the most important measurements. Figure 4 shows the measurements we use in the analysis, derived from the (hospital) process description described in Figure 1 and Paragraph 2.1:

A. The access time for the radiology examination (if more than one examination: the access time to the last appointment)

   Measurement: working days between first outpatient appointment and (last) radiology examination

B. The duration between radiology examination and availability of the radiologist's report

   Measurement: working days between radiology examination and availability of the radiologist's report

C. The access time for the second outpatient consult (personal or telephonic)

   Measurement: working days between radiology appointment and second outpatient consult

D. The throughput time of the diagnostic track

   Measurement: working days between first and second outpatient consult (D = A + C)

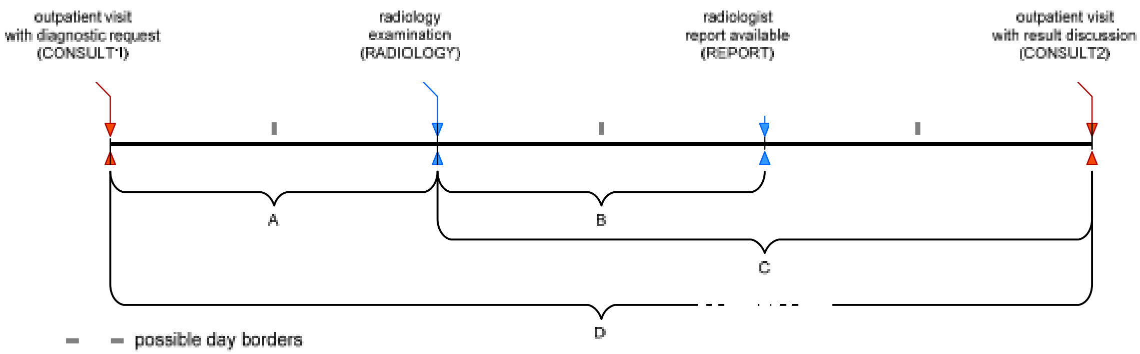

Figure 4. Time measurements

We will use the first four measurements (A-D) for our analysis and the selection of approaches. Moreover we use the following patient and organisational indicators to evaluate the effects of different approaches:

E. Waiting time of the patient within the hospital

F. Number of visits to the hospital during the diagnostic track

G. The over time of the radiology department (assistants and radiologists)

H. The idle time of the radiology department (modalities, assistants and radiologists)

2.4 Current performance diagnostic track

To assess the current performance of the process involved with the diagnostic track, we first have to gather data. Paragraph 2.4.1 describes the way we gather our data set and which selections we make to ensure validity of our findings. Paragraph 2.4.2 presents the current performance of the diagnostic track.

2.4.1 Data selection

To analyse the diagnostic track, we need information about the patient flow between the outpatient department and the radiology department. During the analysis phase of our research, the new hospital information system (EZIS) consists of 6 months of historical data (October 2007 – March 2008) about consults in the outpatient department. We obtain information about the CT scanner from the radiology information system (RIS), consisting of more than two years of historical data (January 2006 – March 2008). The analysis of the diagnostic track is based on the overlapping time frame in the two data sets: October 2007 – March 2008.

Within this time frame a total number of 3260 outpatient CT requests are performed by the radiology department. Not all of these requests are applicable to our study; we exclude long term requests (see Paragraph 1.2): remaining 2022 short term requests.

Next, we find a corresponding physician consult before and after each of these requests. Because there is no data or record link between a radiology request and the corresponding outpatient consults, we have created rules to derive this link. Appendix D describes the rules we developed to create a match between the different data sets. With these rules we are able to match – find a corresponding first and second outpatient visit – 1492 of 2022 requests (73,79%).

For a large part of the unmatched requests, we cannot find a corresponding outpatient consult before or after the CT scan (481 of 530: 90,57%). Explanations for this absence are: (1) the size of our data set, the outpatient consults occur before the start or after the end of our data set, (2) the rules used for matching, we require that the request and discussion of the results is performed by the same specialty (we exclude patients with multi-disciplinary treatment with this requirement), (3) erroneously registered appointments (not registered as performed).

It is difficult to verify whether the data match described above is reliable. Most of the patients have many other appointments (treatment, consults with other specialties etc.) during the diagnostic track. Therefore it is difficult for example to be sure if the second outpatient consult in the match, is the actual consult where the result of the radiology examination is discussed with the patient. To overcome this issue we add the following extra selection criteria for the outpatient consults.

For the first outpatient consult we ensure that the diagnostic track is planned directly after the outpatient consult (within 2 working days). CT appointments requested before or more than two working days after the first outpatient consult are therefore excluded (563 appointments). For the second outpatient consult, we use the access time of this consult as limiting criterion: less than 20 working days. This leads to a decrease of tracks in our data set from 929 to 812 appointments.

Although we validated our data, by adding selection criteria, we are not sure if the data is complete, for example the number of patients with multi-disciplinary treatment tracks is unknown. We therefore recommend making it easier to automatically link outpatient consults with radiology examinations in a valid and complete way. A possibility is to record the outpatient consults on the radiology request form, which requires a digital form.

We conclude that 812 of the 2022 (40,16%) short term outpatient CT requests fall within our definition of a diagnostic track. Moreover, these 812 requests account for 24,91% of the total number of outpatient CT requests (3260).

2.4.2 Performance diagnostic track

Table 1 shows the performance of the diagnostic track using average and standard deviation for each of the defined performance measurements A-D (Figure 4). We distinct two patient groups within our sample: urgent and short term requests. We base this distinction on the groups found in the histogram of the access time of the CT scanner (measurement A). Figure 5 shows the variation in access time for the CT scanner. We can clearly distinguish two groups in this graph, within one week (0-4 working days) and between one and 4 weeks (5-20 working days).

The first group consists of CT requests with urgency ('within one week'). We plan these urgent CT requests in the closed yellow slots of the CT schedule (see Paragraph 2.2.1). The second group (short term) consists of requests, which are scheduled in regular 'green' slots as soon as possible.

		access time CT scanner (A)		throughput time radiologist's report (B)		access time 2nd outpatient consult (C)		throughput time diagnostic track (D)	
	patients	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**
urgent	199	2,06	1,24	0,99	1,23	4,90	3,48	6,96	3,64
short term	613	12,28	3,61	1,05	0,91	4,63	2,68	16,90	4,55
Total	812	9,77	5,44	1,03	0,99	4,69	2,89	14,47	6,09

Table 1. Performance diagnostic track per outpatient group in working days (Data CT: 07-10-2007 – 31-03-2008)

We validated measurement A with the radiology department. The access time for short term requests (12,28 working days) is consistent with statements of different people within the radiology department that the access time is generally some 2 weeks. They also state that urgent requests are always planned within the next couple of days, which complies with the average of 2,06 working days found.

Table 1 shows that the most influencing measurements on the total throughput time are different for the two patient groups. For urgent requests, 70,40% of the length is determined by the access time for the second outpatient consult. The throughput time for short term requests is determined for 72,66% by the access time for the CT scanner.

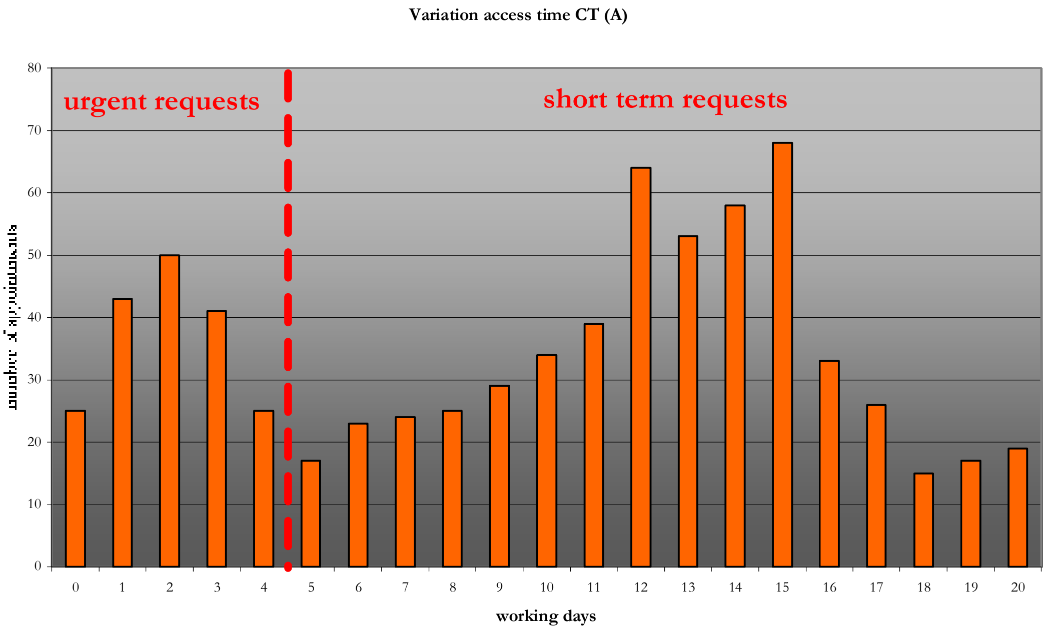

Figure 5. Variation in access time CT scanner (Data CT: 07-10-2007 – 31-03-2008)

Another observation from Table 1 is the (relatively) low average in throughput time of the radiologist's report (indicator B), in the planning protocol this is set at a delay of 4 working days between radiology and outpatient visit to guarantee all reports are finished by the radiologists. This 'rule of thumb' of 4 working days results in the average for indicator C: 4,69 working days. Nearly 70% of the appointments are planned within the current standard of 5 working days.

Table 2 and Table 3 show the performance of the diagnostic track per specialty. Internal medicine is the most important specialty with respect to the number of CT requests. They account for a large part (43,09%) of the diagnostic tracks.

The number of requests per specialty for urgent requests (Table 2) is too low (<20 observations) for most specialties to ground a discussion about the differences. Differences in performance can originate from the small sample size or different policies. We therefore focus on differences in the measurements for short term requests.

Table 3 shows there is no large difference between access times for different specialties. The access time for GYN (11,31 working days) is an outlier. However, this difference in access time in comparison with other values is not significant, because of the low sample size of this specialty (16 requests).

Differences in the throughput time of the radiologist's report (1,00 – 1,33 working days) need further investigation as we cannot explain this on this time. Differences in access time for the second outpatient consult are also difficult to explain (indicator C). Although we see a variation in access time between, for example, 3,96 (GAS) and 5,76 (RT) working days, we are not able to explain this difference. Possible explanations can be found in the difference between planning methods and the number of consultation hours per specialty.

To improve the throughput time of the diagnostic track we have to improve all measurements (A-C). To improve the access time for the CT scanner, we will analyse the current performance of the CT scanner in the next Paragraph (2.5). To improve the throughput time after the CT examination, we analyse the working standard of 4 working days for the radiologist's report (indicator B) in Paragraph 2.6.

To analyse indicator C, we have to analyse the link between access time for the second outpatient consult and the capacity of the outpatient department. As described in Paragraph 2.2.2, the capacity is flexible: when a there are no free slots available in a physicians schedule, the patient is booked in overtime. This flexibility makes it difficult to analyse the capacity of the outpatient department and therefore left out of this research.

		access time CT scanner (A)		throughput time radiologist's report (B)		access time 2nd outpatient consult (C)		throughput time diagnostic track (D)	
	patients	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**
CHI	19	1,74	1,45	1,00	0,94	3,89	1,82	5,63	2,14
GAS	19	2,63	1,16	1,26	2,79	8,11	4,27	10,74	3,75
GYN	10	2,50	0,71	0,80	1,14	6,00	4,52	8,50	4,48
INT	84	2,11	1,15	0,95	0,91	4,69	3,33	6,80	3,46
KNO	10	3,10	1,10	0,80	0,79	6,40	3,63	9,50	4,09
LON	29	1,38	1,37	1,07	1,07	4,62	3,62	6,00	3,56
RT	8	1,50	1,20	1,00	1,07	4,75	2,38	6,25	2,49
URO	20	2,10	0,91	1,00	0,86	2,90	1,52	5,00	1,75
Total	199	2,06	1,24	0,99	1,23	4,90	3,48	6,96	3,64

Table 2. Performance in working days of the diagnostic track for urgent requests (Data CT: 07-10-2007 – 31-03-2008)

		access time CT scanner (A)		throughput time radiologist's report (B)		access time 2nd outpatient consult (C)		throughput time diagnostic track (D)	
	patients	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**
CHI	65	12,09	3,98	1,02	0,98	5,26	3,10	17,35	5,40
GAS	91	12,21	3,17	1,00	0,76	3,96	2,33	16,16	3,98
GYN	16	11,31	4,83	1,19	0,98	4,25	1,84	15,56	5,40
INT	262	12,44	3,62	1,04	0,84	4,38	2,43	16,82	4,41
KNO	24	12,17	3,16	1,33	1,86	5,75	3,37	17,92	4,40
LON	52	12,21	4,00	1,04	0,84	4,50	3,19	16,71	4,55
RT	34	12,21	3,96	1,06	1,10	5,76	2,51	17,97	5,28
URO	69	12,28	3,24	1,01	0,70	5,07	2,79	17,35	4,29
Total	613	12,28	3,61	1,05	0,91	4,63	2,68	16,90	4,55

Table 3. Performance in working days of the diagnostic track for short term requests (Data CT: 07-10-2007 – 31-03-2008)

2.5 Current performance CT scanner

To analyse the performance of the CT scanner we define our data set (2.5.1) and define the patient groups as basis for the analysis (2.5.2). The actual analysis consists of three parts: use of the capacity (2.5.3), the number of slots requested (2.5.4) and the access time for the CT scanner (2.5.5).

2.5.1 Data selection

For the analysis of the CT scanner we collect and use two years of historical data (January 2006 – March 2008) from the radiology information system (RIS). We do not use the data set used to test the current performance of the diagnostic track because the set does not cover all CT requests. We extract and label the data using the data extraction manual given by Den Braber (2007).

2.5.2 Definition of patient groups

To define the patient groups for the CT scanner, we make distinction between the types of patient (inpatient or outpatient) and the urgency of the examination. We derive the urgency from Figure 5, it is clear there is a group of patients scheduled within one week, within four weeks and more than four weeks. Table 4 shows the patient groups and their sizes used in the performance analysis of the CT scanner. The last column gives the percentage of patients needing preparation the day before.

Group	Planning window	Size	Preparation
inpatient	0-2 working days	9,26%	70,53%
outpatient: urgent	0-4 working days	15,28%	55,38%
outpatient: short term	5-20 working days	42,59%	65,29%
outpatient: long term	> 21 working days	32,87%	77,13%

Table 4. Patient groups CT scanner (current planning window, size and percentage of patients needing preparation)

2.5.3 Use of available capacity

The current capacity of 199 green slots per week for general CT requests (see Paragraph 2.2.1) is not enough to accommodate all requests made by physicians. Figure 6 shows the number of CT scanner slots used per week, the blue line shows the current reserved capacity. As described in Paragraph 2.2.1, the time between the blocks of green slots is used to plan urgent outpatient and inpatient requests. There is enough personnel to fill 56 slots (8:20 – 17:40 hour) per day which leads to a theoretical maximum capacity of 280 slots per week. However, this maximal capacity per week is never reached. On average, 72,25% of the capacity is used with a variation of 78-245 slots with a standard deviation of 19,67 slots.

Figure 6 shows five outliers, caused by the following situations: (2006-45) and (2007-44) planned maintenance (CT scanner for 2 working days out of order) and (2006-52), (2007-52) and (2008-01) holiday season (Christmas and New Years Eve) leading to limiting opening hours.

2.5.4 Number of slots requested

Figure 7 shows the total number of slots requested per week (outpatient and inpatient). Apart from the outliers in the holiday seasons (2006-52, 2007-52 and 2008-01) the process is in control. The variation in the number of slots requested is large, between 151 and 293 slots per week. The variation in the number of short term outpatient slots requested is smaller (Figure 9), apart from outliers: variation between 101 and 194 short term slots requested. However, this variation is in practice rather large, 84 slots account for 1,5 day of CT time in one week (30,00% of the maximum capacity per week).

The difference between the variation in number of slots requested and the variation in use of the available capacity leads to the expectation of a buffer of patients. This buffer of waiting patients is used to balance the variation in requests with the available capacity. In practice a buffer of patients is experienced as access time for the CT scanner.

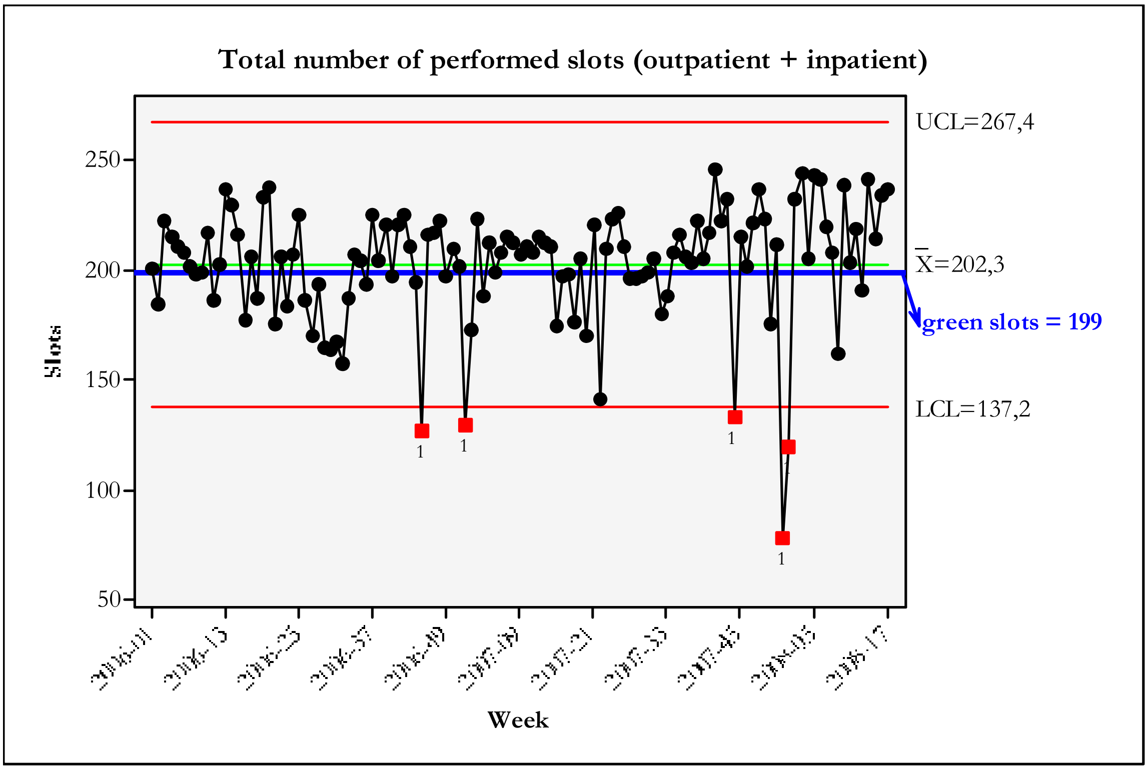

Figure 6. Total performed CT slots (outpatient + inpatient)

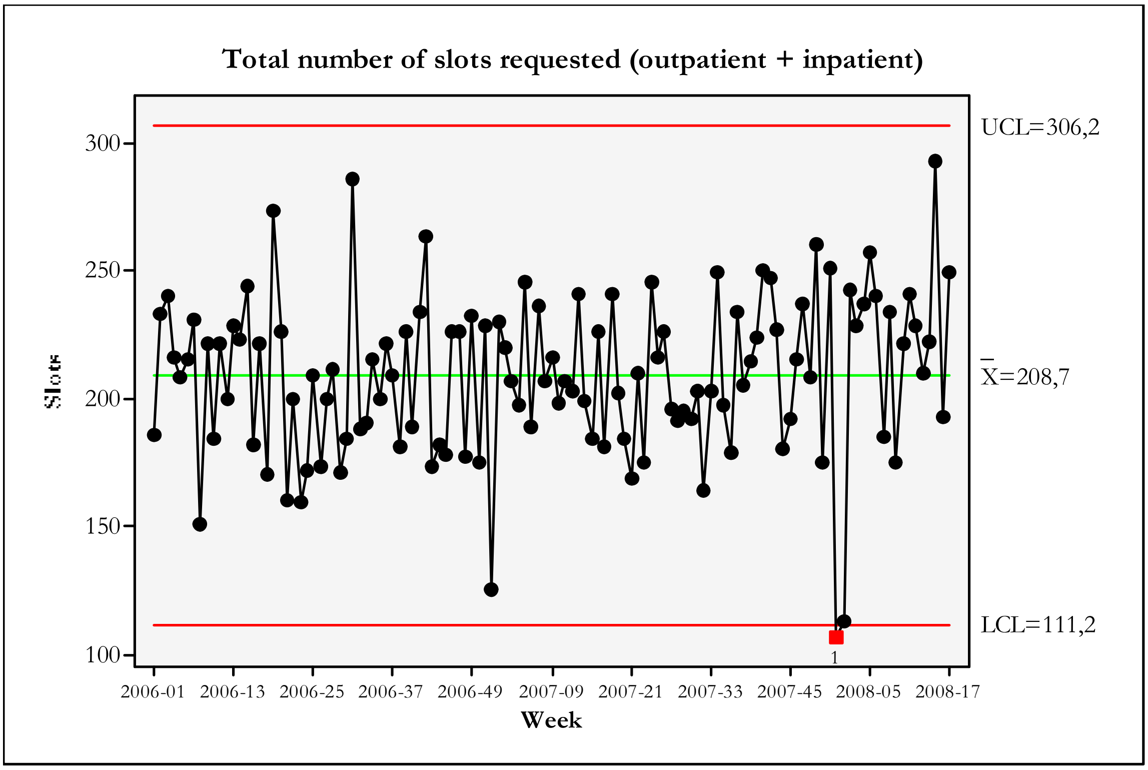

Figure 7. Number of slots requested per week (outpatient + inpatient)

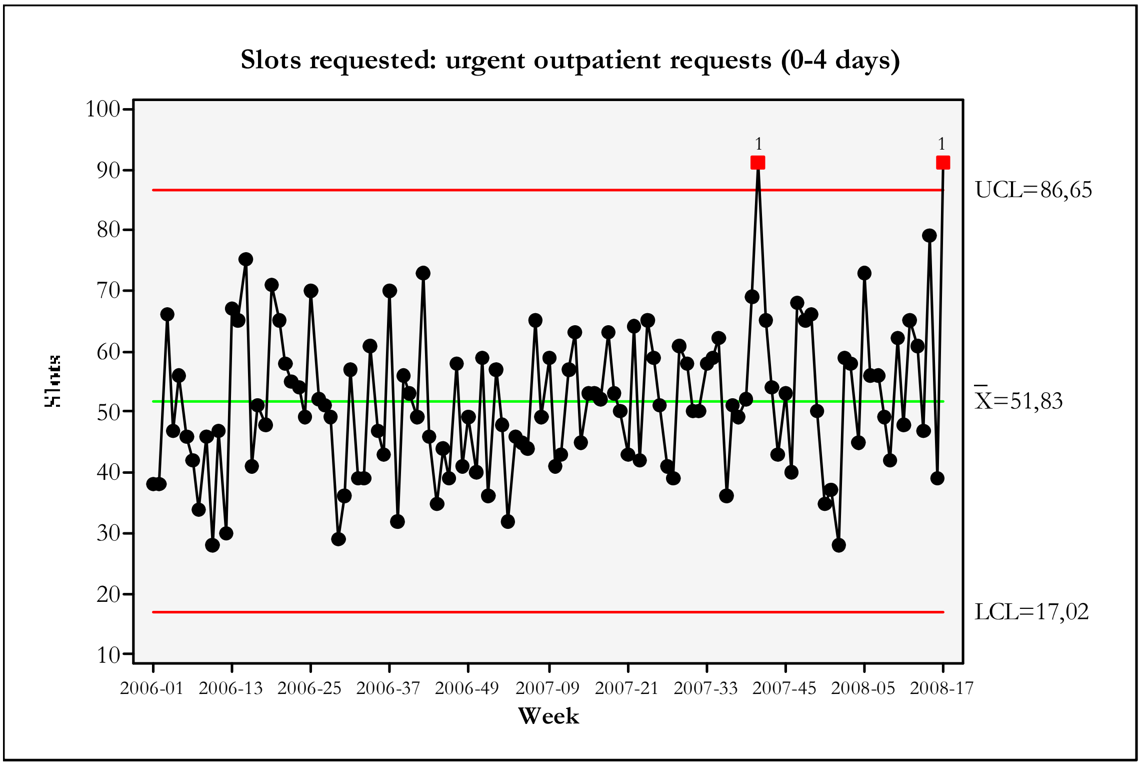

Figure 8. Urgent (0-4 working days) outpatient slots requested per week

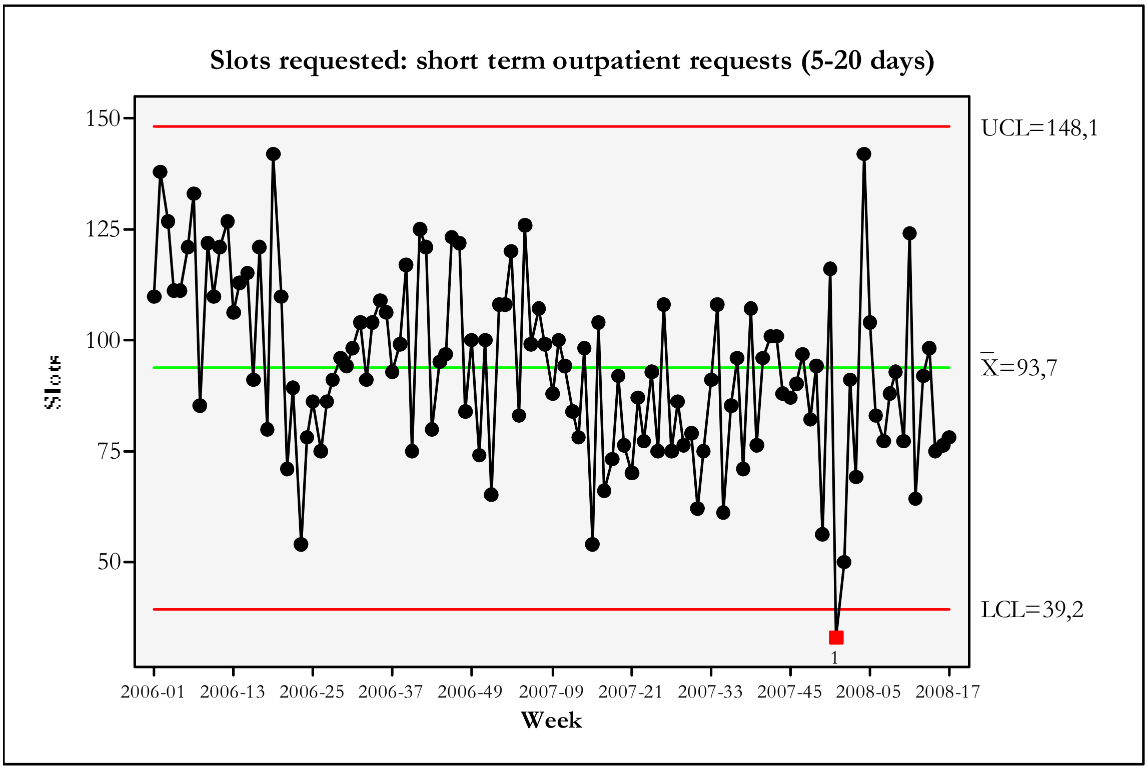

Figure 9. Short term (5-20 working days) outpatient slots requested per week

2.5.5 Access time

Figure 10 shows a chart of the average access time per week, it is clear that it is not on a constant level. To search for explanation of this variation, we use techniques from Statistical Process Control (SPC). SPC was developed as a quality control instrument for the industry by Shewart in the early 1920s, but is currently in wide spread use in different industries as well as in health care (Carey & Stake, 2003; Thor et al., 2007; de Mast, Does, & de Koning, 2006).

SPC makes distinction between two types of variation: normal and special cause variation. The normal variation can be found in the nature of processes, they are never static. Special cause variation is variation of a process outside the 'natural control limits' and is caused by a special situation in or outside the process. The most commonly used way to visualise this difference, is by using control charts (Carey & Stake, 2003).

Figure 10 shows a control chart of the average access time (measured in the week of planning of the appointment) for outpatient CT scans within 20 working days per week since 2006. The green line is the average access time of all the data points, the control limits (UCL, LCL) are constructed of 3 times the standard deviation (3σ).

When the process is within the control limits, the process is considered controlled and changes in average access time are due to common cause variation. Special case variation can be analysed with the following three tests (Mohammed, Worthington, & Woodall, 2008):

1. A run of eight (some prefer seven) or more points on one side of the centre line;
2. Two out of three consecutive points appearing beyond 2 SD on the same side of the centre line (i.e., two-thirds of the way towards the control limits);
3. A run of eight (some prefer seven) or more points all trending up or down.

Given the tests above, we distinguish 6 clusters of average access times: (1) week 2006-01 until 2006-40 with normal cause variation, (2) week 2006-41 until 2007-11 special case variation: test 1 and 2, (3) week 2007-12 until 2007-28 normal cause variation, (4) week 2007-30 until 2007-41 special case variation: test 2, (5) week 2007-42 until 2007-50 special case variation: test 1 and (6) week 2007-52 until 2008-14 special case variation: test 1.

We explain the variation (increase in average access time) in cluster 2 by the dip in the number of performed outpatient CT scans in week 2006-45 (first outlier in Figure 6). Because our planning horizon is 4 weeks (20 working days), a decrease in performed CT appointments (available slots) in week 45 affects at least the access time in week 41-45. As with cluster 2, cluster 5 (2007-42 until 2007-50) can be explained by a dip in CT scans in week 2007-44. In both situations, the dip is caused by 2 days of preventive maintenance of the CT scanner. As can be seen in the graph, these 'lost days' are not compensated in the weeks after.

The decrease in average access time in cluster 4 (2007-30 until 2007-41) can be explained by the time period (summer holidays) and an increase in the number of performed outpatient CT appointments in the weeks 2007-35 until 2007-43 in comparison to the number of appointments in the weeks 2007-13 until 2007-32 (Figure 6). The decrease in the last cluster (2007-52 until 2008-14) can be explained by an increase in performed outpatient CT scans (special case variation: test 2) in week 2008-02 and 2008-03 (Figure 6).

We conclude that the access time of the CT scanner is a process in control. However, apart from natural variation in the process, we found some special cause variation in the process. The most influencing factor in the radical change of the access time is a decrease in regular ('green') slots available during a week (due to maintenance).

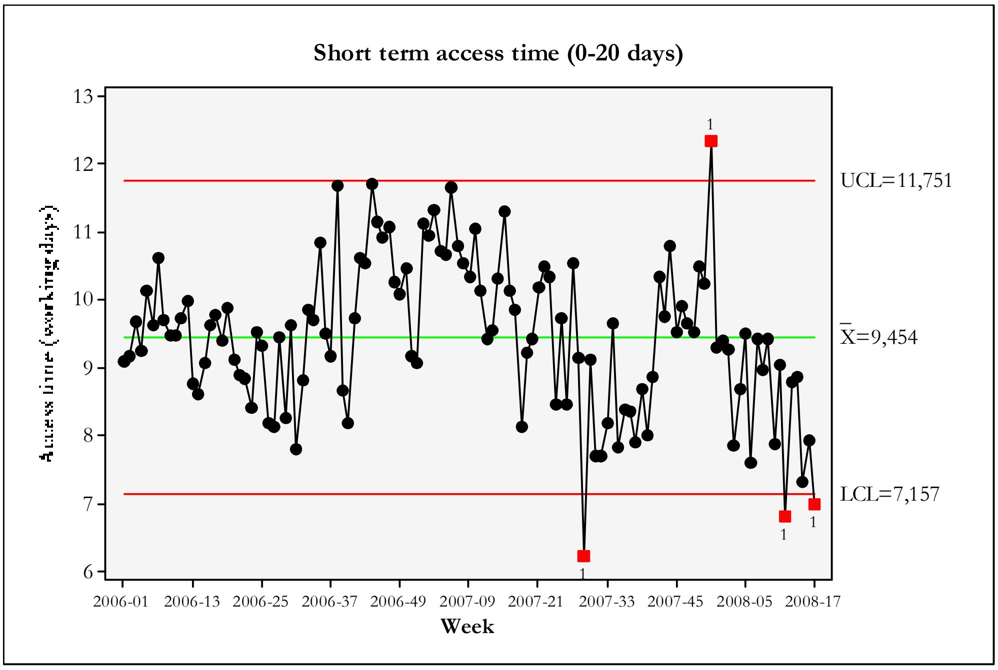

Figure 10. Average access time per week for short term outpatient CT scans, data: appointments with access time of 0-20 working days (RIS 2006-2008)

2.6 Performance radiologist's report throughput time

After the radiology examination, the radiologist has to describe the outcomes of the examination in a report for the physician. This report is important for the physician because most of the physician can not interpret the images from the scan on their own. It is therefore important to have the report available before the patient visits the physician again.

Table 5 and the yellow line in Figure 11 show the throughput time of reporting for the CT examinations with day 0 as the day of the examination. Most of the CT reports (~95%) are available after 2 working days after the day of the examination. After these two working days increase in the number of reports available is only marginal.

The throughput time of reporting depends on several factors. Radiologists can report on-line or off-line. On-line reporting is based on speech recognition and reports are directly available after authorisation. With off-line reporting the dictation is processed by a medical typist and afterwards authorised by the radiologist. Figure 11 shows the difference in speed between on-line and off-line reporting. The percentage of on-line reports available on the same day as the examination is clearly higher (58%) than off-line reports (18%).

Whether a radiologist dictates on-line or off-line is a personal preference, 49% of the radiologists use on-line reporting versus 51% using off-line reporting. Table 6 shows that the throughput time is also depending on the radiologist. There is a large difference per radiologist in the percentage of examinations pending dictation after two working days [1,14% – 13.85%].

The current working standard for the throughput time of the radiology report is 5 working days. To decrease this number of days to for example 2, the outpatient department requires that 99% of the reports of all radiology modalities are available after 2 working days. It is not easy to adapt the working standard only for the CT scanner, because of ambiguity with combination appointments (CT scan and MRI for example). We will therefore analyse the throughput times for other modalities as well.

The throughput time of the report of the Ultrasound and Bucky examinations show the same pattern as the CT examinations, see Appendix E. The throughput time of MRI reports is longer, after 2 working days only 84,96% of the reports are available.

Nearly half of the remaining 531 reports (229 reports) are 'MRI mammae' examinations, another 22% (115 reports) are 'MRISC' examinations. Of the then remaining 187 reports, a large part concerns head-neck examinations (74 reports). The remaining 113 reports cannot be assigned to specific patient groups.

We can explain the delay in the head-neck reports, because these examinations are first reported by the assistant radiologists, discussed with their supervisor and after that they revise the report and authorise it. This process does not take place on the same day and depends on the availability of the supervisor (radiologist).

days	number of reports completed	cumulative percentage reports available
0	2373	37,24%
1	2865	82,19%
2	760	94,12%
3	165	96,70%
4	45	97,41%
5	45	98,12%
6	14	98,34%
>= 7	106	100,00%
Total	*6373*	

Table 5. Throughput time radiology report CT-scanner (RIS 2007)

radiologist	total reports	> 2 working days	percentage
1	341	15	4.40%
2	689	26	3.77%
3	797	24	3.01%
4	722	100	13.85%
5	811	46	5.67%
6	1521	53	3.48%
7	967	11	1.14%
8	955	83	8.69%

Table 6. Throughput time radiology report CT-scanner radiologists

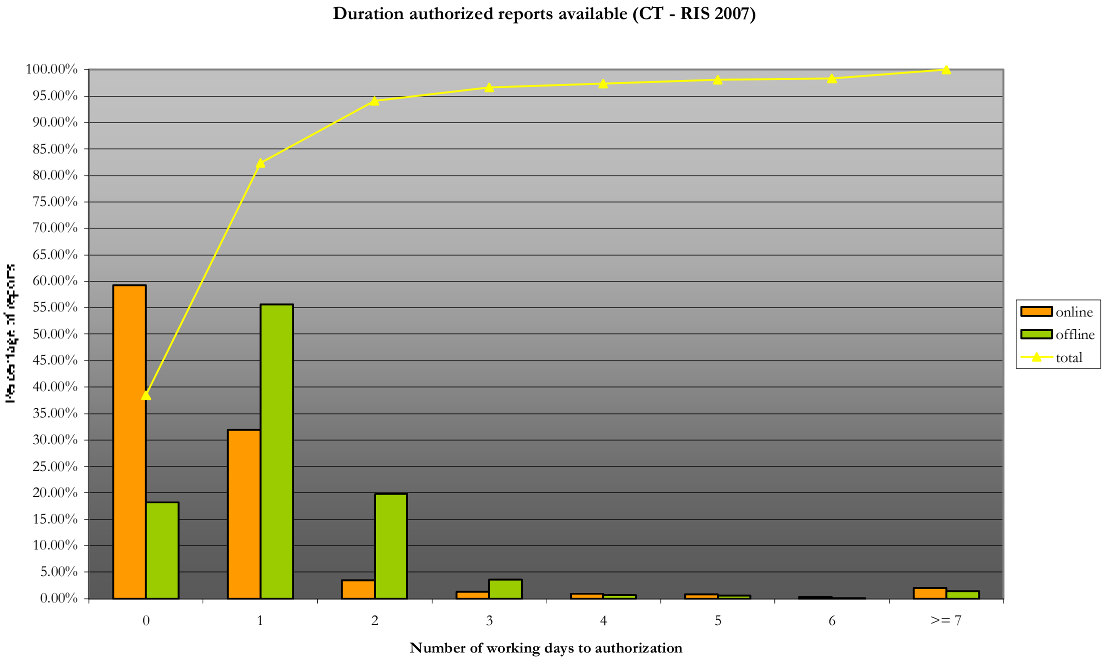

Figure 11. Throughput time radiology report CT-scanner: online versus offline (RIS 2007)

days	number of reports completed	cumulative percentage reports available
0	1235	34,64%
1	1215	68,72%
2	579	84,96%
3	229	91,39%
4	111	94,50%
5	70	96,47%
6	35	97,45%
>= 7	91	100,00%
Total	***3565***	

Table 7. Throughput time radiology report MRI-scanner (RIS 2007)

2.7 Conclusion

At first, our definition of the diagnostic track seems to be "too strict". From the available data, we could derive a diagnostic track for 24,91% of the total CT requests. As an example, diagnostic tracks of CT scans requested more than one month before the examinations are outside our definition of the diagnostic track, because they do not happen in the near future. They however, account for a one third (32,87%) of all CT scans requested and most of them (69,31%) have the same characteristics as short term tracks (outpatient consult – radiology examination – outpatient consult). We will make recommendation for long term requests in Paragraph 4.4.

In the analysis of the diagnostic track, we found that the "short term" patient group has to be split in two: patients with urgent requests (plan within one week) and short term requests (plan within one to four weeks). Table 8 presents the current performance of the diagnostic track for the two different patient groups. The most influencing factor for the throughput time of the diagnostic track is different for the two patient groups. For urgent requests this is the access time for the second outpatient consult (70,40% of the throughput time), where for the short term requests it is the access time for the CT scanner (72,66%).

The access time for the second outpatient consult is influenced by two factors: (1) the number of times a physician has consultation hours and (2) the throughput time of radiologist's report. The first factor cannot be changed easily, because the physician's agenda is linked to a lot of other processes (operating rooms, ambulatory treatment clinic, wards etc.). The second factor is easier to influence, Table 8 shows that the average throughput time of the report is currently 1,03 working days. In comparison, the current planning rule used by the outpatient department for the report time is 4 working days.

The access time for the CT scanner is influenced by four factors: (1) the number of times the CT scanner is offline (maintenance or no personnel), (2) the available capacity per patient group, (3) the dedication and planning of the capacity and (4) the fluctuation in demand. The first factor explains why there is special case variation in the access time for the CT scanner over time. However, it does not explain why there is a waiting list of more than two weeks for short term requests. This could be explained by an unbalance between available capacity and demand per patient group. In the current situation there is more capacity available than demanded: 72,25% of the total number of slots (urgent and normal slots) is filled. This suggests the remaining factor, dedication and planning of the capacity, is causing the high access times.

To answer the research question *"What are the factors influencing the throughput time of the diagnostic track?"* we have to make a distinction in patient groups for within the diagnostic track: urgent and short term (non-urgent) requests. The most important factor for urgent requests is the throughput time of the radiologist's report. For short term requests the factor is the access time of the CT scanner.

		access time CT scanner		throughput time radiologist's report		access time 2nd outpatient consult		throughput time diagnostic track	
	patients	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**
urgent	199	2,06	1,24	0,99	1,23	4,90	3,48	6,96	3,64
short term	613	12,28	3,61	1,05	0,91	4,63	2,68	16,90	4,55
total	812	9,77	5,44	1,03	0,99	4,69	2,89	14,47	6,09

Table 8. Performance diagnostic track per patient group (Data CT: 07-10-2007 – 31-03-2008)

3 Selection of approaches and model

Our goal is to minimise the throughput time of the diagnostic track and set service levels for patients. We decrease this throughput time for the whole patient group with urgent and short term requests and not only for a number of patients or a specific patient group. The question that follows is: what is the effect of improvement in service level on the efficiency of the organisation? To answer this question we have to define: what are we going to change, what are the preferred service levels and how are we going to measure the effect.

We have to make changes in three different factors, based on the conclusions of the process analysis: (1) the number of slots per patient group (capacity), (2) the dedication of these slots and (3) the maximum throughput time of the radiologist's report. The dedication of slots depends on the maximum access time per patient group. For example, if we choose to set the access time for inpatient and outpatient (excluding long term) requests on a maximum one working day, we can make two types of slots: long term and next day slots (grouping inpatient and outpatient urgent and short term slots).

The preferred service level for the maximum throughput time of the diagnostic track is based on the characteristics of the requestor of the service: the outpatient department. Most of the patients visit a standard consultation hour of their physician (e.g. Monday morning). We therefore assume that the length of each diagnostic track is preferred to be in multiples of weeks (for example from Monday morning to Monday morning the next week). Within this week(s) we have to perform and report a CT scan for patients with an urgent or short term outpatient request.

To measure the effect of changes in the processes we build a simulation model in Microsoft Excel. Input for this model is given by the current process (distributions of the number of requests) and by different approaches. Approaches describe a combination of settings for the factors described above: dedication of slots, maximum access time and maximum throughput time of the radiologist's report. The outcomes of the model per approach are: the optimal number of slots per patient group, the length of the diagnostic track and the performance of the organisational measurements (see Paragraph 2.3: idle time, overtime and opening hours).

Box 1 outlines the modelling steps we use to build our model and analyse the outcomes of the model. These steps are based on the steps described by Law & Kelton (2000) to build a simulation model. Paragraph 3.2 describes the approaches used (Step 1). Paragraph 3.3 describes the theoretical optimisation problem the model solves (Step 2). Paragraph 3.3 describes the simulation settings, including the calculation of distributions (Step 4 & 5). Chapter 4 describes the rest of the steps.

Box 1. Modelling steps

1. Choose and describe approaches for different service levels (in throughput time of the diagnostic track)
2. Model description formulation
3. Implement model (in Microsoft Excel) based on model description
4. Calculate the distribution of the number of requests per patient group
5. Calculate simulation settings: warm-up period and run length
6. Validate model with data of 2007 and a sensitivity analysis
7. Calculate the optimal number of slots per patient group and dedication
8. Calculate for each approach and describe the practical implications of each approach, using the performance measures:
    - Idle time
    - Over time
    - Opening hours
9. Select the best two approaches
10. Calculate the optimal allocation of slots over the day for the two remaining approaches
11. Describe the organisational implementation (issues etc.) of these approaches

3.1 Approaches

Each of the approaches described in this paragraph represent a certain service level for each patient group. The approaches are based on a set of target service levels (throughput time of the diagnostic track) and corresponding settings for the factors described before (access time, throughput time of the radiologist's report and grouping of patient groups). Before we can define the approaches for urgent and short term requests in Paragraph 3.1.2 we have to remove influence of other patient groups on the service levels for these requests.

In the current situation, long term and short term requests are dedicated to the same regular ('green') slots. Long term requests are planned long before short term requests. It is possible that at the start of a week, the whole week is already fully booked with long term requests, leading to a minimum access time of one week for short term requests (as they are planned in the same slots). Thus, in the current situation, long term requests influence the service level (access time) for short term requests. Paragraph 3.1.1 describes how we can solve this problem by separating the capacity for these two patient groups.

3.1.1 Long term slots

In the current schedule, short and long term outpatient requests are dedicated to the regular ('green') slots, and inpatient and urgent outpatient requests are dedicated to regular ('green') as well as emergency ('yellow') slots. This means that, if at the start of the week all regular slots of that week are allocated by long term requests' the access time for short term requests (requested at the start of that week) is at least one week, because they also have to be planned in regular slots. To overcome this problem we dedicate different slots to short and long term requests.

As long term requests are scheduled long before their actual appointment date, it is not possible to anticipate on the fluctuation in demand of other patient groups on the appointment date. The most practical solution therefore is to create a fixed number of slots every day for long term requests. This results in a predictable demand not interfering with variation of requests of other patient groups. By limiting the number of long term slots (in comparison with the current situation) we force the requests to be spread over days and weeks. Spreading is possible because it is not essential that a follow-up appointment is exactly after half a year, it is possible to schedule that appointment a week earlier or later.

To calculate the number of slots, we use the average number of long term requests performed per day (12,59 requests per day). In practice there are more examinations requested than performed, as patients cancel their appointment or do not show up. The percentage cancellations and no-shows of the total number of requests is 5,12% (RIS CT 2007). To calculate the number of long term slots per day, we include this percentage. This leads to a minimum of 13 slots for long term requests per day (= 65 slots per week).

Figure 12 shows the number of long term outpatient requests performed per week in 2007. In 35,29% of the weeks, the number of long term requests performed was larger than 65. At the same time, in many weeks 50 slots or less are filled, creating possibilities of spreading. In some periods there is no possibility to schedule requests a week earlier or later (2007-35 – 2007-42) suggesting to create more slots than 13 per day, to be able to accommodate changes in the number of requests. We recommend allocating 15 slots for long term requests per day and using remaining capacity for other patient groups (urgent, short term and inpatient requests).

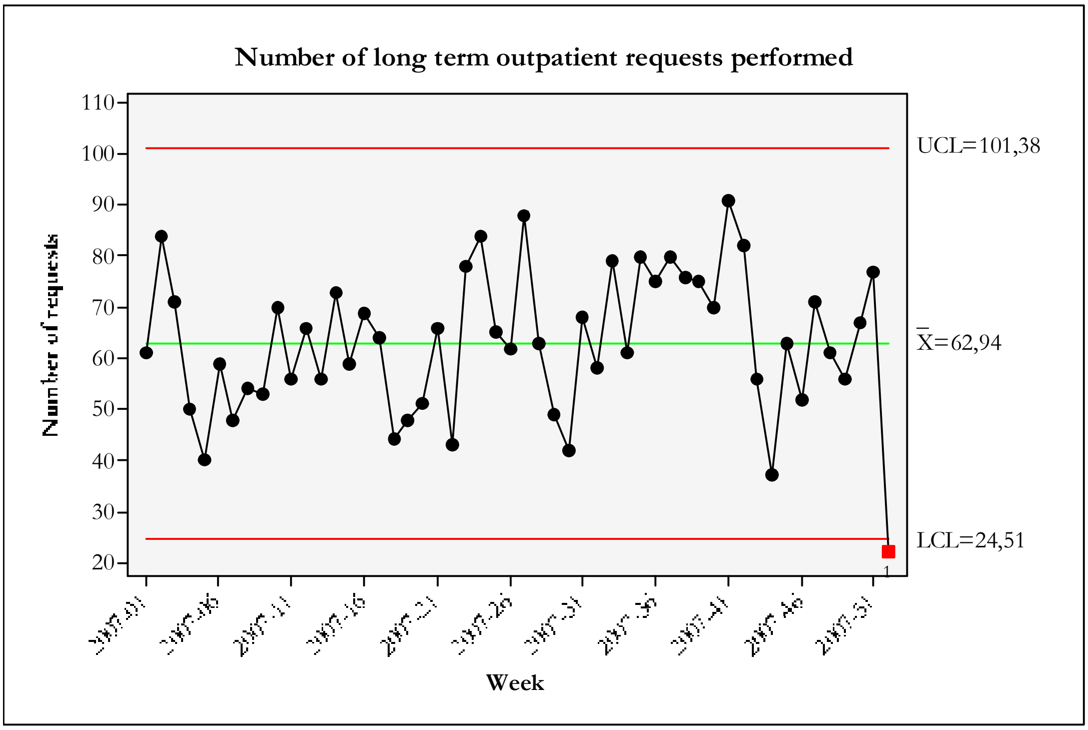

Figure 12. Number of long term outpatient requests performed per week (RIS 2007)

3.1.2 Description of approaches

First, we describe the characteristics and service levels for each approach. All approaches are based on the solution presented in the previous paragraph, to allocate dedicated slots to long term requests. After the description of the approaches we describe the configurations of the approaches and how we evaluate the performance of the approaches.

Approach 1 represents the current situation including dedicated slots for long term requests. This approach does not improve the service level to patients, as the same maximum access times and throughput time of the radiologist's report are used as in the current situation.
Approach 2 represents the situation where the throughput time of diagnostic track is one week maximum for urgent requests and two weeks maximum for short term requests. Therefore, the approach adds dedicated slots for all patient groups.
Approach 3 represents the situation where the throughput time of diagnostic track is one week maximum for both urgent and short term requests. Therefore, the approach groups urgent and short term slots.
Approach 4 represents the situation where the access time for urgent and short term requests is one working day maximum. Therefore, the approach groups urgent, short term and inpatient slots. All these patients are scheduled before the end of the next working day.

Table 9 shows the corresponding configurations of the following factors for each approach: maximum access time, maximum throughput time of the radiologist's report and the grouping of patient groups. To be able to compare the different approaches we set the maximum throughput time of the radiologist's report on two working days for all approaches. The effect of lowering the throughput time on the performance of the approach is discussed in Paragraph 4.2.3.

We compare the outcomes of the different approaches by using the performance measurements for the organisation and the patient described in Paragraph 2.3. Patient measurements: (E) waiting time of the patient within the hospital and throughput time of the diagnostic track. Organisational performance measurements: (G) over time of the radiology department and (H) idle time of the radiology department.

<table>
<tr><th rowspan="2"></th><th colspan="3">max. access time
(working days)</th><th colspan="3">max. report time
(working days)</th><th colspan="4">dedication of slots</th></tr>
<tr><th>inpatient</th><th>outpatient: urgent</th><th>outpatient: short term</th><th>inpatient</th><th>outpatient: urgent</th><th>outpatient: short term</th><th>inpatient</th><th>outpatient: urgent</th><th>outpatient: short term</th><th>outpatient: long term</th></tr>
<tr><td>Current</td><td>1</td><td>4</td><td>-</td><td>0</td><td>4</td><td>4</td><td colspan="4">X</td></tr>
<tr><td>Approach 1</td><td>1</td><td>4</td><td>14</td><td>0</td><td>4</td><td>4</td><td colspan="3">X</td><td>X</td></tr>
<tr><td>Approach 2</td><td>1</td><td>2</td><td>7</td><td>0</td><td>2</td><td>2</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Approach 3</td><td>1</td><td>2</td><td>2</td><td>0</td><td>2</td><td>2</td><td>X</td><td colspan="2">X</td><td>X</td></tr>
<tr><td>Approach 4</td><td>1</td><td>1</td><td>1</td><td>0</td><td>2</td><td>2</td><td colspan="3">X</td><td>X</td></tr>
</table>

Table 9. Simulation settings (access time, report time, dedication of slots) per approach

3.2 Model description

There are two goals for the model per approach: (1) determine the optimal configuration of slots per patient group, minimising variation in idle time and overtime and (2) calculate and show the mean, standard deviation and confidence interval (95%) for the performance measurements (idle time, overtime and opening hours). This paragraph elaborates on the optimisation problem stated in the first goal. Appendix F presents a summary of all variables and constraints used in our model.

We use the current planning rule as basis for our model: schedule inpatient, urgent and short term requests in the first available slot. The model has to obey the maximum access time (defined in the different approaches as service levels) by using overtime slots if there are no more regular slots available. The model is based on discrete-event changes in days. Every day in the model the number of requests per patient group is drawn from the calculated distributions. The planning horizon changes every day.

Definitions:

- Patient groups $G_g\left(g \in \{1,2,3\}\right)$:
  - 1: inpatient
  - 2: outpatient – urgent
  - 3: outpatient – short term
- Arrival (stochastic) distribution of requests per patient group (g) per day: $\lambda(g)$
- Percentage of patients needing preparation per patient group (g): p_g
- Maximum days of waiting per patient group: n_g

- Capacity of slots per patient group (g) per day: S_g
- Penalty for overtime: α
- Requests on day d and patient group $g : R_{dg} \sim \lambda(g)$

Variables:

- $P(t,d,g)$ is the number of requests scheduled on day t; requested on day d for patient group g. $P(t,d,g)$ equals the number of requests in the queue ($Q(t,d,g)$) if this number is smaller or equal to the remaining capacity ($A(t,d,g)$), or equals the remaining capacity ($A(t,d,g)$) if the number in the queue is larger than the remaining capacity:
    - o $P(t,d,g) = \begin{cases} Q(t,d,g) & \text{if } Q(t,d,g) < A(t,d,g) \\ A(t,d,g) & \text{else} \end{cases}$, where:
        - ▪ $Q(t,d,g)$ is the number of requests in the queue requested on day d, which requests are not scheduled on the days before day t (where $t \geq d$):
            - • $Q(t,d,g) = R_{dg} - \sum_{x=d}^{t-1} P(x,d,g)$
        - ▪ $A(t,d,g)$ is the remaining capacity on day d for patient group g equal to the number of standard slots for the patient group (S_g) minus the number of requests already planned on day d:
            - • $A(t,d,g) = S_g - \sum_{x=d-n_g}^{d-1} P(t,x,g)$
- The number of requests that do not need preparation ($N(d,g)$) and can be scheduled today if there are slots available:
    - o $N(d,g) = (1-p_g) * R_{dg}$
- Overtime $O(d,g)$ equals the number of requests planned ($P(t,d,g)$) minus the available slots (S_g), if larger than zero:
    - o $O(d,g) = \max\left\{\left(\sum_{x=d}^{d+n_g} P(x,d,g) - S_g\right), 0\right\}$
- Idle time I equals the slots for patient group g minus the number of requests planned on day d and requested on days $\{(d-n_g)...d\}$
    - o $I(d,g) = S_g - \sum_{x=d-n_g}^{d} P(d,x,g)$

Constraints:

- The number of planned slots (slots all have the same size: 10 minutes) on the day of request must be equal or lower than the number of requests without need for preparation ($N(d,g)$):
    - $P(d,d,g) \leq N(d,g) \quad (\forall d,g)$

Objective:

- Minimise the variation (standard deviation) in the idle time and overtime (X_d):
    - $\min \left(\sqrt{\frac{\sum_d (X_d - M)^2}{d}} \right)$, where:
        - $X(d)$ is the summation of the idle time and overtime on day (d) including penalty for overtime (α):
            - $X(d) = \sum_g I(d,g) + \alpha O(d,g)$
        - M is the average of the summation of idle time and overtime (X_d):
            - $M = \frac{\sum_d X(d)}{d}$

To offer the radiology department insight into the practical implications of different approaches, we add a variable describing the opening hours of the CT scanner per day:

- Opening hours (OH) depend on the total overtime (TO) and regular planned time (TT), if the overtime is zero, the total time equals the regular planned time. If there is overtime, the opening hours are given by the standard capacity (C) plus the overtime (O):
    - $OH(d) = \begin{cases} TT(d) & \text{if } TO(d) = 0 \\ C + TO(d) & \text{else} \end{cases}$, where:
        - $TT(d) = \sum_g \left(S_g - I(d,g) \right)$
        - $TO(d) = \sum_g O(d,g)$
        - $C = \sum_g S_g$

3.3 Modelling technique

Based on the model description formulated in Paragraph 3.2, we choose a matching modelling technique. The most important decision variable in the model is $P(t,d,g)$ (the number of slots planned on day t). The value of the variable depends on the number of slots available in normal capacity in the planning window (limited by the maximum access time) for patient group g. The capacity on itself depends on the number of slots already planned before the current day. Thus, the value of $P(t,d,g)$ depends on the state (availability).

The dependency on state of the model requires that we use a state dependent modelling technique. We exclude Monte Carlo Simulation and Queuing theory as both methods are based on state independent models. Simulation (Law & Kelton, 2000) is applicable for our model as it can be modelled state dependent. Next to that, simulation is widely used in health care to answer "what if" questions, like "what happens to our capacity if we close 2 of our 10 beds". This is also the case in our situation, as we ask *what* happens with our organisational performance *if* we reduce the throughput time.

Based on the state dependency of the model and the type of question we try to answer, we choose simulation as modelling technique for implementation our model description.

3.4 Simulation settings

To construct reliable and valid output of the simulation model we calculate the warm-up period of the model and the run length (Law & Kelton, 2000). Because we start with an empty system, the warm-up period is needed to generate a realistic state for the number of requests in the queue. The run length describes the number of days the model has to 'run' to construct a 95% confidence interval for the average of each of the output parameters (idle, over and total time). The run length is based on a relative error of 5% (γ = 0,05). Appendix G shows the calculation of these two parameters, resulting in a warm-up period of 50 days and a run length of 3050 days.

Appendix G shows the calculation of the distributions for the different patient groups (inpatient, outpatient urgent and outpatient short term). We based the distributions on one year of data (RIS: 2007) to prevent influences of schedule changes and other planning differences. Next, with these distributions we generate the number of requests for each of the patient groups for 3050 days (run length). This data set is used as input for the simulation model.

3.5 Model

We build the model according to the model description (Appendix G) in Microsoft Excel. We use one worksheet ('Calculations') for all the calculations. The calculations are based on input values on the number of requests per patient group per day drawn from the calculated distributions (worksheet 'Input'). The rows (in worksheet 'Calculations') represent each day of the simulation and the columns provide information about the variables.

Figure 13 shows worksheet 'Overview' of the model, the left side (green parameters) is used to change the steering variables and the right side (orange values) gives the outcomes of the chosen approach. The value of the minimisation objective of the formal problem is marked red. Box 3 gives a step-for-step manual on how to use the simulation model.

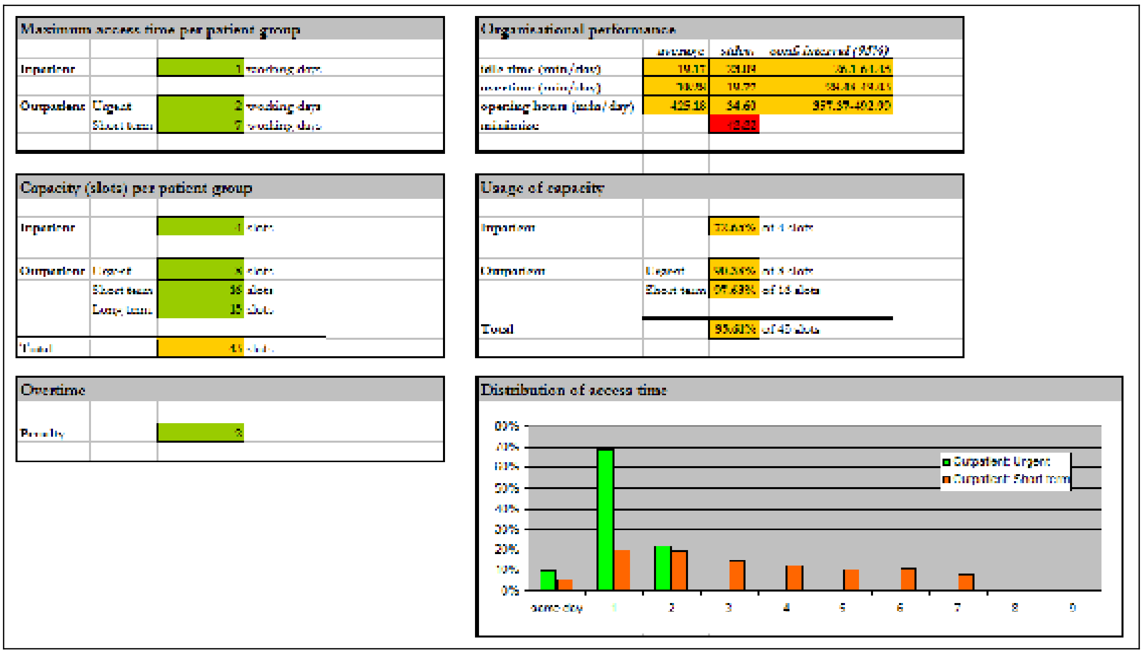

Figure 13. Worksheet 'Overview' of the model built in Microsoft Excel (showing Approach 2)

We use the Solver plug-in of Microsoft Excel, to find the optimal number of slots for each patient group (heading: Capacity). We minimise the standard deviation in idle time and overtime (the red cell) for each approach, given by the maximum waiting times per patient group. Cells within the heading 'Characteristics' give information about the performance of different measurements: idle time, overtime and opening hours. The last two headings give performance information about the usage of capacity and the difference in individual access times. The last heading (Access time) also shows the percentage of requests scheduled on the same day as the request.

To model the difference in dedication of slots between Approach 2 and 3, we automatically group the requests of urgent and short term outpatient requests together when the maximum waiting times for these groups are the same. The model does the same with the capacity for the two groups.

Box 2. User manual for the simulation model

The ‘overview’ worksheet of the simulation model (Figure 13) consists of several different parameters. Green coloured parameters can be changed by the user and orange coloured parameters are output of the model. The capacity under ‘Capacity (slots) per patient group’ is dimensioned in number of 10 minutes slots per day.

You can use the model by changing the maximum access times for the different patient groups and use the Solver add-in to calculate the optimal setting for the number of slots per patient group (given the optimisation criteria in the problem description of paragraph 3.2). The solver can be found in the menu (Tools -> Solver). The solver is pre-configured and can be started by pressing ‘OK’. The solver will change the parameters under the heading ‘Capacity (slots) per patient group’. These parameters can also be adjusted manually.

When changing the input parameters (access times or capacity), the model automatically adjusts the output parameters on the right side of the worksheet. There are three sets of output parameters:

Organisational performance
These parameters describe the average, standard deviation and confidence interval of the performance measurements: idle time, overtime and opening hours.

– *Usage of capacity*
These parameters describe the usage of capacity per patient group and in total.

– *Distribution of access time*
This graph shows the distribution in access time for the different patient groups over the planning horizon.

4 Computational results

In this chapter, we use the model described in the previous chapter to evaluate the performance of the four approaches. The simulation model has two sets of outcomes: the optimal number of slots per patient group per approach per day (4.1) and performance of approaches (4.2). The performance of the approaches (4.2) is discussed from an organisation as well as a patient perspective. Paragraph 4.2 also discusses the effect of lowering the throughput time of the radiologist's report on the performance of the organisation. Paragraph 4.3 evaluates the validity of the model and its outcomes. Paragraph 4.4 discusses the possibilities of further reduction of visits to the hospital on top of the shorter throughput time.

4.1 Optimal solution per approach

Paragraph 3.1.2 describes the characteristic and settings of the four approaches. The model calculates the corresponding optimal number of slots per patient group per day using the minimisation problem described in Paragraph 3.2. Result of the model is the number of slots where the variation of idle time and overtime is minimal, because we use these two parameters to evaluate the performance of each approach. Table 10 shows the results of the calculation, the optimal number of slots per patient group per day.

<table>
<tr><th></th><th colspan="5">number of slots</th></tr>
<tr><th></th><th>inpatient</th><th>outpatient: urgent</th><th>outpatient: short term</th><th>outpatient: long term</th><th>total</th></tr>
<tr><td>Current</td><td colspan="4">37</td><td>37</td></tr>
<tr><td>Approach 1</td><td colspan="3">24</td><td>15</td><td>39</td></tr>
<tr><td>Approach 2</td><td>4</td><td>8</td><td>16</td><td>15</td><td>43</td></tr>
<tr><td>Approach 3</td><td>4</td><td colspan="2">24</td><td>15</td><td>43</td></tr>
<tr><td>Approach 4</td><td colspan="3">28</td><td>15</td><td>43</td></tr>
</table>

Table 10. Calculated optimal number of slots per patient group per day for each approach

4.2 Performance of the approaches

Using the access and throughput times (Paragraph 3.1.2) and the configuration of slots per patient group (previous paragraph) the model calculates the performance of the given approach. Table 11 shows the results of the performance measurements (idle time, overtime and opening hours) for each approach. We use the mean, standard deviation and confidence interval (95%) of the measurements to describe their performance.

	idle time			overtime			opening hours		
	mean	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*
Current	21,10	53,14	-83,05-125,26	38,35	35,67	-31,57-108,26	421,378	83,93	236,88-565,88
Approach 1	14,05	29,01	-42.81-70.91	45,40	32,13	-17,57-108,37	424,64	38,13	327,74-501,54
Approach 2	19,17	23,09	-26,10-64,43	10,28	19,77	-28,48-49,03	425,18	34,60	357,37-492,99
Approach 3	20,05	29,71	-38,18-78,28	11,41	23,81	-35,26-58,08	425,74	40,92	345,54-505,93
Approach 4	28,74	34,30	-38,49-95,98	30,16	44,18	-56,44-116,75	429,98	65,52	281,56-538,41

Table 11. Performance of approaches (idle time, overtime and opening hours) in minutes per day

4.2.1 Organisational performance

The performance of the current situation is derived from RIS data (2007). As described in Paragraph 4.3, in the current situation there is no maximum in access time for short term outpatient requests and there are no dedicated slots for long term outpatient requests. On top of these differences, the number of performed requests is strongly influenced by the changing opening hours (due to personnel and maintenance). Therefore, it is not remarkable that the current situation performs worse on most of the measurements (average and variation of idle time and opening hours and the average in overtime).

Approach 1 (dedication of long term slots) reduces the variation for all the performance measures compared **to the current situation**. At the same time it increases the average overtime and opening hours. However, if we compare the confidence intervals for the three performance measurements, Approach 1 performs better on all three.

Approach 2 (dedication of slots for each patient group) performs better on all aspects **compared to Approach 1**. The major difference between these two approaches is the average overtime explained by the following two factors: (1) urgent and inpatient requests have dedicated slots instead of overtime slots in the current situation (leading to the use of regular instead of overtime slots) and (2) in total there are more slots reserved 39 slots vs. 43 slots (leading to a lower need for overtime).

Approach 3 (grouping of urgent and short term slots) performs slightly worse in variation of idle time (6,62 minutes), overtime (4,04 minutes) and opening hours (6,32 minutes) than **Approach 2.** The most important difference between the approaches is the higher standard deviations of Approach 3 in comparison to Approach 2. The averages in idle time and overtime only differ a couple minutes, where the standard deviation for idle time and opening hours increases by more than 5 minutes. Explanation for this difference can be found in the reduced planning window for short term requests, shorten from 7 to 2 working days. A shorter planning window prohibits us to spread demand, increasing the variation in idle time and overtime.

Approach 4 (maximum access time of one day for all groups) is **performing worse than Approaches 1, 2 and 3** on several measurements. Most outstanding is the high variation in all three factors compared to the other approaches.

4.2.2 Service level performance

The presentation of the results above focuses on the organisational performance of the CT scanner process. Next to the organisational performance, the approaches all have a different effect on the service level for patients. Table 12 shows the maximum service level set for the access time, the throughput time of the radiologist's report and the throughput time of the diagnostic track for each approach.

Approach 1 improves the access time for some patients, but there is no major improvement in service level for all patients. **Approach 2** improves the service level by setting maximum values for the throughput time of the diagnostic track (4 working days for urgent requests and 9 working days for short term requests). This is an improvement over the current situation: throughput time of 6,96 working days for urgent requests and 16,90 working days for short term requests. **Approach 3** and **Approach 4** improve the service level further by reducing the throughput time for short term requests to a respective 4 and 3 working days.

	max. access time (working days)			**max. report time (working days)**			**max. throughput time (working days)**		
	inpatient	*outpatient: urgent*	*outpatient: short term*	*inpatient*	*outpatient: urgent*	*outpatient: short term*	*inpatient*	*outpatient: urgent*	*outpatient: short term*
Current	1	4	-	0	4	4	1	8	-
Approach 1	1	4	14	0	4	4	1	8	18
Approach 2	1	2	7	0	2	2	1	4	9
Approach 3	1	2	2	0	2	2	1	4	4
Approach 4	1	1	1	0	2	2	1	3	3

Table 12. Maximum access time, report time and throughput time of the diagnostic track per approach

4.2.3 Overall performance

Combining the findings from the organisational and service level performance, we can exclude Approach 1 and Approach 4 from the rest of our discussion. Approach 1 performs moderate from an organisational perspective, but does not increase the service level for the patient. Approach 4 performs well from a service level perspective, but does not perform well from an organisational perspective.

For the rest of our discussion we will use the other two approaches (2 and 3). Approach 2 performs best on all (organisational) performance measurements: idle time, overtime and opening hours and improves the service levels in comparison to the current situation. Approach 3 offers the best service level to the patient with a throughput time of one week for all urgent and short term outpatient requests. The increase in service level lead to a decrease in organisational performance of Approach 3 compared to Approach 2: a higher average and variation for all performance measurements.

Approach 3 does not perform poorly, as the differences in averages and variations are relatively small. The larger variation compared to Approach 2 does not lead to (large) capacity problems. The percentage of days the opening hours are longer than our current maximum daily capacity (56 slots = 560 minutes) for Approach 3 is 0,62% (~ 3 days per two years). With Approach 2 it occurs in 0,20% of time (~ 1 day per two years). In conclusion, although Approach 2 performs better on organisational performance, Approach 3 is also suitable to implement in practice, accepting a slight decrease in performance.

To evaluate the effect of the maximum throughput time of the radiologist's report on the performance of the approaches we define three different sub-approaches for Approach 2 and 3. In these sub-approaches we vary the maximum throughput time of the radiologist's report: (A) 2 working days after the examination (same as Approach 2 and 3 above), (B) 1 working day after the examination and (C) the same day as the examination.

Table 13 shows the settings for the maximum access time and maximum throughput time of the radiologist's report for each sub-approach. The total throughput time should be lower than 5 or 10 working days, thus, by lowering the throughput time of the radiologist's report one day, we can increase the maximum access time with one day.

	max. access time (working days)			max. report time (working days)			dedication of slots			
	inpatient	*outpatient: urgent*	*outpatient: short term*	*inpatient*	*outpatient: urgent*	*outpatient: short term*	*inpatient*	*outpatient: urgent*	*outpatient: short term*	*outpatient: long term*
Approach 2A	1	2	7	0	2	2	X	X	X	X
Approach 2B	1	3	8	0	1	1	X	X	X	X
Approach 2C	1	4	9	0	0	0	X	X	X	X
Approach 3A	1	2	2	0	2	2	X	X		X
Approach 3B	1	3	3	0	1	1	X	X		X
Approach 3C	1	4	4	0	0	0	X	X		X

Table 13. Simulation settings (access time, report time, dedication of slots) per approach

Table 14 presents the performance of the sub-approaches for Approach 2 and 3. Overall we see that a decrease in the throughput time of the radiologist's report lead to an improvement in performance: lower average and variation for all measurements. This can be explained by the larger planning window created by a larger maximum access time. If the planning window is larger we are able to spread more requests over the window, using more idle time and less overtime.

The largest difference in average and variation is found between Approach 3A and 3B: more than 4 minutes difference in variation of overtime and opening hours. The other differences between sub-approaches are smaller: decreases of 0-2 minutes. Another observation is that the difference in performance between Approach 2 and 3 becomes lower in sub-approaches B and C. Thus, we conclude that a reduction in maximum throughput time of the radiologist's report leads to significant improvement of the organisational performance, especially for Approach 3.

	idle time			overtime			opening hours		
	mean	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*
Approach 2A	19,17	23,09	-26,10-64,43	10,28	19,77	-28,48-49,03	425,18	34,60	357,37-492,99
Approach 2B	18,21	22,45	-25,79-62,22	9,25	18,62	-27,25-45,75	424,53	32,89	360,06-489,00
Approach 2C	17,88	22,07	-25,38-61,14	8,84	18,14	-26,71-44,39	424,29	32,13	361,31-487,26
Approach 3A	20,05	29,71	-38,18-78,28	11,41	23,81	-35,26-58,08	425,74	40,92	345,54-505,93
Approach 3B	17,84	28,00	-37,03-72,71	9,12	19,53	-29,15-47,40	424,52	36,18	353,60-495,44
Approach 3C	17,21	27,27	-36,25-70,67	8,41	17,67	-26,22-43,04	424,13	34,39	356,72-491,54

Table 14. Performance Approach 2 & 3 with different values for the throughput time of the radiologist's report in minutes per day

4.2.4 Discussion and conclusion

Approach 1 is not improving the service level for patients and Approach 4 does not increase the efficiency of the organisation. Both Approach 2 and 3 improve the service level for patients as well as the efficiency of the organisation.

From an organisation perspective we favour Approach 2 as it performs best on all (organisational) performance measurements: idle time, overtime and opening hours. This means this is the most cost-effective approach, as idle time and overtime generate extra personnel costs. Next to the costs, a low variation in the process generates less stress than high variation processes, improving work satisfaction of personnel.

From a patient perspective we favour Approach 3 as it has the best service levels of the four approaches. The organisational performance is not the same as with Approach 2, but it does not perform poorly. The difference in organisational performance can be compensated by lowering the maximum throughput time of the radiologist's report.

Balancing the two objectives we recommend implementing Approach 3, grouping urgent & short term requests, as it leads to a major change in service to patients. Patients with short term requests complete their diagnostic track within one week with Approach 3 instead of two weeks with Approach 2. To improve the organisational performance within Approach 3, we recommend lowering the radiologist's report to a maximum of one working day (Approach 3B).

4.3 Model validation

We propose a different way of planning using maximum throughput times for the short term outpatient requests. At the same time we separate the capacity for short and long term requests. The most valuable validation of the model is therefore performed by discussing the model with the radiology department. All stakeholders (head radiologist, clinical physicist and head of radiology assistants) agree on the input as well as the outcomes of the model.

The input data used in the model is generating more requests per day in comparison with the number of scans requested in practice in 2007 (2007: 37,87 requests/day; model: 40,14 requests/day). This increase of 5,98% suggests that our calculated distributions are not valid. We choose to accept this input flaw (an increase in number of requests), as it reflects the current situation in 2008 (growth in patient volume).

To test the sensitivity of the model, we use real data about the number of requests per day (RIS CT 2007) as input for our model, instead of simulation data. Table 15 presents the performance of the different approaches with real data.

The model generates more idle time in comparison to the simulations. For example for Approach 2 the average idle time with simulation data is 19,17 minutes and with real data it is 40,70 minutes. This difference can be explained by the lower amount of requests in reality compared to the simulation. The differences in performance found in Paragraph 4.2.1 between Approach 2 and Approach 3 remain when using real data. Approach 2 still performs better on all performance measurements compared to Approach 3.

	idle time			overtime			opening hours		
	mean	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*
RIS 2007									
Approach 2	40,70	29,35	-16,82-98,23	9,84	18,74	-26,89-46,58	408,67	45,95	318,62-498,73
Approach 3	42,70	36,01	-27,88-113,27	11,88	25,69	-38,48-62,23	410,20	54,37	303,63-516,76
Simulation									
Approach 2	19,17	23,09	-26,10-64,43	10,28	19,77	-28,48-49,03	425,18	34,60	357,37-492,99
Approach 3	20,05	29,71	-38,18-78,28	11,41	23,81	-35,26-58,08	425,74	40,92	345,54-505,93

Table 15. Comparison of performance approaches in minutes per day between simulation model and RIS 2007 data

Next to the validation against real data, we also ensure that all requests inserted into the model are performed within the maximum access time and the demand per patient group equals number of performed requests per patient group.

In practice, sometimes there is no capacity available due to maintenance or not enough available personnel (staff meetings etc.). If we include these capacity outings in our simulation model, it influences the average and standard deviation of overtime. However, as we guarantee that the maximum waiting time is never abandoned, requests are performed in overtime. In practice this means we should anticipate on planned maintenance or other planned outing, by reserving extra capacity (in this model seen as ‘overtime’) on the day before and after the outing. This is currently not the standard procedure.

A more fundamental problem exists within the data sets used in our analysis and model. We have labelled all requests with an access time between one to four weeks as ‘short term’. We assume it is possible to plan these requests within for example two working days, instead of three weeks. However, some of these requests have to be categorised as 'long term', as it is a specific requirement from the physician that they are scheduled in exactly three weeks. Thus, we cannot schedule these requests in the next two days.

The size of this 'long term' patient group within our 'short term' patient group is unknown and cannot be derived from the data. If we change the definition of 'short term', from 1-4 weeks to 1-3 weeks, this would result into 5,13 less short term requests per day (16,51 to 11,39 requests/day) and the same amount more long term requests per day (12,42 to 17,48 requests/day). As only part of the 3-4 week group consists of long term requests in practice the shift in number of requests is not as large as 5,13.

To solve the problem described above, we recommend reserving extra capacity for long term requests at the start of the implementation and monitor the usage of slots dedicated to short and long term requests. After two months, we should be able to determine the actual sizes of the different patient groups and the corresponding number of slots needed.

4.4 Possibilities of further reduction of visits to the hospital

In an ideal situation, the hospital facilitates as much appointments for a patient on the same day as possible. In the current situation, however, planning systems of different departments are not directly linked to each other making it hard to translate this goal in to practice. Nevertheless, apart from the planning there are possibilities to offer, for example, same day appointments as shown in the Ultrasound pilot in Chapter 5 .

To reduce the visits of patients to the hospital we have to cluster outpatient and radiology examination on the same day where possible. We design diagnostic tracks which acknowledge the difference between patient groups and individual patients on the following characteristics: (1) type of request (inpatient, long term or urgent/short term); (2) need for preparation and (3) in-person or by phone discussion of results (second outpatient consult). These three characteristics lead to differences in preferences for the availability of appointment slots in the CT schedule and maximum throughput time for the radiologist's report.

We describe the different characteristics per patient group: inpatient, long term outpatient and urgent and short term outpatient (4.4.1). Next, we group requests with similar characteristics together into five different diagnostic tracks (4.4.2). We discuss these tracks and describe the implications for the quality of service and the organisation (4.4.3).

4.4.1 Characteristics of the diagnostic track per patient group

Patients with **inpatient requests** have to be treated with urgency, both in scheduling an appointment as reporting the examination. There is no differentiation in the two other factors, as patients are already in the hospital. The appointment time (current or next day) does not influence the times the patient visits the hospital.

For patients with **long term requests** there is no difference in times of visits between requests with or without need for preparation, as the examination is always scheduled after the day of request. Thus, for long term requests we distinguish two diagnostic tracks: (1) patients with a follow-up consult in person after the radiology examination and (2) patients with a follow-up consult by phone. For the first group it would be ideal to combine the radiology examination and discussion of the results on the same day. For the second group a consult by phone on the same or next day would be preferable.

For patients with **urgent and short term requests**, there are three different diagnostic tracks: (1) patients without need for preparation, (2) patients with need for preparation and a follow-up consult in person and (3) patients with need for preparation and a consult by phone. The first group can be scheduled as same day appointments, clustering the first outpatient consult and radiology examination. The other patients (2 and 3) have to be scheduled after the day of request, their preferences overlap with the two long term groups.

4.4.2 Diagnostic tracks reducing the number of visits

We group the diagnostic tracks described in Paragraph 4.4.1 into five tracks based on overlapping characteristics. Box 3 summarises these tracks and presents the size in percentage of total requests per patient group. The sizes of the tracks are estimates derived from our analysis of the diagnostic track (Paragraph 2.4.1).

Track 1 does not require any changes in the organisation, as it describes the current practice of inpatient requests.

Track 2 is the largest group: 52,14% of all CT requests. Implementation of this track in practice requires changes in the radiology and outpatient department. First, we have to allocate all slots in the morning (11 slots for 'urgent & short term' and 10 slots for 'long term') to accommodate all requests in Track 2. Second, the radiologist's have to report before the end of the morning with online dictation and the physician has to be available in the afternoon. Third, currently nearly 40% of the physicians do not have any afternoon consultation hours in the week. These physicians should perform an extra consultation hour or perform only these specific tracks in extra time ('reserve poli').

Track 3 includes 17,00% of all CT requests. Implementation of these tracks also requires changes in the radiology and outpatient department. First, the radiologist's report should be available in the afternoon of the next day, shorten the throughput time of the report further compared to the level proposed in Paragraph 6.3. Second, in the current situation, physicians perform consults by phone during their regular consultation hours. There should be more flexibility to schedule these consults by phone, to achieve the service levels described in Track 3.

Track 4 and Track 5 include 21,60% of all CT requests. If we want to accommodate all same day requests (max. 35% per patient group) and at the same time comply with our service levels for other diagnostic tracks, we need to increase the capacity of 'short term & urgent' slots or accept long waiting times for same day patients. We use our simulation model to calculate the minimum capacity increase. Using Approach 3B, we have to add at least 7 slots to the group 'short term & urgent'.

Box 3. Possible diagnostic tracks reducing patient visits

Track 1. Patients with inpatient requests (9,26%):
- Schedule CT scan with urgency
- Report CT scan available after maximum one working day

Track 2. Patients with urgent and short term requests with need for preparation and follow-up consult (27,56%) and patients with long term requests and follow-up consult (24,58%):
- CT scan in the morning
- Report CT scan available before the start of the afternoon consultation hours
- Discussion of the results with physician in the afternoon

Track 3. Patients with urgent and short term requests with need for preparation and consult by phone (8,71%) and patients with long term requests and consult by phone (8,29%):
- CT scan in the morning or afternoon
- Report CT scan available next day
- Discussion of the results with physician by phone on the next day

Track 4. Patients with urgent and short term requests without need for preparation and a follow-up consult in-person (11,07%):
- CT scan on same day as first outpatient consult
- Report CT scan available after two working days
- Discussion of the results with physician as soon as possible

Track 5. Patients with urgent and short term requests without need for preparation and a follow-up consult by phone (10,53%):
- CT scan on same day as first outpatient consult
- Report CT scan available next day
- Discussion of the results with physician by phone on the next day

4.4.3 Discussion and conclusion

The sizes of the different tracks presented above can be questioned as we base these sizes on the same data set as our analysis of the diagnostic track. Paragraph 2.4.1 describes that it is not possible to link all CT requests to a diagnostic track. Thus, we should interpret these figures with caution.

Track 2, Track 4 and Track 5 reduce the number of visits to the hospital where Track 1 and Track 3 do not. Track 1 is already current practice and although Track 3 does not reduce the number of visits, it does improve the quality of service by reducing the access time for the second outpatient consult (by phone).

The Ultrasound pilot (see Paragraph 5.3) shows that same day access requires more capacity than used in practice. Thus, if we implement Track 4 and Track 5 (same day CT scan) we have to add (same day access) capacity to the CT scanner schedule. Track 4 and Track 5 therefore lead to a decrease in the performance of the organisation (more idle time). Accommodating all same day requests will decrease our performance. However, we can provide part of the patients same day access by offering unused urgent, short term and long term slots as same day access slots.

Track 2 does not require extra capacity, but requires that we use our capacity in a different way. We have to schedule the CT scan together with the outpatient consult. This requires more effort and communication from radiology desk and outpatient desk but does not decrease the performance of the outpatient and radiology performance (idle time and overtime).

We recommend researching the possibilities to implement Track 2 (offering radiology examination on day of second outpatient consult) in practice using the same pilot methodology as we use in our research. Track 2 effects most of the patients and we expect that it will not effect the performance of either outpatient or radiology department. Successful implementation of the pilot requires collaboration and support of all stakeholders involved: radiology desk, outpatient desk, physicians and radiologists.

The radiology department can start the pilot in collaboration with the physicians performing consultation hours in the afternoon of the specialty requesting most of the CT requests (internal medicine). Next, we have to define a patient group; 'urgent & short term' requests are the most suitable because of the short planning window. If we use long term requests as basis for our pilot, we should run it for a couple of months before we can evaluate its effect.

5 Pilot same day access

As described in the introduction, the radiology department would like to implement the results of Gilles (2007). Gilles (2007) concludes that it is possible to implement same day access on the ultrasound modality. Implementing the results directly into practice requires many (cultural) changes in the organisation. Therefore, we start with a pilot of same day access on a specific weekday during two months. This pilot has two goals: (1) let the different stakeholders get experienced with same day appointments and (2) evaluate the practical implications of same day access.

Paragraph 5.1 analyses the patient flow to propose a weekday for the pilot and allocation of the same day access slots within the ultrasound schedule. Paragraph 5.2 describes the characteristics of the pilot and defines measurements and statements to evaluate the performance of the pilot. Paragraph 5.3 presents the performance of the measurements and evaluates the predefined statements. Paragraph 5.4 discusses the results of the pilot and proposes directions for the future.

5.1 Analysis

We use basic data analysis techniques to propose same day access slots for the pilot, because we cannot validate the simulation model of Gilles (2007), see Appendix C. The most important performance indicators in this analysis are the expected idle time of radiologists and the waiting time of the patient between arrival at the radiology department and examination.

For the pilot we select patients who can accept or reject a same day slot. Therefore, we use the following criteria: (1) outpatient requests, (2) regular ultrasound requests (no speed trail) and (3) requests with a planning horizon of less than 15 working days (exclude follow-up patients).

First, we determine the most suitable working day for the pilot, based on the arriving number of patients suitable for same day on this working day. Tuesday (1107) and Friday (1048) are most suitable in comparison with Monday (795), Wednesday (787) and Thursday (743). Because the radiology department requests to start with one weekday, we choose the weekday with the most requests: Tuesday. Second, we set a standard for the waiting time of the patient together with the radiology department. The waiting time of a patient for a same day slot should be less than 30 minutes. This is an assumption about the patient preferences and should be tested in practice.

We collect data about the number of patients (falling within our criteria set above) arrived between January 2007 and December 2007 from the Radiology Information System (RIS). Based on the assumption about the maximum waiting time of patients, we define time intervals of 30 minutes shifting every 10 minutes between 8:00 and 17:30 hour (e.g. 8:00 – 8:30, 8:10 – 8:40, 8:20 – 8:50 etc.). We calculate the utilisation of the time intervals using the percentage of weeks in 2007 where there arrived at least one patient during the time interval. We repeat this calculation to calculate the utilisation for at least two and at least three patients per time interval.

Figure 14 shows the calculated utilisation percentage per time interval. The three lines represent the idle time for respectively one, two and three number of same day access slots after the time interval. The first spot on the blue line shows that in 5% of the time (weeks) a same day access slot on 8:30 hour would be used. Because the time intervals are small (30 minutes), the probability that two or more patients are arriving (purple and yellow line always) is always less than 60%. Therefore, clustering of same day slots (2 or more) is not recommended.

Next, the radiology department determines a threshold for the utilisation of the same day slots. This threshold is set on 80%, taking into account holidays and other special days (showing a lower number of ultrasound requests). Table 16 shows the same day slots above the given threshold. Although, the slot "14.10 hour" is below the utilisation threshold, it is expected that the waiting time threshold of patients is higher around lunch time, so there will be in practice more than people applying for this slot. This leads in practice to a higher utilisation than 74,51%.

To evaluate the effect of this intervention on the throughput time of the diagnostic track of patients with ultrasound requests, we calculate the current throughput time. We gather, filter and match the data in the same way as with the CT scanner (see Paragraph 2.4.1). Table 17 presents the performance of the diagnostic track for two patient groups: urgent and short term requests.

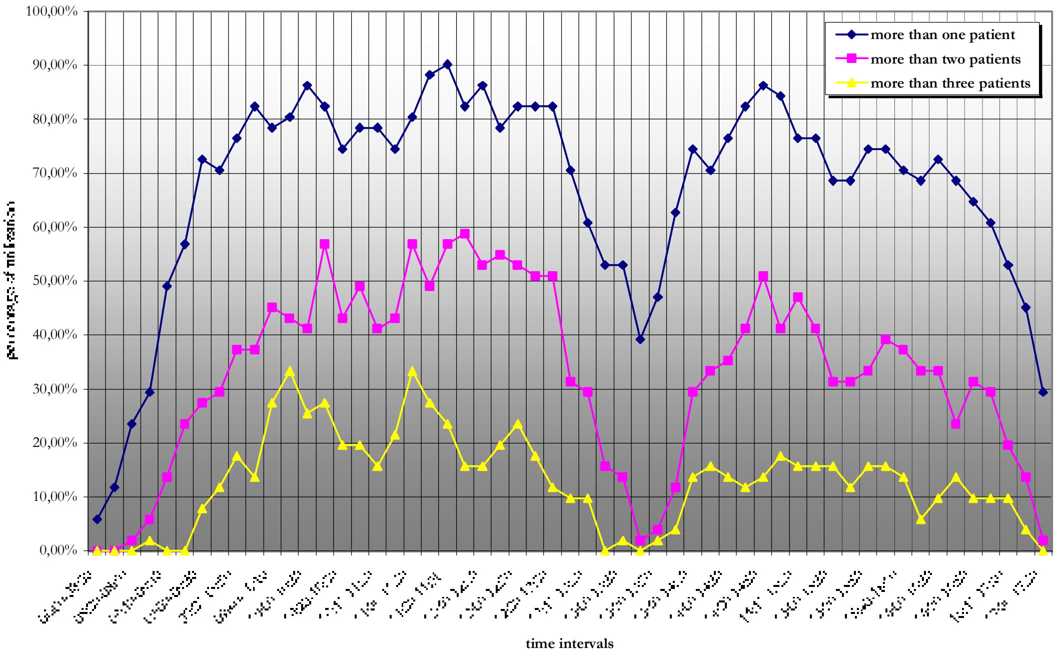

Figure 14. Expected utilisation per same day access slot based on a maximum waiting time of 30 minutes per patient presented for 1, 2 and 3 grouped slots

	same day slot	time interval	utilisation (%)
1.	10:00 hour	09:30 – 10:00 hour	82,35%
2.	10:30 hour	10:00 – 10:30 hour	86,27%
3.	11:40 hour	11:40 – 12:10 hour	88,24%
4.	12:10 hour	12:10 – 12:40 hour	86,27%
5.	12:50 hour	12:50 – 13:20 hour	82,35%
6.	14:10 hour	13:40 – 14:10 hour	74,51%
7.	14:50 hour	14:20 – 14:50 hour	86,27%

Table 16. Proposal for the allocation of same day slots in the ultrasound schedule on Tuesdays and the calculated performance in utilisation per same day slot

		access time ultrasound (A)		throughput time radiologist's report (B)		access time 2nd outpatient consult (C)		throughput time diagnostic track (D)	
	patients	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**	**average**	**stdev.**
urgent	393	1,57	1,42	0,53	0,98	4,13	2,26	5,70	2,48
short term	477	7,47	2,39	0,44	0,84	4,43	2,25	11,91	3,18
total	870	4,81	3,56	0,48	0,91	4,30	2,26	9,10	4,23

Table 17. Performance diagnostic track Ultrasound in working days (Data: 07-10-2007–31-03-2008)

5.2 Intervention: pilot for same day access

Together with the radiology department we make a choice for a subset of the proposed same day slots in Paragraph 5.1 (Table 16). We start a pilot with five same day access slots: 10:00 hour, 10:30 hour, 11:40 hour, 14:10 hour, and 14:50 hour. The average percentage of utilisation for the chosen slots is 83,53% (Table 16). The pilot runs for two months (Tuesday June 3, 2008 – July 29, 2008).

To measure the effects of our intervention – same day access for the ultrasound modality – we need patients who can accept or reject same day appointments. Inpatient and urgent patients fall outside this classification. The selection criteria for the same day slots are: (1) outpatient request, (2) short term request (within 3 weeks) and (3) no urgent request.

To evaluate the assumptions in our calculations and the performance of the pilot, we define the following hypotheses:

Hypothesis 1. *The percentage of utilisation is lower than the expected 83,53%*

Hypothesis 2. *Patients would like to wait longer than 30 minutes for a same day appointment*

Hypothesis 3. *The average throughput time of the diagnostic track is faster than the current average of 11,91 working days (see Table 17)*

We use the following measurements during the pilot to evaluate these hypotheses:

- Access time Ultrasound (normal slots)
  Measurement (working days): once per day measurement of the access time for other patients
- Waiting time same day patient
  Measurement (minutes): time between time of planning appointment at radiology desk (PLAN) and start time of ultrasound examination (START)

- Maximum acceptable waiting time for a same day appointment
  Measurement (minutes): question to patients with a same day appointment, maximum waiting time that is acceptable to them
- Occupational level of same day slots by preferred patients
  Measurement (percentage): number of slots filled with preferred patients / number of slots available
- Idle time radiologists
  Measurement (percentage): number of slots unfilled / number of slots available
- Throughput time diagnostic track
  Measurement (working days): time between ultrasound examination and second outpatient consult

We change the schedule for the ultrasound modality 2 months (June – July) in advance. The five same day slots are locked until the start of every Tuesday. The radiology desk determines at the start of every Tuesday the normal access time (without same day slots) for the patient group described above. Then the radiology desk registers the type of patient (no patient, preferred same day patient, other patient) for every same day slot during the day and asks what the maximum acceptable waiting time for the patient is for a same day appointment. If a patient rejects a same day appointment, the reason why is registered. Appendix H shows the evaluation form registered by the radiology desk during the pilot.

After two months, we derive the waiting time of the patients from the RIS and base the throughput time of the diagnostic track on data from EZIS. We use this data together with the registration forms filled in by the radiology desk to evaluate the statements and the performance of the pilot. We present the results of the pilot and discuss them with the radiologists, radiology desk and ultrasound assistants.

5.3 Results of the pilot

This paragraph presents the results of the pilot for same day access on the ultrasound modality. We present the results according to the measurements given in Paragraph 5.2. Next to the discussion of the quantitative results of the pilot, we discuss the experiences of the stakeholders (radiology desk, ultrasound assistants and radiologists). The results are based on a total number of 40 slots (8 weeks times 5 slots per week).

Table 18 and Table 19 present the performance for each measurement defined. Table 18 compares the utilisation of same day slots measured in the pilot with the percentage of utilisation calculated beforehand. The calculated average percentage of slots filled (83,53%) is higher than average measured in the pilot (82,50%). However, the actual difference is little: 1,03%. The difference between the two percentages for individual slots is larger, suspecting a flaw in the calculation of the expected percentage. Hypothesis 1 (percentage of utilisation is lower than 83,53%) is therefore rejected, although the difference in utilisation percentage between calculation and performance in the pilot is small.

		same day slots filled (%)	
	same day slot	**calculated utilisation**	**utilisation within pilot**
1.	10:00 hour	82,35%	50,00%
2.	10:30 hour	86,27%	62,50%
3.	11:40 hour	88,24%	100,00%
4.	14:10 hour	74,51%	100,00%
5.	14:50 hour	86,27%	100,00%
	average	*83,53%*	*82,50%*

Table 18. Percentage of same day slots filled in the pilot (based on 8 pilot days) compared to the percentage of same day slots filled calculated beforehand

Table 19 shows that patients accept to wait longer for a same day slot than currently expected. They accept to wait for at least 30 minutes, with an average of 1 hour and 33 minutes. In the pilot patients have waited on average longer than they suggested, on average 1 hour and 49 minutes. Especially patients living far from Amsterdam or needing assistance to come to the hospital, accept a long waiting time for a same day slot. Hypothesis 2 (patients would like to wait longer than 30 minutes for a same day appointment) is accepted; most of the patients accept to wait longer than 30 minutes with an average of 1 hour and 33 minutes.

	source	unit	average	stdev.	minimum value	maximum value
max. acceptable waiting time	evaluation form	hours/patient	1:33	1:08	0:30	5:00
waiting time 1 (PLAN-APP)	RIS	hours/patient	1:49	1:09	0:00	3:36
waiting time 2 (APP-START)	RIS	hours/patient	0:18	0:19	0:00	1:05
regular access time	evaluation form	working days	5,00	2,14	3,00	8,00
length diagnostic track	EZIS	working days	4,61	2,56	1,00	14,00
idle time radiologist	RIS	time/day	0:08	0:09	0:00	0:20

Table 19. Performance of measurements in pilot, given the data source, the measurement unit, the average, standard deviation, minimum and maximum of the measurement (n = 33)

As expected, same day access decreases the throughput time of the diagnostic track. Currently the length of the diagnostic track is 11,91 working days. Table 19 shows the average length of the diagnostic track measured in the pilot is 4,61 working days (stdev. 2,56). The reduction of 7,31 working days can be explained by the absence of access time for same day appointments. The average access time for other short term outpatient requests measured during the pilot is on average 5,00 working days (Table 19). Hypothesis 3 (average throughput time of the diagnostic track lower than 11,91 working days) is accepted; the average length is decreased by more than a week to an average of 4,61 working days.

In addition to the waiting time between arriving at the radiology desk (PLAN) and the planned appointment time (APP), the patient has to wait before the examination starts (START). Table 19 shows that on average people have to wait for 18 minutes in the waiting room. A large part of the patients (45,45%) has to wait for more than 15 minutes before the examination starts. The ultrasound assistants found this second waiting time was one of the most important disadvantages of same day access. For same day patients, it is more inconvenient if their examination starts after the planned appointment time than for other (non-same day) patients. Same day patients already waited a long time before their planned appointment time in comparison with other patients.

Another difficulty experienced by the assistants was that they could not anticipate on the types of ultrasounds examinations (neck, stomach etc.) arriving. An ultrasound neck can be performed at the same time with an ultrasound stomach in the other room, but not with another ultrasound neck. They suggested creating a clustered same-day hour ('walk-in'), without specific appointment times, but with a time window (between 11.30 and 12.30) for example. This way, some of the ultrasound examination can be combined.

Observing the patient flow, most patients with a same day request arrive between 11:00 and 13:00, the last two hours of the morning consultation hours in the outpatient department. This corresponds with the data in Table 18, low utilization in the morning (before 11:00) and high utilization after 11:00 hours. This makes it possible to cluster the same-day slots around these times.

The radiology desk stated that patients were generally enthusiastic about same day appointments and did not mind to wait for a couple of hours. The most important reason was that the patient could choose between waiting for a same day appointment or returning a couple of days later for a regular appointment.

To draw a conclusion on the results of the pilot, we summarise the evaluation of the hypotheses defined in Paragraph 5.1:

- **Hypothesis 1** – percentage of utilisation is lower than 83,53% – **is rejected**: the percentage of utilisation measured during the pilot was 82,50%;
- **Hypothesis 2** – patients accept to wait longer than 30 minutes for a same day appointment – **is accepted**: patients accept to wait on average for 1:33 hour;
- **Hypothesis 3** – average throughput time of the diagnostic track lower than 11,91 working days – **is accepted**: the average length of the diagnostic track for same day patients is 4,61 working days.

We conclude that the pilot is a success, as we gained more insight into the utilisation of same day slots, the acceptable waiting time for patients for same day slots and the effect of same day slots on the throughput time of the diagnostic track. For the organisation, there is a slight loss in efficiency (82,50% versus 95,00% utilisation rate) as not all same day access slots are filled.

For the patient, same day access has positive and negative effects on the quality of service. The positive effects are that same day access reduces the number of visits to the hospital and it shortens the total throughput time of the process (diagnostic track). The negative effect is found in the increased waiting time before the appointment. The reduction in throughput time of the diagnostic track shows that same day access is one of the possible solutions to obtain our research objective.

5.4 Discussion and conclusion

The utilisation of same day slots during the pilot was lower than calculated beforehand. It appears that we included patients with urgent as well as short term requests in our calculations for the percentage of utilisation. As urgent requests were not part of the pilot the number of requests suitable for the same day slots was lower than used in our calculations. If the number of requests is lower (because we exclude urgent requests) and the time interval (max. 30 minutes waiting time) is the same as used in our calculation, we expect to see a lower utilisation. However, the average utilisation of same day slots is not significantly lower than calculated (82,50% vs. 83,53%). This suggests that the maximum waiting time of patients (time interval) is larger than 30 minutes, which corresponds with our findings (on average 1 hour and 33 minutes). Concluding, the number of requests suitable for same day access is lower than calculated but patients are willing to wait longer than expected, leading to a utilisation percentage of 82,50%.

All same day slots in the afternoon (14:10 and 14:50 hour) were filled before 13:00 hour. This leads to two problems: patients always have to wait at least (1:10 hour) for an afternoon slot and patients arriving after this time were not able to obtain a same day slot. The first problem can be solved by moving the afternoon slots to an earlier time, for example, 13:00 and 13:10 hour. This solution is in line with the observation that these slots were all filled before 13:00 hour. This solution leads to the same percentage of utilisation and at the same time shorter waiting times for patients. The second problem can be solved by adding same day slots to the end of the afternoon to the ultrasound schedule. This solution should be tested in practice as we cannot predict the allocation and utilisation of these same day slots based on the pilot data.

The waiting time between the planned appointment time and the actual start of the appointment is an important success factor in the further implementation of same day access. We can solve this problem by giving patients with same day appointments urgency over other appointments. In this way we ensure that the appointments start around the planned appointment time. If this measure is fair to other patients is questionable. The best way to overcome this problem is to reduce waiting time for all patients, by starting on time and request assistance from other radiologists if the waiting time rises over a certain threshold level (for example 10 minutes). The radiology department is equipped with two ultrasound devices, which makes it possible to examine two patients at the same time with two radiologists and two assistants.

The ultrasound assistants suggest grouping capacity for same day and urgent patients on the end of the morning hours. First, the goal of same day access is to improve the service level for short term requests not for urgent patients (as this service level is already perceived as good). Grouping these two groups decreases the service level to patients with short term requests as urgent patients can take their place. Next, urgent requests are currently used to spread workload over the days and to level the number of requests over more and less experienced radiologists. Finally, if we allocate the same day slots at the end of the morning, we increase the waiting time for patients arriving early, between 10:00 and 11:00 hour. We conclude, based on these three reasons to continue excluding urgent requests from same day slots and not grouping the same day slots.

Most of the stakeholders are enthusiastic about the same day access pilot and suggest continuing and rolling out same day access slots to other weekdays. As the number of requests and available capacity vary over weekdays, we cannot use a standard number of same day slots every day. On Monday and Thursday mornings ultrasound capacity is dedicated to the 'one stop breast cancer clinic' and on Wednesday afternoon there are no radiologists available. Moreover, the number of requests is lower on other days than Tuesday. Therefore we have to develop different same day schedules for each weekday.

Table 20 presents a proposal for the number and allocation of same day slots per weekday. These slots are calculated analogous to the way described in Paragraph 5.1. This time we included solely urgent requests. We used a maximum waiting time of 90 minutes as time interval. We calculate the percentage of weeks in 2007 there arrived one or more patient for every time interval. Then, we select the same day slots performing above an utilisation rate of 80%. These slots are listed in Table 20.

Not all of the same day access slots are filled (on average ~ 85%). We need to compensate these slots otherwise the access time for other patients will increase (as we limit the capacity). We recommend adding 4 extra slots per week (15% idle time x 25 slots per week = 3,75 slots) to the ultrasound schedule.

Implementation of this schedule can be done using the same methodology as within our pilot. First, define the expected percentage of utilisation per weekday. Next, implement the schedule and monitor the average percentage of utilisation of same day slots per weekday during two months. If a weekday performs significantly worse than the level set beforehand, adapt the schedule by moving or removing same day slots. If the slots of a weekday are always utilised for 100 percent, try to add another same day slot, to further improve the service level offered to patients.

We conclude that the pilot was a success based on the reduced throughput time of the diagnostic track, reducing the number of visits to the hospital and the utilisation of the same day slots of more than 80%. Therefore, we recommend continuing to offer same day access for short term requests. To ensure success of 'same day access' the waiting time between planned and actual start of the examination should be reduced for all patients.

The allocation of same day slots in the ultrasound schedule used during the pilot should be altered, to lower the waiting time for patients. Roll out of same day access to other weekdays is possible, although we cannot use a uniform allocation of same day slots for every day. Every weekday has other characteristics and demand in number of requests, leading to a different number and allocation of same day slots per weekday.

		#	same day slots
Monday	morning	0	no same day access ('mamma-poli')
	afternoon	2	16:00 / 16:30
Tuesday	morning	5	10:40 / 11:40 / 12:30 / 12:40 / 12:50
	afternoon	3	15:30 / 16:00 / 16:30
Wednesday	morning	4	11:40 / 12:30 / 12:40 / 12:50
	afternoon	0	no same day access (no radiologist)
Thursday	morning	0	no same day access ('mamma-poli')
	afternoon	3	15:30 / 16:00 / 16:30
Friday	morning	5	10:40 / 11:40 / 12:30 / 12:40 / 12:50
	afternoon	3	15:30 / 16:00 / 16:30
Total number of same day slots		25	

Table 20. Proposal same day schedule based on RIS 2007

6 Implementation

In the previous chapters, we have analysed the process of the diagnostic track, measured its performance and found ways to decrease the throughput time of the track. We calculated the effect of different approaches in service levels for patients and CT scanner capacity allocation on organisational performance. Together with the analysis, we have successfully piloted 'same day access' on the ultrasound modality. This chapter uses these findings and approaches to propose implementation of changes in the organisation to achieve the goal of our research: *decrease the throughput time of the diagnostic track for all patients and translate these throughput times into service levels.*

We recommend in Chapter 4 using Approach 3B for the allocation and scheduling of capacity of the CT scanner as it delivers the best service level to the patient and the organisation. Approach 3B groups urgent and short term requests and reduces the throughput time of the radiologist's report to one day. Approach 3B is the basis for the implementation steps described in this chapter, but it can also be applied to Approach 3A and Approach 2. Where there is difference in implementation of an approach we provide the details for each specific approach.

First, we describe changes needed in the organisation to lower the throughput time of the diagnostic track. Chapter 2 concludes that to achieve a fast throughput time, we have to decrease the access time of the CT scanner and the throughput time of the radiologist's report. To lower the access time, we need to remove fluctuation in the level of available capacity (6.1) and change the schedule and scheduling methodology for the CT scanner (6.2). The required changes in the organisation to decrease the throughput time of the radiologist's report (6.3) are based on the analysis described in Paragraph 2.6.

Second, we describe the way we can control the defined service levels. These levels have to be controlled within the radiology department (6.4). As CT scans are requested by another department, we have to be able to control the service levels on an interdepartmental level as well. We propose using a service level agreement between the radiology department and the outpatient department (6.5). Third, based on this service level agreement we suggest changes to the current planning process of the diagnostic track described in Paragraph 2.1 and 2.2 (6.6).

After successful implementation of steps described above, the radiology department can further increase their service levels by reducing the number of visits to the hospital for patients. Paragraph 6.7 describes the different diagnostic tracks that can be distinguished to cluster as much of the outpatient and radiology appointments on the same day. It also describes the changes needed to implement these tracks.

This chapter ends with a discussion about the implications of our recommended approach and the corresponding implementation steps (6.7).

6.1 Remove fluctuation in available capacity

The model and approaches described in Chapter 4 are based on the availability of a constant capacity. Of course, in practice it is never possible to guarantee a constant capacity due to unforeseeable events, such as unexpected maintenance. However, in the current situation there are foreseeable circumstances that influence the capacity on weekly basis, these are: staff meetings, maintenance and other factors (e.g. personnel). For example, every four weeks there is a planned maintenance window of 2 hours on the CT scanners performed by the radiotherapy department (from 12:00 – 14:00). This loss in capacity is not compensated by offering extra slots in overtime on that day or other days.

In our simulation model we assumed that there is no maintenance needed, however, this is not in accordance with current practice. To calculate the effect of maintenance on the performance, we include monthly (2 hours) and yearly maintenance (2 working days) in our model. Table 21 shows the effect on organisational performance of two different approaches: Approach 3.1 represents the situation where maintenance is excluded (as in Chapter 4); Approach 3.2 represents the situation with maintenance included.

The model complies with the maximum access times set for Approach 3 (maximum of 2 working days for urgent and short term requests). Therefore, as there is no (more) regular capacity available due to maintenance, it schedules requests in overtime. This effect can be seen by the increase in average (11,41 to 15,51 minutes) and standard deviation (23,81 to 31,38 minutes) of overtime from Approach 3.1 to Approach 3.2 in Table 21.

	idle time			overtime			opening hours		
	mean	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*
Approach 3.1	20,05	29,71	-38,18-78,28	11,41	23,81	-35,26-58,08	425,74	40,92	345,54-505,93
Approach 3.2	15,75	31,04	-45,10-76,60	15,51	31,38	-46,00-77,02	431,44	46,24	340,80-522,08

Table 21. Performance of approaches without (3.1) or with (3.2) maintenance included (idle time, overtime and opening hours) in minutes per day

We conclude that if we do not compensate outage of capacity due to maintenance and at the same time introduce service levels for maximum throughput time, the average and variation of overtime and opening hours will substantially increase. We recommend compensating the maintenance as much as possible to reduce the average and variation of overtime.

To achieve a low variation in the available capacity, there are three solutions: (1) schedule regular maintenance and staff meetings outside opening hours, (2) use other CT scanner while CT scanner is under maintenance and (3) allocate overtime capacity and schedule extra personnel to compensate unavailable regular slots.

The first solution prevents the need for other solutions, as maintenance and meetings do not longer lead to unavailable capacity. Unfortunately, this solution is not always possible in practice: unexpected maintenance, maintenance personnel is not available after opening hours and some maintenance windows last longer than a couple of hours. Moreover, maintenance in evenings or weekends is more expensive than during working hours.

The second solution requires collaboration with other departments owning a CT scanner: nuclear medicine and radiotherapy department. In the current situation there is already collaboration between the radiology and nuclear medicine department. This collaboration focuses on structural capacity alignment, for example the radiology department can use the nuclear medicine CT scanner (PTCT06) every working day from 16:00 hour. However, they could focus the collaboration more on an incidental basis, for example to compensate scheduled maintenance. In this way, personnel can be scheduled during regular working hours, decreasing the need to schedule requests in (costly) overtime.

The third solution, allocating overtime, requires action from the assistants' team leader (scheduling extra personnel) as well as from the radiology desk (scheduling requests in overtime). Allocation of overtime in the current Radiology Information System is time consuming; a new schedule for the whole CT scanner needs to be designed and applied to a specific week. Instead, the head of the radiology desk and the team leader could decide together which extra time windows are used to schedule the requests. The question: *"how can we allocate overtime so we can comply with the service levels set for all patients?"* should be leading in this decision.

To illustrate the last two solutions we give an example. In a certain week we schedule a whole day of maintenance for our main CT scanner (CT04) on Wednesday. Figure 15 shows a possible solution to compensate the capacity outage on Wednesday: blue represents normal capacity, red represents unavailable capacity and green represents extra capacity. On Wednesday we schedule inpatient and urgent outpatient starting at 16:00 hour on the CT scanner of nuclear medicine (PTCT06). If we open this CT scanner from 16:00 – 19:00 hour we compensate a large part (3,0 of the 7,5 hours) of the capacity outage. The rest of the compensation is spread over the days before and after the day of maintenance. In this way, we are able to comply with our service levels and we can schedule personnel and patients in a regular way.

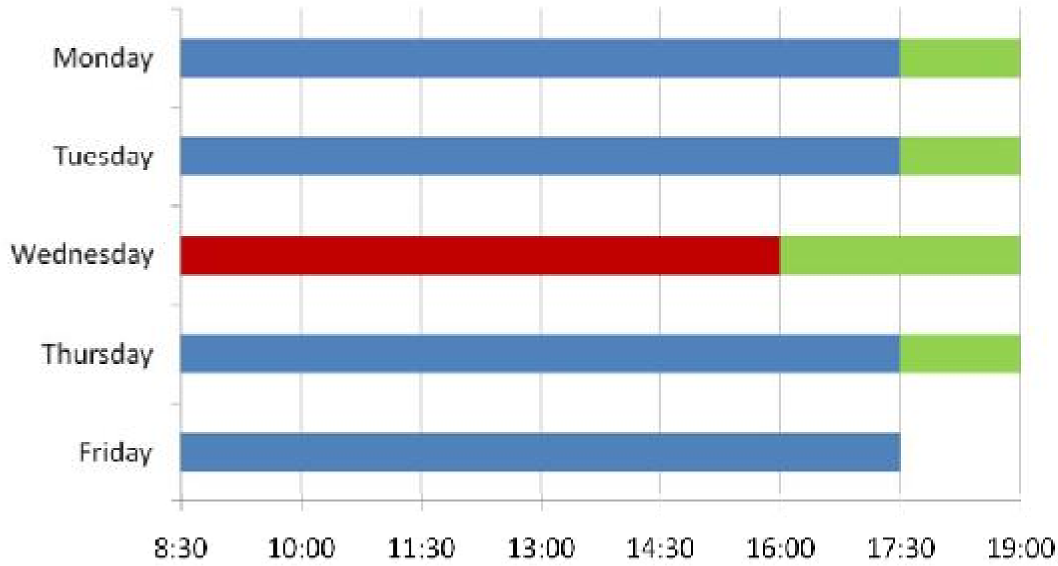

Figure 15. Possible solution to compensate capacity downtime

This example also makes it possible to calculate the effect of closing the CT scanner for one day. We can compare the extra costs for personnel (after 18:00 hour) with, for example, the extra costs for maintenance during the weekend.

We recommend anticipating on (scheduled) capacity outings beforehand. This way the need for unexpected overtime is reduced. We recommend focusing on the first two given solutions as they do not generate extra costs due to overtime.

6.2 Change the schedule and scheduling methodology

The current schedule for the CT scanner has regular slots for short term and long term requests and emergency slots for inpatient and urgent requests. Based on our analysis and simulation modelling we recommend allocating slots for three different groups (Approach 3B): inpatient slots, urgent and short term slots and long term slots.

Table 22 presents the number of slots per day and the planning window per patient group. The number of slots presented is derived from the number of slots calculated by the simulation model for each approach (Paragraph 4.1). Based on the model validation (Paragraph 4.3), we increase the number of long term slots to 18, because we are not sure about the number of long term requests per day. We calculate the number of slots (18 slots) by adding the average number of long term requests per day (13 slots) to the size of the maximum number of long term requests incorrectly labelled as 'short term' (5 slots).

Adding 5 slots to the capacity for long term requests, we also create an overcapacity of 5 slots in total, leading to extra idle time. After two months, we are able to determine the actual sizes of the outpatient long term patient group, by analysing the idle time per slot group. This allows us to remove this overcapacity from either the capacity for long term slots or short term slots.

	Approach 3B		Approach 3A		Approach 2	
	slots	**planning window**	**slots**	**planning window**	**slots**	**planning window**
inpatient	4 slots	0-1 working days	4 slots	0-1 working days	4 slots	0-1 working days
outpatient: urgent	24 slots	**0-3** working days	24 slots	**0-2** working days	8 slots	0-2 working days
outpatient: short term					16 slots	0-7 working days
outpatient: long term	18 slots	not applicable	18 slots	not applicable	18 slots	not applicable

Table 22. Proposal for the number of slots and planning window per patient group per day for Approach 3B, 3A and 2

To develop an actual schedule for the CT scanner there are several conditions we need to take into account. First, as there are differences in the number of slots needed per type of examination (1, 2 or 4 slots), we cannot create a schedule where we alter the type of slot every 10 minutes (for example, 8:30 urgent slot, 8:40 inpatient slot, 8:50 long term slot). Second, we would like to offer all patients with outpatient requests an appointment in the morning or in the afternoon (current practice). Third, inpatient request have to be scheduled before 16:00 hour and after the end of the morning (as the most same day requests arrive during the morning).

Figure 16 shows a proposal for a new CT schedule based on Approach 3B. We cluster the slots per patient group in groups of 3, 4, 6 and 9 slots (Condition 1). We offer both patients urgent & short term and long term requests slots in the morning and afternoon (Condition 2). We allocate the inpatient slots between 14:00 and 14:40 hour (Condition 3).

Important in the usage of the schedule is to fill up the blocks of slots from left to right. For example, if there are already patients scheduled between 8:30 and 9:00 hour, schedule the next patient at 9:00 hour and not on 9:20 as it creates a gap in the schedule. These gaps lead to scheduling inflexibility, as we cannot schedule all types of examinations into a gap of one or two slots (see Condition 1).

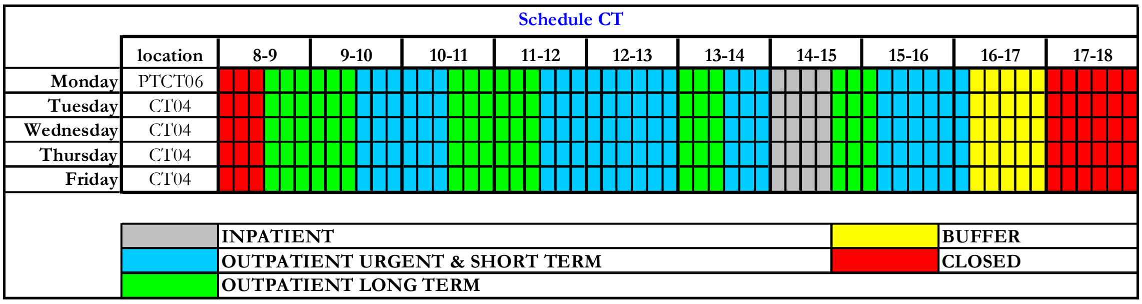

Figure 16. Proposal for new CT schedule based on Approach 3B

As a second aspect of the implementation of the new schedule we need to ensure the current scheduled appointment (the backlog) are incorporated into the new schedule. We reduce the backlog of patients with short term requests to the point were we can offer an access time of one day less than the maximum, at which point we can implement the new schedule. In this way we do not start with 'a full system' where we are unable to spread new requests over the coming days. For example, if the service level for the access time short term requests is set on a maximum of 2 working days, we reduce the backlog of requests to an access time of 1 working day. We reduce the backlog by planning short term requests in overtime slots in the current planning ('yellow slots'). After the removal of the backlog of short term requests, patients with long term CT requests have to be rescheduled. They have to be transferred from the current regular slots ('green slots') to their new dedicated capacity.

6.3 Decrease throughput time radiologist's report

To implement Approach 3B we have to reduce the throughput time of the radiologist's report to a maximum of one working day. This means that if an examination takes place today, the radiologist's report is available at the end of the following working day. Based on preliminary results of our analysis the decision was already taken by the radiologists to adjust the service level for the throughput time of the radiologist's report from a maximum of one week (4 working days) to a maximum of two working days. This service level is appropriate for the implementation Approach 2 and 3A, but not for Approach 3B. Therefore, we need to make changes in the dictation process to achieve a service level of one day.

The changes are based on the analysis described in Paragraph 2.6. The first change, assistants who have to report an (head-neck) examination should report on the day after the examination and be able to discuss their report on that day with their supervisor. Second, typists have to type out the dictation within a couple of hours after dictation or all radiologists have to switch to on-line dictation. Third, radiologists should report the examinations of the day before in the morning; discuss difficult reports with other radiologists or physicians during lunch time and correct and authorise the report during the day. Especially the last change requires a lot of discipline from the radiologists and should be assisted with a control mechanism to ensure the report is available on time.

One of possible control mechanisms is to let someone from the radiology department check at the end of every day (for example around 17:00 hour) if there is a final report available for all examinations performed one day before. If there are reports missing they should report their findings to the responsible radiologist in time for appropriate action.

6.4 Control of service levels and capacity

After the implementation of the changes in capacity management, CT schedule and radiologist's report needed to achieve the recommended service levels, we have to control these service levels. First, we need someone within the radiology department who is responsible to measure, control and evaluate the service levels and the usage and availability of CT capacity. This person should initiate the analyses and evaluations described below.

To evaluate the changes in capacity management, we record the number of times capacity is (partially) unavailable, the reason why it was not available (e.g. unexpected maintenance, staff meeting), how many slots were affected and if service levels were breached or which measures were taken to ensure the service levels. This information gives insight into the percentage of capacity unavailable per week or month and the way these outings are handled. These findings can be discussed with the relevant persons: radiology desk and team leaders.

To analyse the capacity usage and availability of the CT scanner, we monitor the same measurements used in our model: idle time and overtime for each patient group. At least one month of data should be used to analyse the effect of the implementation and to evaluate the allocation of slots over the different patient groups. As basis for this evaluation we use the values generated by the model for idle time and overtime presented in Paragraph 4.2.1 (Table 11).

For example, if the short term slots generate a lot more idle time than found in Table 11 and at the same time long term slots generate a lot of overtime, we can decide to exchange slots between the two patient groups. Next to the exchange of slots we should be able to reduce up to five slots (in short term or long term slots), as these were added to the number of 'long term' slots in Paragraph 6.4 as overcapacity to correct an error in the calculation of these slots.

To evaluate the changes in throughput time of the radiologist's report we monitor the percentage of reports available after the maximum throughput time and discuss these findings with the head radiologist on a weekly or monthly basis.

Before we can analyse the indicators described above, we have to develop reports containing the performance of the measurements described above (idle time, overtime, capacity outings) extracted from RIS.

6.5 Service level agreement

The radiology department is concerned that a decrease in access times will lead to an increase in the number of requests from physicians as results are available within a short time. Lower throughput times lead to a lower threshold to request a CT examination. The best way to overcome this concern is to create a service level agreement between the radiology department and the outpatient department.

This agreement should specify the service levels for radiology examinations: maximum access time per patient group and the maximum throughput time of the radiologist's report per patient group. These service levels cannot be guaranteed for an unlimited number of requests. Thus, the service level agreement should include the limits in number of requests per patient group per month. As the requests fluctuate the maximum number of requests per month should be given as well as the average number of requests (on a yearly basis). It should also include the expected percentage of growth in patient volume.

The actual number of requests per specialty should be monitored by the radiology department and reported back to the physicians. Reporting and discussion of the results should be done in a structural way, for example in a monthly or bimonthly meeting between the radiology and outpatient department. On a yearly basis the service level agreement and costs implications should be reviewed, discussed with the stakeholders, adapted to the new situation and finally renewed. This process should be initiated by the radiology department.

6.6 Adapt diagnostic track planning process

After the implementation of service levels for the throughput time of the diagnostic track, we can alter the planning process of the diagnostic track. In the current situation the second outpatient consult is scheduled after the scheduling of the radiology examination for urgent and short term requests, as the assistant at the outpatient desk does not have up-to-date information about the access time for the CT scanner. In the new situation, the outpatient desk can schedule the second outpatient consult before the scheduling of the radiology examination. The outpatient desk schedules the second consult over at least the maximum throughput time of the diagnostic track of the relevant patient group (for example after 5 working days).

The radiology desk on their turn should always follow the service levels for the maximum access time, although, a patient can always request to schedule an examination after the maximum access time. If it is not possible to schedule a patient in regular or overtime slots within the maximum access time, the radiology desk has to contact the person responsible for service levels (mentioned before) to discuss the matter. This person has to decide what action should be taken and if it is not possible to comply with the service level and whether or not this should be communicated with the outpatient department.

This change in the scheduling process makes it more 'lean' for the patient, as it removes one step: walking back from the radiology desk to the outpatient desk, to schedule the second outpatient consult. In the new situation the patient can schedule the second outpatient consult directly at the outpatient desk after the physician requested the radiology examination.

To improve the communication between the outpatient department and the radiology department, we recommend changing the radiology examination request form filled in by the physician. Adding a field to the form that describes when the radiology report has to be available (date and time). Based on this field and the service level for throughput time of the radiologist's report the radiology desk knows when they have to schedule the examination.

6.7 Discussion and conclusion

We propose a radical change in the scheduling of CT requests: all urgent and short term requests are examined and reported within one week. This change improves the service level to patients and the outpatient department. However, before we can start with the offering of these service levels, we have to be sure we have enough resources and capacity to deliver these levels for all patients.

During the study, the PACS system containing all CT scan images was not available for a couple of days. Without these images radiologists are unable to report the performed CT examination. There was an alternative for inpatient and emergency requests available, but this solution could not be used for the rest of the requests. In the current situation, there is enough time to fix the problem before the report has to be available (four working days). However, in our proposed situation, this time is much shorter (one or two working days). Thus, with our proposal we increase the risk that a problem within the diagnostic track leads to a major impact on other processes.

For situations as described above the involved departments need to agree beforehand about the appropriate actions to take when these situations occur. Moreover, as described in Chapter 6 it has to be clear who is responsible in these (kind of) situations to decide which actions need to be taken. The same accounts for management of the available capacity, one person need to be responsible to ensure that there is enough capacity available to comply with our service levels.

Finally, we underline that it is important that before we implement the new CT schedule and scheduling method we make changes in the organisation (capacity management), settle agreements about service levels, inform all stakeholders (physicians, radiologist, radiology desk and outpatient desk personnel) and ensure we are able to deliver the service levels.

7 Conclusion and recommendations

This chapter describes the main conclusions of our study based on our research questions (7.1). Paragraph 7.2 present practical recommendations and recommendations for future work.

7.1 Conclusion

The central research question of our research is:

> *How can we improve the throughput time of the diagnostic track (the outpatient visit with the radiology request(s), the radiology examination(s) and the outpatient visit to discuss the results) by aligning capacities and improving the planning method of the outpatient and radiology department?*

Answering the research questions formulated in Paragraph 1.3 we present the conclusions of our research below.

What is the process description of the diagnostic track, its control and its current performance?

The analysis of the diagnostic track, described in Chapter 2 focuses on the urgent and short term outpatient requests for the CT scanner. The current average throughput time of the diagnostic track for urgent requests is 6,96 working days and for short term requests 16,90 working days. The throughput time of the diagnostic track is influenced by three factors: access time for the CT scanner, throughput time of the radiologist's report and access time for the second outpatient consult.

What are the factors that influence the throughput time of the diagnostic track?

The answer to this question is different for the two patient groups we have distinguished (urgent and short term). The most important factor influencing the throughput time of the diagnostic track for urgent requests is the access time for the second outpatient consult (70,40% of the throughput time). For short term requests this factor is the access time of the CT scanner (72,66% of the throughput time).

The access time for the second outpatient consult is based on the service level for the throughput time of the radiologist's report (currently 4 working days) and the number of consultation hours per physician. As the last factor is difficult to analyse and improve, we focus on the first factor: improving the service level for the throughput time of the radiologist's report.

The access time of the CT scanner for short term requests is based on the availability of capacity for these requests. The availability of capacity is influenced by two factors: (1) non-available capacity due to maintenance and staff meetings and (2) the dedication of the capacity. The first factor shows a problem in the current capacity management. The second factor describes a problem in the allocation of slots per patient group. In the current situation, long term and short term requests make use of the same capacity. Therefore, long term requests (scheduled before short term requests) influence the remaining capacity and access time for short term requests.

What are suitable approaches to improve the throughput time?

First, we removed the influence of long term requests on the access time of short term requests, by dedicating separate capacity (slots) for these two groups. Next, in line with our goal to improve the throughput time of the diagnostic track, we developed four approaches which represent different service levels for the throughput time of urgent and short term requests.

Current represents the situation in 2007 without separated slots for long term requests.
Approach 1 represents the current situation including the separated slots for long term requests discussed above. This approach is used to compare other approaches with the current performance of the organisation.
Approach 2 represents the situation where the throughput time of diagnostic track is one week maximum for urgent requests and two weeks maximum for short term requests.
Approach 3 represents the situation where the throughput time of diagnostic track is one week maximum for both urgent and short term requests.
Approach 4 represents the situation where the access time for urgent and short term requests is one working day maximum.

To evaluate the effect of the throughput time of the radiologist's report we define three sub-approaches for each approach which differ in the maximum length of this throughput time: (A) maximum of two working days, (B) maximum of one working day, (C) maximum of zero working days (same day reporting).
Finally, we built a simulation model to test the effect of the four approaches on the organisational performance of the CT scanner process. The performance measurements used for evaluation are:

idle time, overtime and opening hours per working day. We calculated the average, standard deviation and 95% confidence interval for these measurements.

What are the computational effects for the different approaches?

Table 23 shows the computational results for the measurements described above. Comparing Approach 1 with the current situation, we observe a decrease in variation for all measurements. This suggests allocating long term slots improves the organisational performance.

Both Approach 2 and Approach 3 improve the service level for patients as well as the efficiency of the organisation. Approach 1 is not improving the service level for patients and Approach 4 does not increase the efficiency of the organisation.

From an organisation perspective we favour Approach 2 as it performs best on all (organisational) performance measurements: idle time, overtime and opening hours. This means this is the most cost-effective approach, as idle time and overtime generate (extra) personnel costs.

From a patient perspective we favour Approach 3 as it has the best service levels of the four approaches. The organisational performance is not the same as with Approach 2, but the approach does not perform poorly. Averages of the performance measurements increase at most 1,13 minutes (overtime) per day, standard deviations increases at most 6,32 minutes (opening hours).

	idle time			overtime			opening hours		
	mean	*stdev*	*conf. interval*	*mean*	*stdev*	*conf. interval*	*mean*	*Stdev*	*conf. interval*
Current	21,10	53,14	-83,05-125,26	38,35	35,67	-31,57-108,26	421,378	83,93	236,88-565,88
Approach 1	14,05	29,01	-42.81-70.91	45,40	32,13	-17,57-108,37	424,64	38,13	327,74-501,54
Approach 2	19,17	23,09	-26,10-64,43	10,28	19,77	-28,48-49,03	425,18	34,60	357,37-492,99
Approach 3	20,05	29,71	-38,18-78,28	11,41	23,81	-35,26-58,08	425,74	40,92	345,54-505,93
Approach 3B	17,84	28,00	-37,03-72,71	9,12	19,53	-29,15-47,40	424,52	36,18	353,60-495,44
Approach 4	28,74	34,30	-38,49-95,98	30,16	44,18	-56,44-116,75	429,98	65,52	281,56-538,41

Table 23. Performance of approaches (idle time, overtime and opening hours) in minutes per day

To recommend one of the two approaches, we have to balance the improvements in service levels with improvements in organisational performance. The improvement in service level in Approach 3 compared to Approach 2 is large (throughput time for two weeks to one week for short term requests) as the improvement in organisational performance in Approach 2 compared to Approach 3 is small (improvement of several minutes in averages and variation). Thus, Approach 3 is favoured over Approach 2.

Moreover, it is possible to increase the performance of Approach 3 by lowering the throughput time of the radiologist's report from a maximum of two working days to a maximum of one working day (Approach 3B). As the increase in performance is not radical (improvement of several minutes in variation), implementation of this reduction in throughput time is only justified if it does not lead to a significance increase in workload of radiologists.

We recommend setting the throughput time of the diagnostic track for urgent and short term outpatient requests at a maximum of one week (Approach 3). The most important advantage is the large improvement in quality of service for patients with urgent and short term requests. If it is possible, we recommend lowering the throughput time of the radiologist's report to a maximum of one working day.

What are the required steps to implement the suggested approach?

Before we can implement the suggested service levels, we have to make sure that we have enough capacity available at all times to comply with these levels. In the current situation, there is a lot of fluctuation in the level of available capacity. To reduce this fluctuation we propose three possible solutions: (1) schedule regular maintenance and staff meetings outside opening hours, (2) use other CT scanner while CT scanner is under maintenance and (3) allocate overtime capacity and schedule extra personnel to compensate unavailable regular slots. The first two solutions are preferable as they do not generate extra (overtime) costs.

After we have ensured we can offer the service levels, we have to implement the service levels for the access time of the CT scanner and the throughput time of the radiologist's report. The access time of the CT scanner is reduced by assigning slots for three different groups: (1) inpatient requests (scheduled today and tomorrow), (2) urgent and short term requests (scheduled within two working days) and (3) long term requests (scheduled after more than 3 weeks).

To control the service levels defined and the usage of capacity, we have to make someone from the radiology department responsible. This person should check if service levels are breached and if so, what action has to be taken. He or she should also check if there are enough slots available for every patient group.

To ensure that the improvement in quality of service is not misused by physicians we recommend formulating a service level agreement between the radiology department and the physician. This agreement can be used to set service levels and number of requests per year for which the radiology department is able to guarantee these levels. This improves the communication and discussion of service levels between the two departments.

If one month after implementation the service levels are offered to all patients, we can change the planning process of the diagnostic track in the outpatient department. With these service levels the outpatient desk can schedule the second outpatient consult before the scheduling of the radiology examination. This improvement reduces one step for the patient (walking back from the radiology to the outpatient desk).

We **conclude** that if all recommendations and changes described above are implemented, we can offer all patients with urgent and short term CT requests a throughput time of a maximum of one week. Moreover, then we accomplish the goal of our research: *decrease the throughput time of the diagnostic track for all patients and translate these throughput times into service levels.*

The same day access pilot on the ultrasound modality showed that implementation of same day access in practice is possible. The pilot was received with enthusiasm by both patients as well as a large part of the radiology department. The most important problem experienced by patients and assistants during the pilot were the large waiting times between the planned appointment time and the actual start of the examination (on average 18 minutes).

We recommend rolling out same day access on the ultrasound modality to all weekdays, taking differences in capacity and demand per weekday into account. At the same time, the waiting time between the planned and actual start of an appointment should be reduced for all patients. This waiting time is one of the success factors for the implementation of same day access.

7.2 Recommendations

We start with a translation of our conclusions into recommendations for the other modalities (7.2.1). We give practical recommendations based on our analysis and observations made during the study (7.2.2). Based on this study we also propose future work (7.2.3).

7.2.1 Recommendations for other modalities

In our research we have analysed the patient flows and schedule of the CT scanner and the Ultrasound modality. Findings from these analysis, simulation model and pilot can be applied to other modalities as well.

The most important conclusion in our research is that we can substantially reduce throughput time of the diagnostic track by changing division and dedication of schedule capacity over the patient groups, improving maintenance management and defining service levels for maximum throughput times for the examination and the radiologist's report.

To reduce the access time for a modality, we have to alter the way we schedule our capacity. In the current situation, patients with different urgency levels (long term and short term) are scheduled in the same capacity. We have to separate these capacities and allocate capacity for all patient groups or set of patient groups.

Service levels are maximum throughput time of the whole track (examination and report) and based on the maximum access time for a modality and the maximum throughput time of the radiologist's report. These levels improve the quality of service for patients and improve the communication with other departments. They also create the possibility to change interdepartmental processes like the diagnostic track.

To offer same day access on other modalities we can use simple data analysis techniques to calculate the fluctuation in patient flow over the day and week. With this analysis we can determine the allocation of same day slots over the week. We have to accept a certain decrease in efficiency (10-20%) for same day slots, which is compensated by the increase in patient satisfaction. Another important success factor of same day access is the waiting time between the planned start and actual start of the examination. This waiting time should be as low as possible (under 10 minutes).

7.2.2 Practical recommendations

Integrate information systems to be able to integrate processes with departmental boundaries (e.g. diagnostic tracks) for the patient. In the current situation, the radiology information system (RIS) and the hospital information system (EZIS) are not linked. It is not possible to schedule a radiology examination within EZIS.

Patients have to schedule their outpatient consults at the outpatient desk and their radiology examination at the radiology desk. A more patient-centred approach would be to integrate these scheduling steps into a process at one of the two desks (preferable the outpatient desk). At the same time, this would be more efficient for the organisation as well as we would not have to staff two different desks.

Reduce the number of visits, by clustering outpatient consults and radiology examinations and offering same day access. In a situation where the outpatient and radiology schedule are part of the same information system, it would be possible to implement this clustering functionality into the information system. This leads to a patient-centred process of appointment scheduling. At the same time it leads to organisational efficiency, the effort required to schedule (and eventually reschedule or cancel) the different appointments is limited to one action of the outpatient desk.

Improve the use of management information from the radiology information system by enabling the generation of more (detailed) reports in the management modules of RIS than in the current situation. For example, it is currently not possible to generate an overview of the number of slots requested per patient or research group over the previous weeks. Extra reports can be used to monitor the availability and use of capacity, waiting times, access times and other performance measures presented in this thesis. Next to monitoring, these reports could also be used for example to discuss request behaviour of physicians.

Improvements in registration of the starting and ending of radiology examinations are needed to ensure valid management information. In the current situation more than 15% of the actual durations of examinations are erroneously registered (less than 5 minutes or more than 29 minutes registered for a 10 minutes slot on the CT scanner). There is also an issue with the RIS itself: if the status of a patient is changed back to 'appointment' (AFSPR) after it is set to 'present' (AANWZ) or 'start of examination' (START), the date of scheduling (PLAN) changes to the current date and time. This leads to incorrect information about the access time of the request.

7.2.3 Recommendations for future work

One of the goals of this thesis is to improve patient satisfaction. However, as Gilles (2007) mentions as well, we currently do not have enough insight in patient preferences. Do patients prefer a short diagnostic track, same day access or low waiting times? What is the opinion of the patient about the current planning process of the diagnostic track at two different desks? We recommend questioning patients about their preferences and link the findings to quality of service improvement projects.

There is also future work at an interdepartmental level, as we described in Paragraph 4.4 we could improve the quality of service further by lowering the number of visits to the hospital for patients. Lowering these visits is possible through collaboration and capacity alignment between the outpatient department and the radiology department.

Finally, the diagnostic track is part of a much larger patient track, which can include surgery, chemotherapy and/or radiotherapy. We recommend researching the rest of the tracks as well to ensure that optimising the diagnostic track does not lead to sub-optimised hospital processes.

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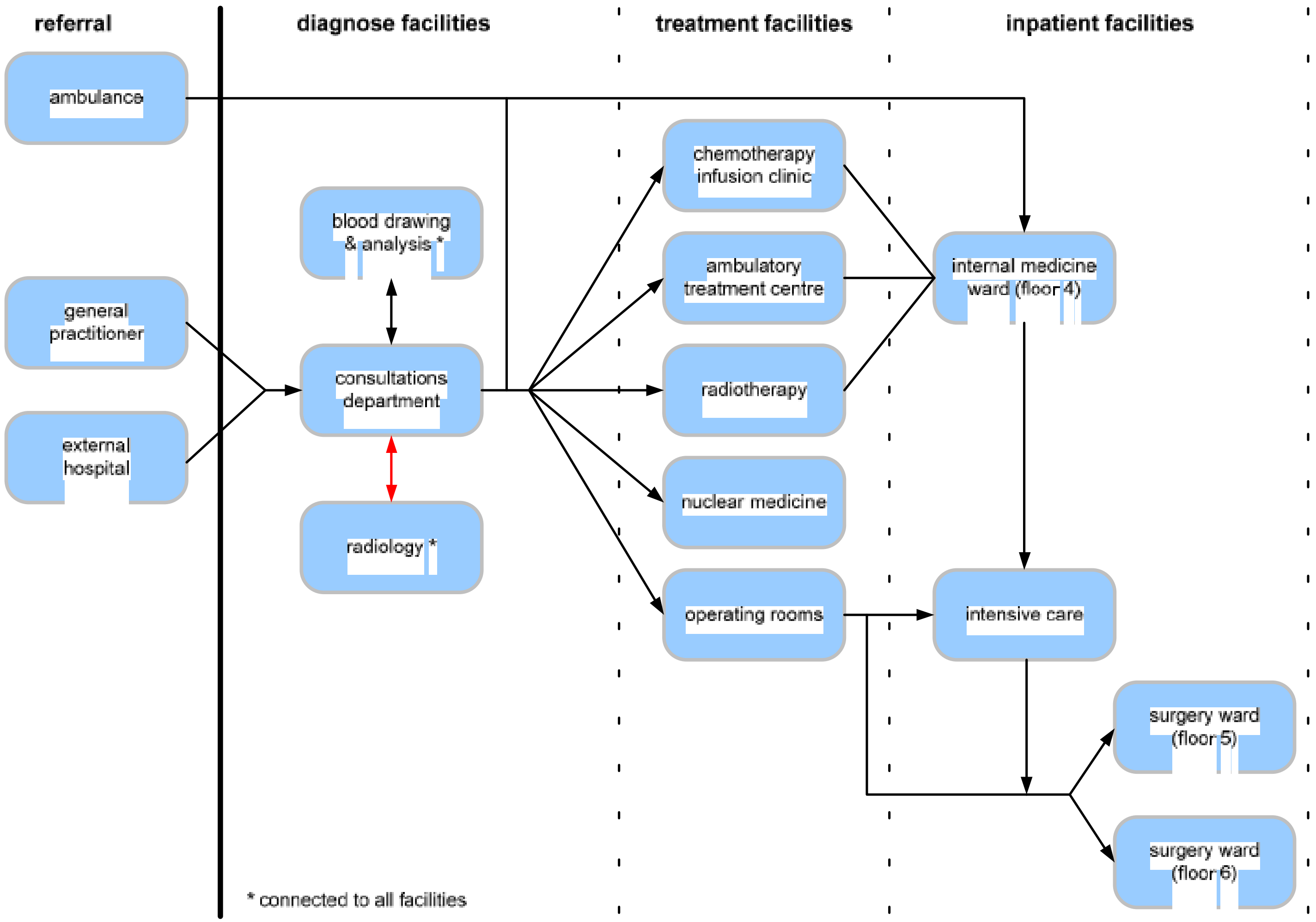
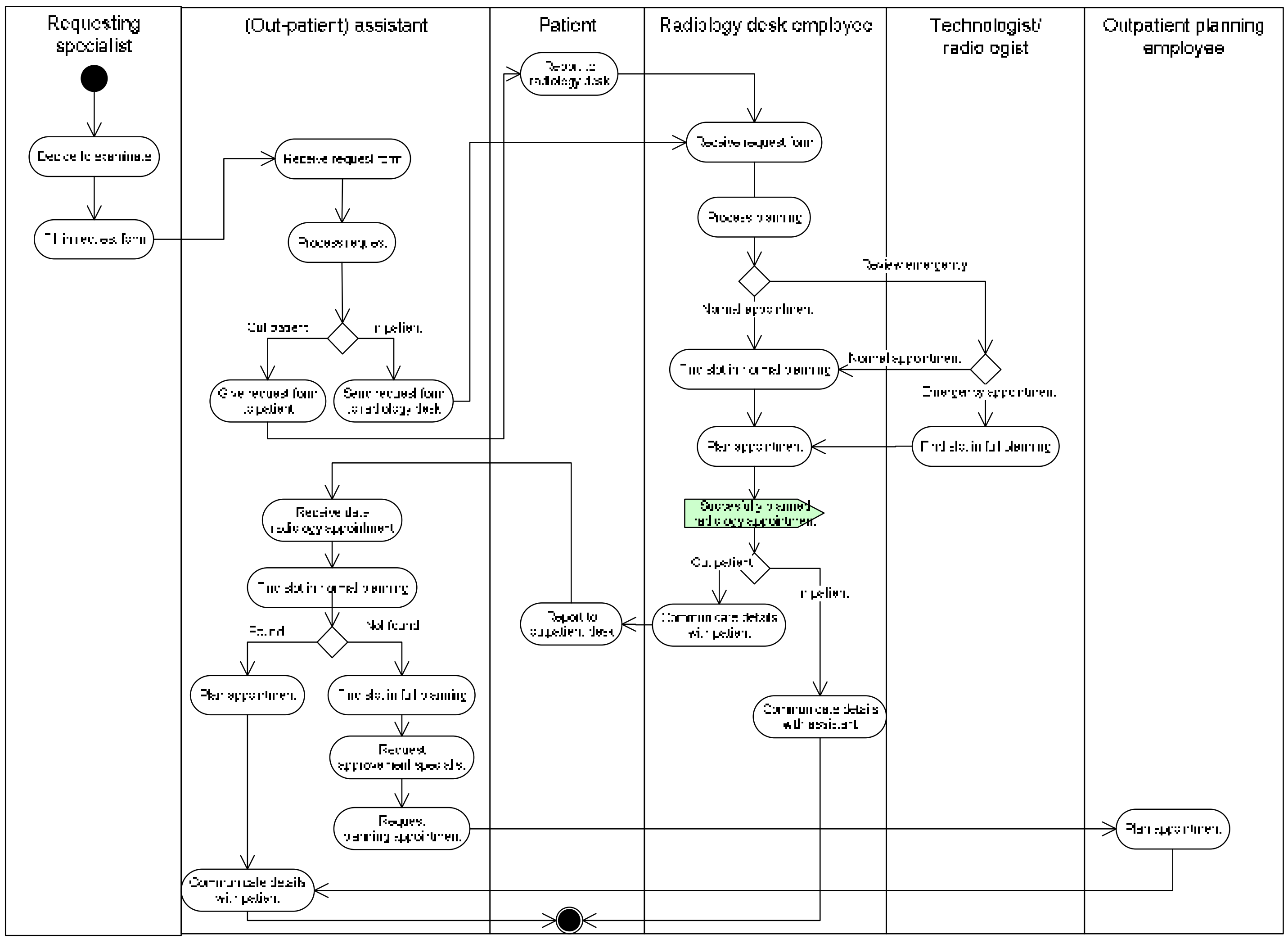
Appendix A. NKI-AvL



Appendix B. Process flow



Appendix C. Previous work

Gilles (2007) uses two analysis files of Den Braber (2007). The first file (Appointment.xls) consists of all the appointments made in the radiology department during 2006. The second file (Duration.xls) consists of all appointments within the radiology department, excluding not performed and non complete appointment data. To analyse waiting times and throughput times, all the events of an appointment – plan date, appointment date, start time, end time, dictation ready and available – should be registered. If one of the before mentioned events is not registered, this appointment is not included in the second file (Duration.xls).

Den Braber (2007) mentions that the file with all appointments has to be used to calculate the total number of radiology examination and the second file should be used to calculate waiting and throughput times. However, Gilles (2007) uses the second file (Duration.xls) to calculate the total number of ultrasound examinations. This calculated number of appointments (4802) is used as input for her simulation model.

Table 24 shows the actual number of performed appointments (appointment status: OK). The difference between the input for the simulation model and the actual examinations performed is substantial: 1276 appointments (26,57%). Therefore the results of the model should be interpreted with care.

	2006	2007
Ultrasound speed track head/throat	87	102
Ultrasound sentinel node	155	44
Ultrasound technetium injection	47	179
Ultrasound	5789	6066
Total	***6078***	***6391***

Table 24. Number of ultrasound examinations performed per examination group (RIS 2006-2007)

It is not possible to calculate the influence of different numbers of appointments on the outcomes of the model, because of choices made in the model. The arrival rates of patient in the model are not documented and can not be validated.

Appendix D. Matching CT appointments

This paragraph gives insight in the derivation of the diagnostic tracks from the available data from the EZIS and RIS. We exclude all fast tracks from our data (head/neck, breast cancer, gynaecology).

The three types of configuration and demarcations given in Paragraph 1.2 and 2.1, lead to the following rules:

1. The first consult is one of the following types of appointments: follow-up (VE), telephonic consult (BE), new patient (NP), new specialty (NS) or a second opion (SO).consult.
2. The last consult is one of the following types of appointments: follow-up (VE), telephonic consult (BE), new specialty (NS) or a second opion (SO) consult.
3. The radiology examination(s) take place after the first consult.
4. The radiology examination(s) can take place on the same day as the second consult, however in most cases, the results will not be discussed on that day, so the third consult (mostly by telephone) should be taken into account.
5. The results of the radiology examination(s) can only be discussed after the radiologist report is available.

Consult 1 (C1), radiology appointment(s) (RAD), radiology report available (REPORT), consult 2 (C2).
Consult have two measurements: date planning of appointment (PLAN) and date of appointment (APP).

- C1-APP ≦ RAD-APP
- RAD-APP ≦ C2-APP
- RAD-APP ≦ RAD-REPORT
- RAD-REPORT ≦ C2-APP

Specialty of physician performing appointment (SPEC_PERF), specialty of physician requesting appointment (SPEC_REQ).

- C1-SPEC_PREF **equals** RAD-SPEC_REQ

- C1-SPEC_PREF **equals** C2-SPEC_PREF

Included appointments for consult 1 and 2: follow-up appointment (VE), new patient (NP), new specialty (NS), second opinion (SO) and telephonic appointment (BE). Included appointments have the status "performed" (performed **equals** true **OR** status **equals** O.K.), except for telephonic appointments (because of registration failures).

Appendix E. Throughput time radiologist's report Ultrasound and Bucky

days	number of reports completed	cumulative percentage reports available
0	1235	34,64%
1	1215	68,72%
2	579	84,96%
3	229	91,39%
4	111	94,50%
5	70	96,47%
6	35	97,45%
>= 7	91	100,00%
Total	***3565***	

Table 25. Throughput time radiology report MRI-scanner (RIS 2007)

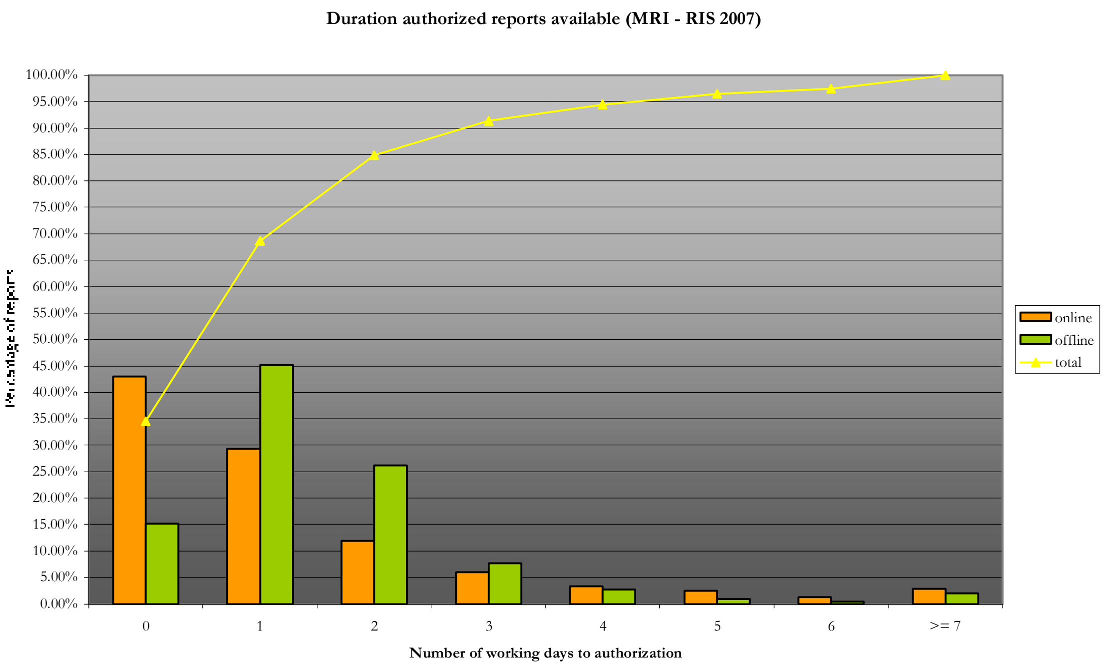


Figure 17. Throughput time radiology report MRI-scanner: online versus offline (RIS 2007)

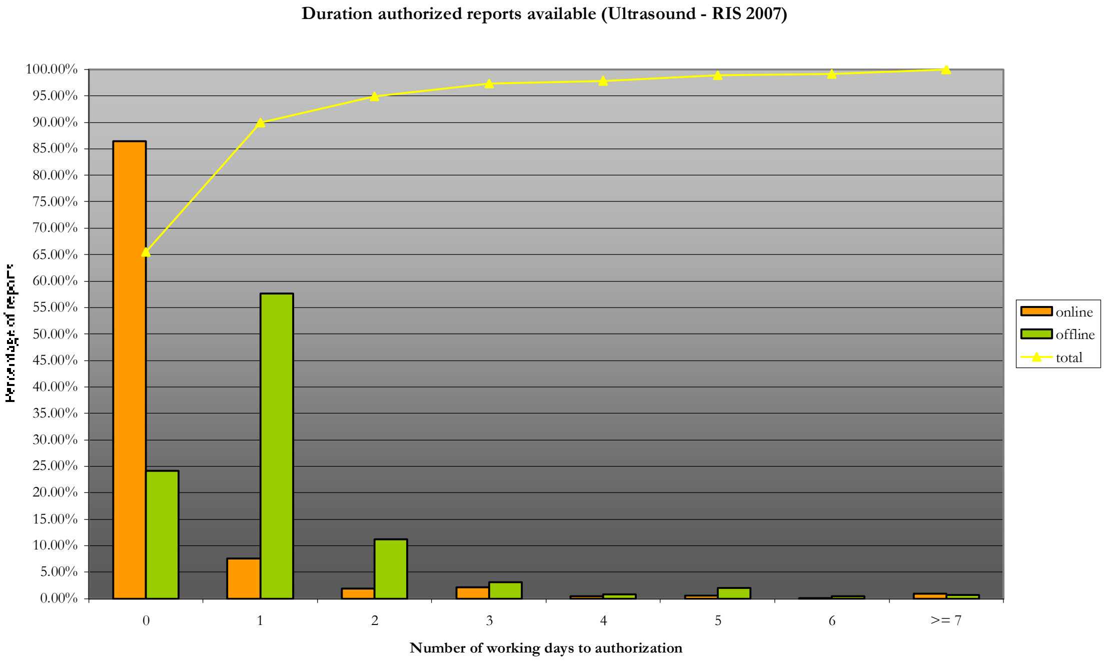


Figure 18. Throughput time radiology report Ultrasound: online versus offline (RIS 2007)

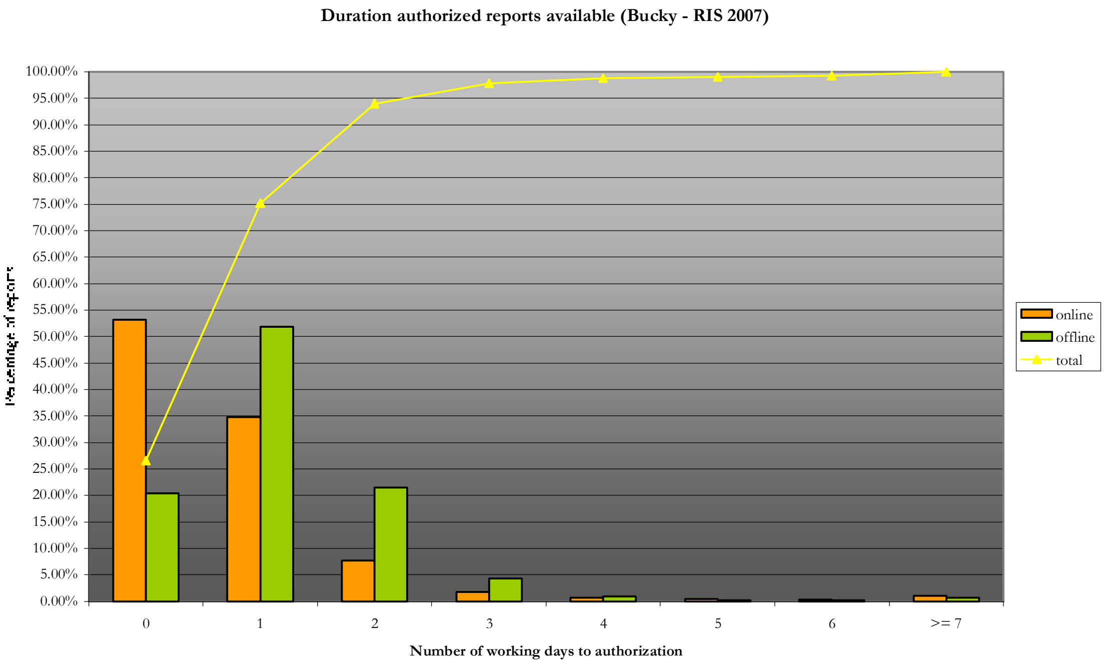


Figure 19. Throughput time radiology report Bucky: online versus offline (RIS 2007)

Appendix F. Problem formulation

Definitions:

- Patient groups $G_g \left(g \in \{1,2,3\}\right)$:
  - 1: inpatient
  - 2: outpatient – urgent
  - 3: outpatient – short term

- Arrival distribution: $\lambda(g)$
- Percentage of patients needing preparation: p_g
- Maximum days of waiting: n_g
- Capacity of slots: S_g
- Penalty for overtime: α
- Requests: $R_{dg} \quad \lambda(g)$

Variables:

- Number of requests in the queue: $Q(t,d,g) \quad R_{dg} - \sum_{x=d}^{t \ 1} P(x,d,g)$
- Remaining capacity: $A(t,d,g) \quad S_g - \sum_{x \ d \ n_g}^{d \ 1} P(t,x,g)$
- Planned requests: $P(t,d,g) \quad \begin{cases} Q(t,d,g) & \text{if } Q(t,d,g) \leq A(t,d,g) \\ A(t,d,g) & \text{else} \end{cases}$
- Summation of the idle time and overtime: $X(d) \quad \sum_g I(d,g) + \alpha O(d,g)$
- Average of the summation of idle time and overtime: $M - \frac{\sum_d X(d)}{d}$
- Idle time: $I(d,g) \quad S_g - \sum_{x \ d \ n_g}^{d} P(d,x,g)$
- Regular planned time: $TT(d) \quad \sum_g \left(S_g - I(d,g)\right)$
- Total overtime: $TO(d) \quad \sum_g O(d,g)$

- Standard capacity: $C \quad \sum_{g} S_g$
- Opening hours: $OH(d) \quad \begin{cases} TT(d) & if\ TO(d) \quad 0 \\ C + TO(d) & else \end{cases}$

Constraints:

- Preparation:
  - o $N(d,g) \quad (1-p_g) * R_{dg}$
  - o $P(d,d,g) < N(d,g) (\forall d,g)$
- Balance requests and demand:
  - o $O(d,g) \quad R_{dg} - \sum_{x \ d}^{d+n_g} P(x,d,g)$

Definitions:

- o $t > d$
- o $d > 1$
- o $I(d,g) > 0 (\forall d)$
- o $O(d,g) > 0 (\forall d)$

Objective:

- Minimise variation in idle time and overtime:
  - o $\min \left(\sqrt{\frac{\sum_{d} (X_d - M)^2}{d}} \right)$

Appendix G. Simulation settings

Distributions of CT requests

We used Crystal Ball, a Microsoft Excel plug-in, to estimate the distributions for the requests of the different patient groups. We used the requests per working day in 2007 as input. Table 26 shows the calculated distributions per patient group.

	distribution	**parameters**
inpatient	max. extreme	location: 2,81; scale: 2,04
outpatient: urgent	max. extreme	location: 4,75; scale: 2,80
outpatient: short term	gamma (3-parameter)	shape: 16,95; scale: 1,46; threshold: -8,32

Table 26. Distributions per patient group

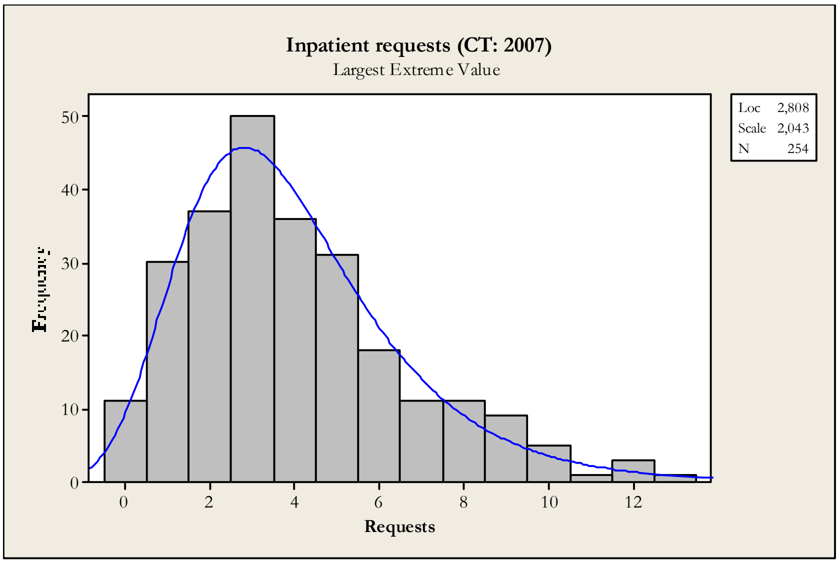


Figure 20. Fitted distribution for inpatient CT requests (RIS: 2007). Distribution: max. extreme (Location: 2,81; Scale: 2,04).

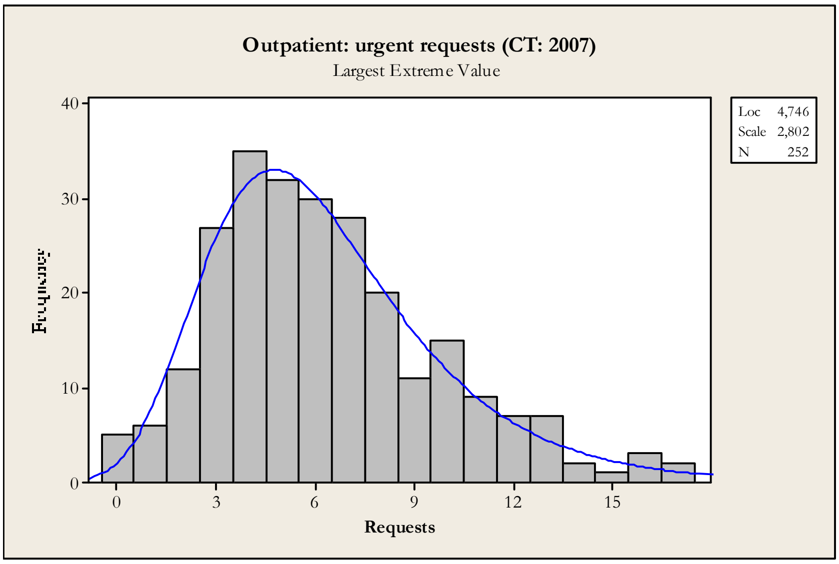


Figure 21. Fitted distribution for urgent outpatient CT requests (RIS: 2007). Distribution: max. extreme (Location: 4,75; Scale: 2,80).

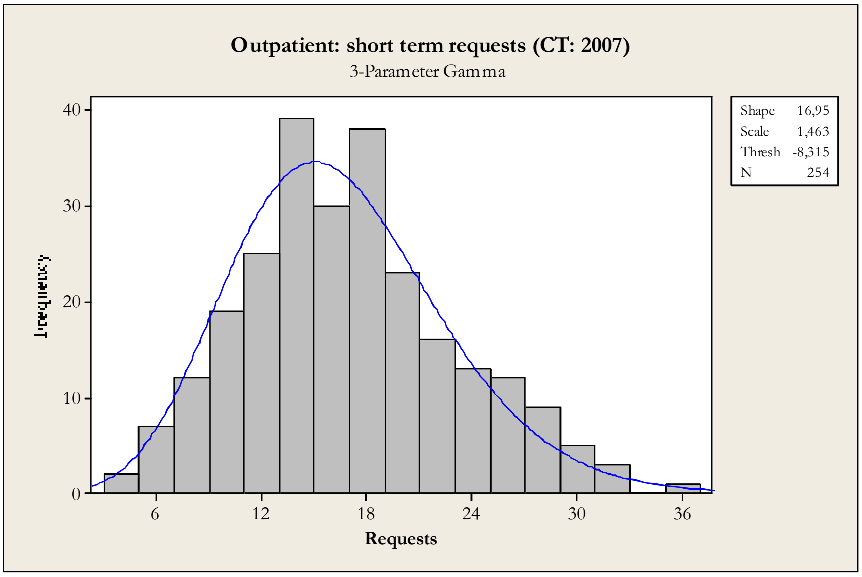


Figure 22. Fitted distribution for short term outpatient CT requests (RIS: 2007). Distribution: Gamma (Shape: 16,95; Scale: 1,46; Threshold: -8,32).

Run length determination

To construct a confidence interval of 95% for the mean of each performance measure (idle time, overtime), we need to calculate the run length of the model in working days. We use the iterative method described by Law & Kelton (2000).

We use a relative error γ of 0,05 and an actual relative error γ' of 0,0476 ($\gamma' \; \frac{\gamma}{(1+\gamma)}$).

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 > 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.

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

Using the "overtime and idle time" ($X(d)$) as parameter we need 2416 runs, using overtime as output parameter we need 3019 runs and using idle time as output parameter we need 37 runs. Therefore, we run the model for at least 3019 days.

Warm-up period

We start the model with an empty system; we have to 'warm up' our model. Figure 23 shows the number of regular slots filled per working day. After 50 days the model becomes stable (variation between 35 and 40 slots). Therefore, we use a warm up period of 50 working days.

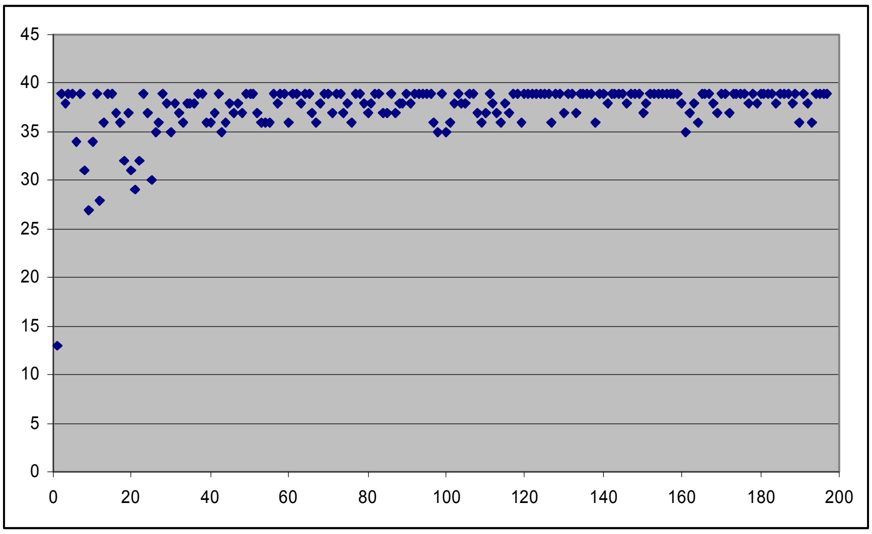


Figure 23. Number of regular slots per day (Model – Approach 2A)

Appendix H. Evaluation form same day pilot ultrasound

Datum: __________ 2008

Access time: _____ working days

The access time is defined as: the number of working days after which the third normal outpatient ultrasound slot is available

Same day slot		Type of patient?	Maximum acceptable waiting time (min/hour) *
10:00 hour		No patient Appointment requested within 1 week Appointment requested as soon as possible Other: ______________	
patientnr: ___________________			
10:30 hour		No patient Appointment requested within 1 week Appointment requested as soon as possible Other: ______________	
patientnr: ___________________			
11:40 hour		No patient Appointment requested within 1 week Appointment requested as soon as possible Other: ______________	
patientnr: ___________________			
14:10 hour		No patient Appointment requested within 1 week Appointment requested as soon as possible Other: ______________	
patientnr: ___________________			
14:50 hour		No patient Appointment requested within 1 week Appointment requested as soon as possible Other: ______________	
patientnr: ___________________			

* The maximum of the waiting time the patient accept to wait for a same day appointment (question from radiology desk to patient)

Reasons to reject a same day appointment:

____

____