The prospect of walk-in for the CT department of AMC

MSc. Graduation Thesis

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Health Care Technology & Management

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Kwaliteit en procesinnovatie, expertisecentrum logistiek

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Management Summary

Introduction

This study reflects on the access system of the CT scan modality in the Academic Medical Center. Earlier research in this hospital has shown that short access times and the combination of multiple hospital appointments on the same day are preferred by patients over short waiting times. Enabling patients to visit the CT scan without an appointment, which is called walk-in, contributes to a higher patient service as access time is completely eliminated.

Problem description

The effects of introducing walk-in on logistical performance indicators as patient waiting time, resource utilisation and overtime are largely unknown, as minor quantitative research has been done regarding walk-in. The goal of this research is to investigate the logistical feasibility when implementing various degrees of walk-in at the CT scan modality.

Approach

Allowing walk-in inherently results in a non-stationary arrival pattern as demand fluctuates, both within as between days. As our process analysis phase shows that walk-in would not be possible for all patient types, we investigate ways to counteract for the non-steady behaviour by scheduling appointments during periods of low expected demand. We introduce several interventions in which the degree of walk-in is varied. Furthermore, we explore an intervention where inpatients are called in from the ward at times the expected waiting time for the CT scan is low. To quantify the input variables, patient data is acquired over the year 2008 and several time-stamp measurements were performed. A discrete-event simulation model is developed to explore the logistical performance of each intervention. The model is validated by performing independent-samples t-tests on access time and patient waiting time. An important principle is that we do not wish to affect waiting time for planned patients. This research took place in close cooperation with the radiology department of AMC, as well as the Alysis hospital in Arnhem.

Results

The logistical performance of introducing walk-in for various interventions is shown in terms of average access time, waiting time, overtime, production and utilisation. Access times of planned patients have been shown to decrease in comparison with the current situation, indicating a more timely access for all patients since walk-in patients' access times are eliminated completely. The current waiting time is 9 minutes on average. When introducing walk-in, waiting time for walk-in patients is determined to be 35 minutes on average, while planned patients' waiting time decreases to between 4 to 8 minutes depending on the intervention chosen. On average no overtime exists, with a deviation of maximally 25 minutes from the planned closing time in 90% of the days. Utilisation is equal in the various interventions due to equal demand, but is shown to increase significantly when an increase of 10% in demand is attained under the same available capacity. Under a 10% growth and same capacity, the average waiting time of walk-in patients increases to approximately 42 minutes. The various interventions put forward proved particularly useful in eliminating the average overtime, and reduce the number of patients that are rejected or decide to go home because of high waiting times.

Conclusions and recommendations

Our context analysis shows, that walk-in for 100% of the patients is not feasible from a practical point of view, as some examinations require the presence of other medical specialists, because large preparation times are required, or simply because some patients will prefer to make an appointment. This research demonstrates that by introducing walk-in in combination with appointments, patient service can significantly be improved. It enables patients to combine multiple appointments on the same day, while lower access times for planned patients can be achieved. Simultaneously, the logistical performance indicators do not exceed the threshold values set. Calling-in inpatients from the ward at times of low expected waiting time reduces the number of rejections and patients that decide to leave because of high expected waiting times. In addition, we have shown that by introducing walk-in, the CT department is able to serve more patients under the same capacity, indicating a higher attainable efficiency. Further improvement of the results is possible, as the model currently imposes strict priorities on planned patients which might be loosened, and prudence is applied in the data analysis.

A few hospitals in the Netherlands have already implemented walk-in at their radiology department, or are starting a pilot aimed at doing so (Tweesteden hospital Tilburg, Alysis hospital Arnhem). This research provides the scientific guidelines for such a system, and creates a deeper understanding of the effects of introducing walk-in on patient logistics. The experience in practice provides several success factors. For a walk-in system to come to full fruition, broad support and clear communication from the radiology department at all levels is indispensable. The work process changes considerably, and the responsibility of laboratory workers and other directly involved in the process increases. Recent trials in other hospitals that are piloting walk-in however show that the work process is perceived as more dynamic and fun due to the increased responsibility and flexibility required.

The approach chosen, where walk-in and appointments are combined to balance non-stationary demand is new in literature. It might find application in areas wider than health care alone, for example in call-centres and bank tellers.

Preface

In October 2008, I received a guest lecture during one of the classes of the course ‘Optimization of Health Care Processes’. The guest lecturer, Jasper van Sambeek, mentioned a vacant master’s assignment at Academic Medical Center (AMC) Amsterdam. The aim of this project was to investigate the logistical feasibility of walk-in for the CT scan modality, where less planning was employed instead of more. This seemed to completely contradict with the common idea of patient scheduling, and applying operations research and queueing theory to optimise health care. Could it really be that simple and just forget all this? At least my attention was drawn immediately!

When I started my graduation project in February 2009, I soon found out that the truth was more complicated. This project just presumed a different perspective on the way many imaging facilities are organised, but OR and logistics will be inevitably connected to health care in the coming decades. The department I was involved in showed me that improving patient logistics is an ongoing process, where specifically the ability to bring about change defines success. In spite of the progressive steps taken last years at numerous fronts, many challenges still lie ahead for the Dutch health care in terms of further introducing patient centeredness and efficiency improvement. The eight months I worked in the hospital helped me to discover that I want to be involved in tackling these challenges.

There are many people I would like to thank for contributing to the completion of this project. First my supervisors from the University of Twente: Dr. Ir. Erwin Hans and Prof. Dr. Ir. Koos Krabbendam. With your immense experience in health care and operations research, you kept me on track and guarded for the scientific value of this project. However, especially your enthusiasm was critical in finishing this project. I also thank my internal supervisors Ir. Jasper van Sambeek and Nikky Kortbeek, MSc. Besides your enthusiasm and commitment, I really enjoyed your cooperative attitude every time we sat down to discuss our approach. Because both of you were at least as curious to the results as I was, you kept me eager often to include more than we initially had in mind! I thank all employees and interns of the department KPI whom I had the pleasure to work with, as well as the employees of the radiology department, both of AMC as well as the Alysis hospital who helped me understand the logistic process of CT scan imaging and the practical implications of my research. I express my gratitude to my parents who always supported me, and my brothers who regularly jumped in to clear my mind. Finally, I thank Inge, as well as her family for the ever continuing support. Without everyone, I wouldn’t be as proud of the result!

Jelmer Kranenburg

6 November 2009, Amsterdam

Table of contents

1 Introduction

1.1 Motivation

Ever since the first indications of the enduring nature of population ageing, society has become more and more aware of the extensive implications. According to the UN 2002 report on population ageing this trend is unprecedented, global, profound, and enduring, having consequences for all facets of human life (UN Population Division, 2002). Not surprisingly, this trend leads to an ever increasing pressure on health care as well. As our population grows older, so will the future health care expenditures due to an increased prevalence of chronic illness and disability. Besides population growth and aging, Rice and Fineman (2004) identify several other factors that also account for the rapid growth in health care spending, such as the transition from acute care to more expensive chronic care, growth in the use of high-cost drugs, and improvement and growth of high-cost technology.

Aside from the increase in health care expenditures another perspective is emerging, namely towards patient centeredness, quality and service. The patient becomes a consumer who is better informed and wants to be involved in his own care process. Health care responds to this new demand by emphasizing elements like timeliness, patient-centeredness, efficiency, efficacy, safety and equality (IOM – 'Crossing the Quality Chasm', 2001). In the Netherlands too, a growing awareness of the importance of patient satisfaction is visible. The introduction of competition in health care where patient satisfaction becomes an investment that yields future benefit certainly contributes as well.

Following these discourses, the pressure on health care leads both to the need to reduce health care expenditures as well as the need to improve patient service. However both objectives seem to contradict, an earlier study in Academic Medical Center (AMC) showed that a combination is possible (Elkhuizen, Van Sambeek, Hans, Krabbendam, & Bakker, 2007).

1.2 Context and scope

This research takes place in Academic Medical Center (AMC), a large academic hospitals in the Netherlands and situated in Amsterdam. Within AMC, the department Quality Assurance and Process Innovation (KPI) strives to attain continuous improvement in delivering health care concerning patient safety, evidence-based practice, patient-oriented care and patient logistics. Within the focus group of patient logistics, central diagnostic facilities like the CT scan have been points of focus in earlier research. An earlier study of the logistic processes around the CT scan resulted in a tremendous improvement as access times reduced from 21 to less than 5 days on average (Elkhuizen et al., 2007).

Patient centeredness is a recurring theme throughout the strategic objectives set out by AMC's board (AMC, 2006), where patients are enabled to choose when they desire treatment. Furthermore, AMC acknowledges that the scarcity of medical care urges the need for using the available capacity as efficient as possible, through patient oriented logistics. Altogether, AMC is a strong partner due to its ongoing quest for academic improvement, and in-house knowledge and expertise in improving patient logistics specifically.

1.3 Problem description

In our aim to as well improve quality and service while reducing hospital costs, this study reflects on the access system at the CT scan department. CT scans appear to be bottlenecks in many patient care processes, and therefore limit optimization of patient services and savings on costs (Elkhuizen et al., 2007). In the 50's, appointment systems were recommended by Bailey (1952) to match demand with capacity, while simultaneously better control waiting times and utilisation of healthcare facilities. However, amongst others due to variability in treatment-lengths, no-shows, and patient lateness, outpatient scheduling remains a topic attracting wide interest of academicians and practitioners (Cayirli & Veral, 2003). The variability in treatment lengths is often covered for by incorporating slack in an appointment slot; adding additional time to the expected appointment length acts as a buffer in case of delay. Besides this potential loss in capacity, appointments create waiting lists between departments, having a disruptive effect on patient flow when seen from a hospital wide level.

A different way of organizing the CT scan process is by introducing walk-in, where patients visit at their moment of choice. Patient service can be increased as patients are offered the possibility to receive the CT scan the same day as a consult in a different department in the hospital, eliminating access time and reducing the number of hospital visits needed. Costs are reduced because planning resources can be allocated otherwise. On the other hand, implementing walk-in increases the fluctuation in demand, which can result in high waiting times at peak times and idle time during periods of low demand. When introducing walk-in, one needs to abandon the necessity of appointments to cope with varying demand. Walk-in is nevertheless not entirely new in central hospital facilities: most hospital laboratories for example operate on a walk-in basis. Recent trials at diagnostic facilities at the Tweesteden Ziekenhuis resulted in very positive reactions by radiologists and laboratory workers involved.

Earlier, a research into patient preferences with respect to walk-in at the CT scan department was conducted in AMC (Scholtens, 2009). Four service aspects that were argued to be most relevant when implementing walk-in were determined: access time, waiting time, the possibility of a 'one-stop shop' and the autonomy in choice of the appointment. Next, a multiple criteria method called the Analytic Hierarchy Process was used to explore and measure the relative importance of each aspect to patients. It turned out that a one stop shop was prioritised as most valuable by the respondents, as multiple hospital visits can be prevented. Ranked next are, in order of priority, short access time, short waiting time and autonomy in choice of moment. Besides, it was concluded that higher waiting times were allowed when introducing walk-in. Elkhuizen (2007) showed similar findings, where combining appointments on a single day was valued more by patients than access and waiting times.

The logistical effects of introducing the concept of walk-in to the CT scan are nevertheless still largely unknown. Because of the inherent uncertain arrival of walk-in patients (both within-day as between days), waiting time and utilisation are less easily controllable because it is unknown (in advance) exactly how many patients need to be seen. Moreover, some patients might require an appointment because of large preparation times or third-party involvement arguing at least for a combination of appointments and walk-in.

<u>The formal problem statement is:</u>

The CT scan department often forms a bottleneck in patient service processes. Access time can be eliminated by introducing walk-in; however the feasibility and effects regarding patient service and logistical performance are unknown.

1.4 Research objective and approach

The objective of our study is to explore the *logistical feasibility* of walk-in for the CT scan modality, given the AMC case mix. We evaluate the performance (in terms of utilisation, overtime, and costs), and patient service (access and waiting times), through employing various interventions. Since logistical performance and service are interrelated, feasibility is a multiple-criterion optimum. Interventions range from a situation with merely bookable appointments to complete walk-in, as well as combinations of both. The CT scan modality of AMC will serve as a case study.

To reach this objective, we answer the following research questions:

1. *Context analysis: What is the current performance of the CT scan modality? (Chapter 2)*

We describe the process at the CT scan modality and the methods of planning and control in AMC. We determine relevant performance indicators and assess the performance as is. Interviews, former research, and an extensive analysis of data available guide the context analysis phase.

2. *Literature review: what literature is relevant to our research and what are its implications? (Chapter 3)*

Relevant literature is acquired to create a theoretical background. The principle of walk-in is not entirely new in health care and is scrutinized for its implications for this particular research. The application of appointment scheduling and simulation in health care is covered in this section, including input variables and performance indicators often used. Literature is reviewed as input for defining promising interventions.

3. *Experiment approach: what interventions do we wish to investigate and how can we conceptualize this? (Chapter 4)*

First, promising interventions are determined based on indications from earlier research and hospital experience. Subsequently we develop a conceptual model and define all relevant parameters. Section 4.3 justifies the selection of the model in order to accurately evaluate the interventions.

4. *Computational experiments and results: how can we assess the interventions? (Chapter 5)*

First, the scenarios are constructed from collected input data. After verification and validation of the model we analyse the performance of each intervention by the performance indicators determined in chapter 2. Besides a sensitivity analysis on various parameters to test the robustness of our model, several additional experiments are performed to increase the insight in system behaviour.

5. *Conclusions and recommendations (Chapter 6)*

Chapter 6 entails the major conclusions and recommendations of this research. The conclusions summarise the implications of our results, the recommendations focus upon possible improvements for further research.

6. *Managerial implications: what are the consequences of our results in practice? (Chapter 7)*

The last chapter deals with the managerial implications of our outcomes. We regard high-level organisational changes as well as some practical implications on the working process when introducing walk-in. Concluding, we identify several 'preconditions for success' that can guide introducing walk-in for CT scan departments and central diagnostic modalities in general.

1.5 Scientific importance

The goal of introducing walk-in is to increase patient satisfaction by reducing or eliminating access times completely. Open access (see section 3.1) has drawn much attention as a philosophy to eliminate backlog and increase the timeliness of patient care (one of the key elements of health care according to the IOM). Walk-in has drawn much less attention, and besides some trials no quantitative research has been performed yet. Besides, the combination of walk-in and appointments to balance non-stationary demand is new in literature. It has implications much wider than in health care, as it is applicable in all situations where fluctuating demand can be counterbalanced by allowing some customers to make an appointment. Future research for example might consider call-centres and bank tellers.

Only one hospital in the Netherlands has already implemented walk-in at the radiology department, another one is starting a pilot aimed at doing so which is described in section 3.1. This research provides the scientific guidelines, and creates a deeper understanding of the effects of introducing walk-in on patient logistics.

2 Context analysis

This chapter analyses the processes and performance of the CT scan department. Section 2.1 describes the entire process, which is divided in two steps: the application process in which an appointment is requested, and the imaging process. A number of important factors are described, which are either examination or capacity related. Section 2.2 entails the planning and control of the appointments and the CT scan devices, and describes the operation procedure of the planning department. In section 2.3 the current performance of the department is given in number of scans, types of examinations, and most important examination characteristics.

2.1 Process description

AMC has three CT scan modalities. Two (a Philips 'Brilliance' labelled CT1 and Philips 'MX8000' labelled CT2) are situated at the radiology department; a third is dedicated to the emergency department. Currently, all outpatients are treated on one of both modalities in the radiology department, while all emergency-patients are scanned in the emergency department. Inpatients are treated either at the radiology or the emergency department. This research focuses upon scheduling and planning aspects of the 'regular' CT scans in the radiology department.

We observed the working process, conducted several interviews with expert laboratory workers and integrated information obtained from earlier in-house research done on the CT scan. Combining all information gives a full perspective of the patient flow process at the CT scan, which is divided in the application process and the patient process at the CT department. The process schedule is validated by expert laboratory workers.

2.1.1 Application process

Currently, examinations require a request for appointment to be made, which is a paper form filled out by a medical specialist. An application originates at an inpatient or outpatient clinic, or sometimes by other hospitals or general practitioners outside the hospital. The requests need to be assessed by a radiologist prior to making an appointment. The assessment is meant to detect faulty applications, or to refer to another diagnostic facility when this is judged to yield better results. After the assessment, the appointment is planned by the planning department. This process is schematically depicted in Figure 1.

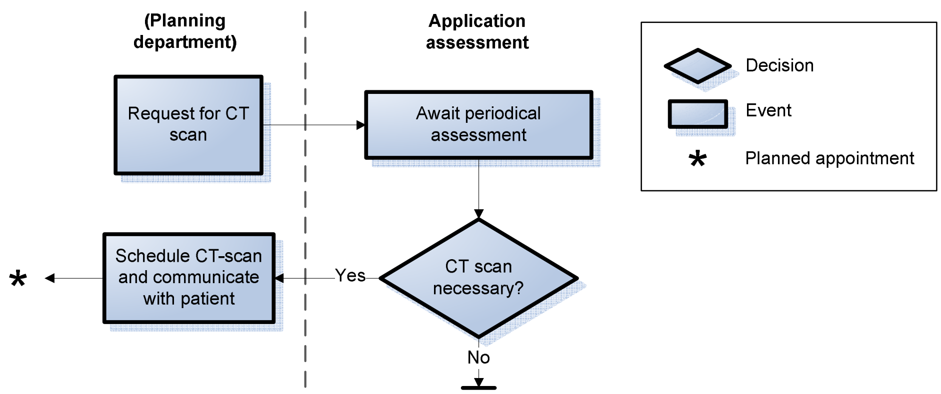

Figure 1: Application process

2.1.2 Imaging process

Figure 2 shows the patient process during the actual appointment. After patient registration, the eligibility is determined. Eligibility depends on the presence of the application, soberness (in case required), preparation against allergy, and the presence of kreatinine values in some cases. Patients often require oral and/or intravenous (IV) contrast. Depending on the type of oral contrast, patients are required to start drinking contrast about half an hour or an hour prior to the execution of the scan. IV contrast requires the pre-placing of an access line in the IV room. In case both oral- and IV contrast are required, the IV access line is placed during the time the patient is drinking oral contrast. Inpatients generally arrive at the CT scan department prepared, meaning that oral contrast is administered and an IV access line is placed on the ward. Therefore inpatients that enter the waiting room are immediately ready for the CT scan. Scan preparation includes changing cloths, positioning of the patient, and administering the IV contrast. Scan follow up is the time the patient needs to exit the room after the scan is made.

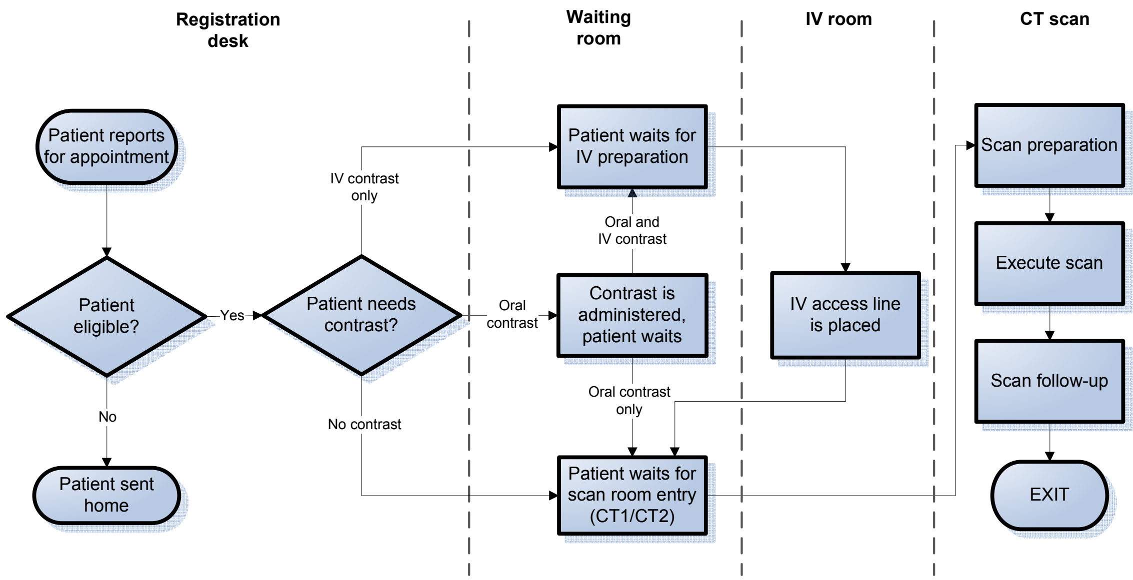

Figure 2: Patient process

Earlier research, the laboratory worker interviews, as well as a thorough inspection of the schedule and planning rules provided us with the following overview of relevant indicators:

Treatment related factors

- Patients have different appointment durations. Outpatient scans typically are fitted in 15 minute slots, where inpatient appointments take up 30 minutes.
- When an access line needs to be placed for IV contrast, patients are asked to report 20 minutes before the actual appointment time. Depending on the type of oral contrast fluid administered, patients need to start drinking either 30 or 60 minutes prior to the examination and are hence requested to report earlier as well. Most other patients are asked to report 15 minutes before the examination. This is referred to as the registration time.
- Examinations with oral contrast require soberness, indicating that patients are not allowed to eat during the 4 hours prior the scan. Drinking is allowed. Soberness is always required when oral contrast is used, but a couple more (mostly abdominal) examinations exist that require soberness.
- Patients can be allergic to the IV contrast, in which case they need to take medication starting 12 hours before the actual scan. An allergy, however, is not always known before administering the IV contrast and can hence prevail just prior to the appointment.
- Examinations that require IV contrast requires that the patients kreatinine value is known. The kreatinine value indicates (weak) kidney performance, and if this value is too low IV may not be administered. Sometimes these test-results are not available: patients are then

referred to the laboratory, and if possible served later that day. No data however is available on the occurrence of missing kreatinine values.

- Sometimes difficulties prevail when placing the IV, for example when the artery cannot be found. After two tries, another doctor or nurse is called in. In the worst case the patient is transferred to an anaesthetist.
- The punctuality of patients indicates their tendency to be early or late. Punctuality is measured with respect to the registration time. Furthermore, cancellations and no-shows occur. Cancellations are patients who declined their appointment some time before the appointment date; no-shows are patients who do not appear at the moment of their appointment without prior notice.
- Changing time exists between subsequent patients, in which for example the CT scan room is tidied or commodities are replenished.
- When intravenous contrast is administered, it is a clinical obligation that this is done under the supervision of a radiologist. Some examinations (for example cardiac scans and scans using sedatives) require the presence of a medical specialist.
- Both machines are not interchangeable in terms of examinations they perform. While some examinations can be done on both scans, others are restricted to the newest CT scan (CT1).

Capacity related factors

Downtimes exist in various forms: periodical (and thus plannable) as well as spontaneous:

- CT1 is calibrated once a day for 20 minutes starting around 12:45 pm (which is somewhat flexible); the calibration of CT2 is planned after closing time and occurs only once a week.
- To create space for coffee breaks, CT2 is closed for 15 minutes twice a day: at 10:30 am and 3:15 pm. Laboratory workers however indicate that in 2009, breaks are often no longer planned as they take breaks by turn.
- Periodical maintenance occurs 4 times a year for both scans individually. One CT scan is scheduled to stay closed for an entire day, maintenance never occurs simultaneously.
- Breakdowns occur randomly; both occurrences as well as durations are highly uncertain.
- Currently, there is a persistent under-capacity of laboratory workers resulting in the closure of 1 CT scan one day per week (Fridays).
- Specific researches and test trails occasionally require resource capacity.

2.2 Planning & control

The radiology department employs a planning department for all imaging facilities responsible for the scheduling of appointments. The digital agenda planning system XCare (by McKesson) is used in the entire hospital, both CT scans have their own agenda. In these agendas, several appointment blocks are predefined, indicating that a certain time-slot is reserved for a specific patient group or specialty. Table 1 shows the schedule blocks used for CT scan appointments in 2008.

Schedule block	Clarification	Unavoidable appointments
CTCOLONG	Reserved for Virtual Colonography	X
CTORBITAN	Reserved for Ophtalmology department	
HARTEN	Heart scans that require cardiologist presence	X
KLINIEK	Reserved for inpatients	
KNO (CTSINUS)	Reserved for Ear, Nose, and Throat department	
NARCOSE	Examinations that require anaesthetics	X
POLI	Outpatients with IV contrast	
POLIZC	Outpatients without IV contrast	
SKELET	Orthopaedic examinations	
SPOEDKLI, KLINSPOED	Slots reserved for emergencies from inpatient clinic	
SPOED, SPOEDBLK	Slots reserved for general emergencies	

Table 1: Schedule blocks used for appointments in 2008

The third column indicates the block types that require appointment slots. CTCOLONG requires preparation starting three days in advance of the examination; hence these patients are not directly admissible. HARTEN requires the presence of a cardiologist, and NARCOSE indicates patients that have to be sedated for which the presence of a team of anaesthetists is required. Blocks appear each week and are scheduled in consensus with the agendas of medical specialists, and are therefore presumed not to be eligible for walk-in. The other blocks are there for historical reasons, for example because an outpatient department claimed restricted capacity. In our opinion as well as the opinion of the planning department, these blocks in theory are avoidable. When an appointment is booked, patient type, urgency, type of examination and future outpatient clinic appointments are considered. For example, patients with oral contrast are not scheduled in slots at the beginning of the day due to their preparation time. The XCare function that automatically suggests slots for a proposed examination is not used. Instead, all entries are done manually. Some employees seek for slots in a backwards manner, for example two weeks prior to the succeeding appointment of the patient at the outpatient department, rather than providing the earliest appointment slot available. As a consequence, the planning and control process proves hard to capture.

2.3 Performance

To determine the current performance, we performed an extensive data analysis over the entire year 2008 in which we specified patient numbers and their types, traits, and attributes. Due to the periodical change of the CT scan schedule, we only consider 2008 and assume the data to be representative for the current situation. Data from two databases is combined: planned patients from XCare and PACS (Picture Archiving and Communication System) for the overall production numbers. To guide our analysis we included former research outcomes and conducted interviews with expert laboratory workers. Besides analysing the patient mix, we are interested in specific time-related issues such as the arrival time of patients (including earliness / lateness), the average waiting time and the average scan time. To this purpose we performed a time measurement from 4 to 15 May 2009, providing data of ten working days.

2.3.1 Production

Table 2 shows the production data over the year 2008. We are only interested in regular working days, hence only scans made during normal opening hours (08:30 AM - 05:00 PM, Monday to Friday) are included. CT scans made at the emergency department are excluded. The total number of scans includes test trails and specific research, which do not involve real patients but do take up resource capacity.

Production days	252
Total scans performed	N = 10983
Total patients scanned	N = 10793
Inpatients	N = 1659
Outpatients	N = 8456
Emergency patients	N = 419
Requests from other hospitals / general practitioners	N = 259
% scans with oral contrast	8.3% requires drinking contrast for 30 min; 14.9% requires drinking contrast for 60 min. Both require that the patient is sober.
% scans with IV contrast	53.6 %
% scans restricted to CT1	36.6 %
% scans that required soberness	2.9 % of the patients besides the ones requiring oral contrast

Table 2: Production data of the CT scan, 2008

2.3.2 Performance indicators

Various performance indicators can be used for both appointment and walk-in systems. Based on our literature survey (see section 3.3.2), we identified the most frequently used performance indicators which are shown in Table 3.

Performance indicator	Clarification
Access time	Access time is the number of days between the doctor's statement that some kind of facility is necessary for a patient, and the moment this patient is actually making use of this facility (Elkhuizen, Van Sambeek, Hans, Krabbendam, & Bakker, 2007).
Waiting time	The waiting time in the waiting room (Elkhuizen, Van Sambeek, Hans, Krabbendam, & Bakker, 2007) in minutes. Only involuntary waiting, caused by appointment delay, is considered.
Utilisation / Production	Utilisation is the time the CT scan rooms are occupied divided by the total time the CT scans are available, but only during regular opening hours. Production is the quantity of services produced (Wennberg & Gittelsohn, 1973), in this case the number of CT scans.
Overtime	Time used for performing scans outside the normal schedule, measured in minutes.
Rejections	The number of patients that are rejected due to time or system constraints. In the current situation, patients are not rejected since they can be referred to the CT scan at the trauma department.
No-shows	The number of patients that do not show up for their appointment.

Table 3: Selected performance indicators

Some additional comment is required: while access time is very important in measuring the efficiency of the appointment-based system, it is absent by definition in the walk-in variant. Since our aim however comprises to assess combinations of appointments and walk-in, access time is still an important indicator which will be assessed for patients still requiring an appointment.

2.3.3 Current performance

Access time

We tried to determine the access time by averaging the number of days between registration and appointment for all patients. This average is from here referred to as the retrospective access time. However, this method did not provide a fair representation of the real access time, as time windows often ran over 50 days or more due to the backwards planning described in section 2.2. We therefore adopt the 3rd-available slot measurement which is obtained monthly by the head of the planning department. The third available slot is a monthly prospective measurement which searches for the third appointment slot still open for a fictitious patient, and was amongst others successfully used by Belardi, Weir, & Craig (2004) in a controlled trial of an advanced access appointment system. It also is often used for benchmarking purposes. The first two available slots are often left open for emergencies or are occasionally empty because of a recently cancelled appointment. They would hence not give an accurate representation of the actual access time, whereas the 3rd-available slot proves to be a more robust measure. Figure 3 shows the results of the prospective access time data acquired from January 2008 until May 2009 (data is missing in August and September 2008 due to a maternity leave). The data is separately recorded for four patient types: orthopaedic patients, outpatients without IV contrast, outpatients with IV contrast, and inpatients. As Figure 3 shows, the access time increased from December 2008 which the department attributed to employee shortness.

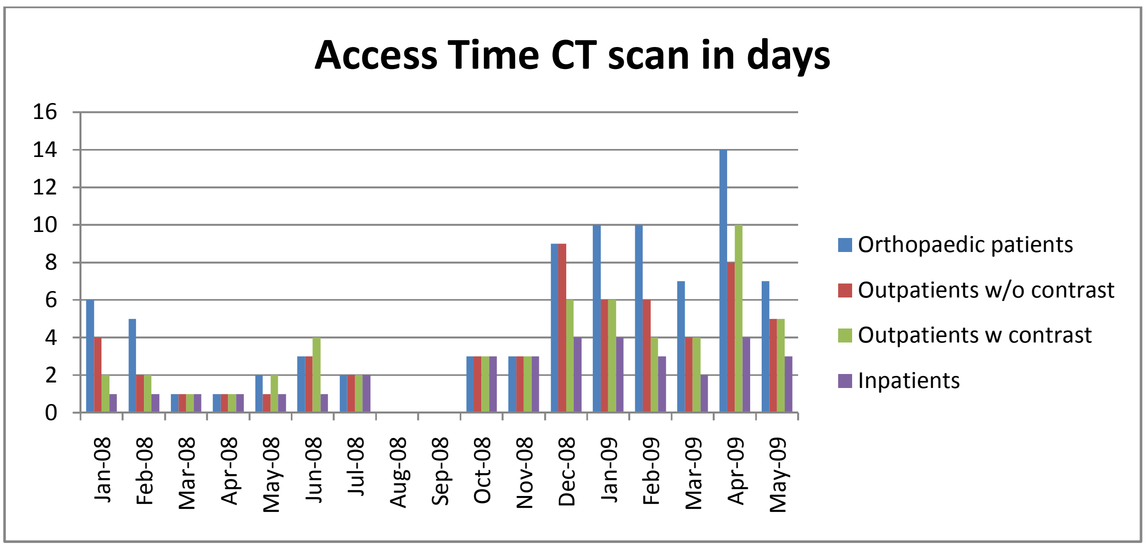

Figure 3: Prospective CT scan access times over the period Jan 08 – May 09

Waiting time

From our time measurement, we calculated the average waiting times for all in- and outpatients (N = 363) by deducting the time the patient reported for his/her appointment by the time the patient entered the CT scan room. Only involuntary waiting time is measured which is caused by the system: hence the waiting time after the planned appointment (earliness would thus be voluntary waiting time). We settled the time measurement for the time patients had to come early because of administering contrast, and found that the average waiting time of patients is 9 minutes on average, with a standard deviation of 13.5 minutes. 40% of the patients encounters no waiting time at all.

Utilisation & production

The utilisation is calculated by summing the occupation time of all patients on both CT scans during a time measurement of 10 working days. We measured a total occupation time of 5391 minutes, which is divided by the number of minutes both CT scans were available (9255 minutes). This shows an utilisation of 58.2% on average. Obligatory downtime due to maintenance and calibrations in regular opening hours are settled for and are not incorporated in the measurement. No planned downtime due to employee shortness occurred. The utilisation is not optimal due to planned slack, changing time per patient, no shows and appointments that were cancelled by patients at the last moment which result in high idle times. To give a more accurate insight in capacity loss, we determine the Operating Equipment Effectiveness (OEE) as proposed by Slack et al (1998). The OEE is determined to be 0.53 (see Table 4), and is defined as:

OEE = a * p * q (where a = Availability Rate = total operating time / loading time; p = Performance Rate = net operating time / total operating time; and q = Quality Rate = valuable operating time / net operating time)

OEE calculation in minutes over the period 4 May – 15 May					
Loading time:		10200			
	available losses	1170	-		
Total operating time		9030		a:	0.89
	speed losses	3640	-		
Net operating time		5391		p:	0.60
	quality losses	0	-		
Valuable operating time		5391		q:	1.00
				OEE:	**0.53**

Table 4: Calculation of Operating Equipment Effectiveness (OEE) in minutes

Available losses consist mostly of personnel shortness and closure due to maintenance and breaks, which is incorporated in the OEE. During our time measurement no planned downtime occurred, which explains the difference found in OEE and utilisation. Speed losses are created by high idle times, no quality losses are encountered. Unfortunately, no benchmark data has been found on the utilisation of the CT scan in other hospitals. Production is the mean production of the CT scans per day. In total 440 CT scans were made, the average production hence was 44 scans per day.

Overtime

The overtime is determined by the difference between the time the last patient leaves, and planned closing time. In our measurement only 3 patients left after 5:00 pm, at latest at 5:27 pm. According to the laboratory workers they do not experience overtime since patients are transferred to the trauma department if deemed necessary.

In perspective

Table 5 shows a small benchmark of access times for the CT scan in several Dutch academic hospitals, for which data has been acquired from the Dutch website www.kiesBeter.nl (RIVM, 2009).

The national standard (Treeknorm, in Dutch) defines that 80% of all patients should have an access time of less than 3 weeks, with a maximum of 4 weeks (tild, 2009). CT scan access times in AMC are low compared to other hospitals, and are well below national standard.

Hospital	Expected access time in weeks
LUMC	5
AMC	2
UMCG	4
AZU	2
AZM	1
Erasmus MC – Sophia	7

Table 5: Benchmark of access times for the CT scan

Table 6 shows the number of CT scans per million inhabitants (OECD, 2009). Remarkably, the Netherlands are somewhere at the bottom, while top ranking countries have five times the amount of CT scans available.

Country	CT scans/mln	Country	CT scans/mln
Australia	56.0	Spain	14.6
Belgium	41.6	Ireland	14.3
Korea	37.1	Slovak Republic	13.7
United States	34.3	Czech Republic	12.9
Iceland	32.1	Canada	12.7
Italy	30.3	New Zealand	12.3
Austria	29.8	France	10.3
Luxembourg	27.3	Poland	9.7
Portugal	26.0	Netherlands	8.4
Switzerland	18.7	Turkey	8.1
Denmark	17.4	Hungary	7.3
Finland	16.4	Mexico	4.0
Germany	16.3		

Table 6: Number of CT scans per million inhabitants for OECD countries

Conclusions

Although the access time for the CT scan modality in AMC is low, an increase is noted from December 2008. The department ascribes this to laboratory worker shortness which forces the occasional closure of one of both modalities. Idle time is high resulting in low utilisation, which was confronting to the management of the radiology department as well. It becomes clear what bottleneck CT scans are for the Netherlands in particular when looking at the OECD health data, as the Netherlands are one of the countries with the lowest number of CT scans per million inhabitants.

3 Literature review

The literature review focuses on several topics that prevailed during the context analysis phase. Before looking into the implications of introducing walk-in, section 3.1 offers a brief survey on outpatient scheduling to get a grasp of the idea behind patient scheduling, and the issues that have been taken into consideration in earlier research. To investigate patient flow in more detail, we choose to employ a discrete event simulation further justified in section 4.3. We describe the application of discrete event simulation in health care in section 3.2, and identify the most common input variables and performance indicators. In section 3.3 we study walk-in for its application in healthcare. We consider queueing theory and some specific implications of walk-in in section 3.4. Section 3.5 provides guidelines for promising interventions we will consider in our computational experiments. Conclusions of the literature review important for this research are summarized in section 3.6.

3.1 Patient scheduling

Scheduling involves rules that determine when appointments can be made (during a day) and the length (spacing) of time between appointments. These rules can have a significant impact on how resources (for example, physicians, staff, or facilities) can be optimally utilized so as to maximize patient flow without incurring additional costs of excessive patient waiting (Jun, Jacobson, & Swisher, 1999). The seminal papers on outpatient scheduling are written by Bailey (1952) and Welch and Bailey (1952), who propose to plan appointments at regular intervals equal to the average consultation time in order to eliminate patient waiting time without noticeably affecting consultant idle time. A lot of papers on the topic written since then focus on a single server problem, including overtime as important performance output (Sickinger & Kolisch, 2009). Most of them consider stochastic service times that are usually fitted on case data retrieved from the organization or department under scrutiny. Articles evaluate schedules (often by using simulation), or design algorithms to find good schedules (Kaandorp & Koole, 2007).

Cayirli, Veral, and Rosen (2006) argue for considering the effect on patient classification when designing an appointment system. They distinguish two decision factors: the sequencing rule, which determines the order in which calling patients are assigned to blocks, and the appointment rule that determines the basic template of the appointment system by specifying the number of patients scheduled to each slot. Patients are classified on type (inpatient, outpatient), arrival process (scheduled, walk-in) and/or urgency (normal, emergency patients). Also found were classifications based on new or return patients, or a classification based on expected service time.

In order to increase the accuracy of a model, disturbances are included such as patient punctuality (earliness and lateness), no-show, and walk-ins (Harper & Gamlin, 2003; Hutzschenreuter, 2005). (Un)planned downtimes are mentioned but not considered by Sickinger & Kolisch (2009).

When modeling health care systems, various approaches are chosen. Some only consider stationary systems while others recognize the non-stationary behaviour of the health care environment as patients might be lost or rescheduled to another day (Hutzschenreuter, 2005; Green, Savin, & Wang, 2006). Regarding the arrival process, either deterministic or stochastic arrival is assumed (around the scheduled time, or random for inpatients and emergency patients). However, some advance this principle and model the varying pattern of demand by using a non-homogeneous interarrival rate in which the interarrival means vary (Swisher, Jacobson, Jun, & Balci, 2001).

Appointment slots are blocks of time that are reserved for specific appointment types (using inclusion and exclusion criteria). Since the appointment slots are often non-interchangeable the result is inflexible schedules, resulting in queues and delays in the system (Murray & Tantau, 2000; Carlson, 2002). From a logistical point of view, the number of appointment slots should hence be kept to an absolute minimum.

There are quite a number of practical considerations related to appointment scheduling, which we might take into account when considering walk-in since omitting them can impose specific issues we didn't think of. In order to elucidate their various levels of control, we adhere to the hierarchical decomposition proposed by Van Houdenhoven, Wullink, Hans, and Kazemier (2007), which identifies four organizational levels: strategic, tactical, operational offline, and operational online.

Strategic

Strategic considerations are the number of servers and providers to employ at the department to cope with demand. A decision on opening hours is made, including the consideration to work with or without overtime restrictions, where overtime can be used to attain access time targets (Patrick & Puterman, 2008).

Tactical (appointment rules)

It is advisable to separate groups of patients with different average consultation times (Welch & Bailey, 1952). The Bailey-Welch rule (with an initial block size of 2 while for each remaining service period 1 patient is scheduled) proved to yield very good results in several studies (Hutzschenreuter, 2005; Cayirli, Veral, & Rosen, 2006; Sickinger & Kolisch, 2009) as doctor idle time is kept low.

Operational offline (sequencing rules)

Cayirli, Veral, and Rosen acknowledge that most studies consider appointment systems with no patient classification, assuming that patients are homogeneous for scheduling purposes (Cayirli, Veral, & Rosen, 2006). Klassen & Rohleder (1996) however do classify patients, and found that patients with low variance should be planned first in order to minimize patient waiting time compared to the idle time of the service provider. Hutzschenreuter, using the same performance indicators, showed that for her study patients with short expected treatment durations should be scheduled first. Both studies seem to argue for planning appointments with low uncertainties early. In ambulatory care, sequencing rules are proved to be relatively important compared to the choice of an appointment rule by Cayirli et al. (2006). Furthermore, panel characteristics such as walk-ins, no-shows, punctuality and overall session volume influence the effectiveness of appointment systems.

Operational online

Cayirli, Veral, and Rosen acknowledge that most studies consider appointment systems with no patient classification, assuming that patients are homogeneous for scheduling purposes (Cayirli, Veral, & Rosen, 2006). For the online sequencing of patients, Kolisch and Sickinger (2008) recommend FCFS (First-come, First-served) for multiple reasons for patients having equal priority.

3.2 Discrete event simulation in health care

We now turn to a specific tool often used in patient scheduling problems, known as discrete event simulation. Hall, Belson, Murali, and Dessouky define patient flow analysis as the study of how patients move through the health-care system (2006). Fighting delays hence is a key issue. Haraden and Resar acknowledge that in many cases, delays are not a resource problem but a flow problem: adding resources thus is often not the answer. According to them, one of the first steps necessary for understanding flow is to accept the dependence on the inherent variation found in health care delivery systems, as a result of clinical variability where no patient is the same and demand and supply vary throughout the day (Haraden & Resar, 2004).

Operations research develops and applies mathematical models to provide decision makers with system models and optimal strategies for managing systems. This enables them to investigate and plan system changes prior to implementation (Patrick & Puterman, 2008). Ondategui-Parra et al. (2004) state that applying Operations Research (OR) can lead to significant improvements in radiology regarding resource use, managing variability, and adapting to changing circumstances. Most health care queueing problems are too complex to be analyzed theoretically and simulation therefore is a popular alternative (Carter, 2002). Discrete event simulation concerns the modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time (Law, 2007). Several health care administrators used discrete-event simulation in the past as an effective tool for allocating scarce resources to improve patient flow, where health care delivery costs were minimized and patient satisfaction increased (Jun, Jacobson, & Swisher, 1999). The extensive use of these models for managing health care departments is ascribed to the ability to assign attributes to simulated patients that influence their progress through the system, and to analyse a specific system in detail. Constraints can be introduced and arrival patterns can be simulated through arrival distributions. These features enable the possibility to explore situations where resources are not assumed to be infinite. In general discrete event simulation provides flexibility, robustness and accuracy (El-Darzi, Vasilakis, Chaussalet, & Millard, 1998). We now turn to the input variables and performance indicators that are often used when modelling and analyzing a hospital department.

3.2.1 Input variables

Fetter & Thompson (1965) identified input parameters such as patient load, patient early or late arrival patterns, no show rates, walk-in rates, appointment scheduling intervals, physician service times, interruptions, and physician lunch and coffee breaks which are important when simulating hospital systems. Table 7 outlines the environmental factors that influence outpatient scheduling as identified by Cayirli and Veral (2003) in an extensive literature review on appointment scheduling.

Problem formulation:

1. Nature of decision-making
    - 1.1. Static
    - 1.2. Dynamic
2. Problem definition and formulation
    - 2.1 Number of services
    - 2.2 Number of doctors
    - 2.3 Number of appointments per clinic session
    - 2.4 The arrival process
        - 2.4.1 Unpunctuality of patients
        - 2.4.2 Presence of no-shows
        - 2.4.3 Presence of walk-ins
        - 2.4.4 Presence of companions
    - 2.5 Service times
    - 2.6 Lateness and interruption level of doctors
    - 2.7 Queue discipline

Table 7: Environmental factors related to outpatient scheduling (Cayirli & Veral, 2003)

The nature of decision making in the reviewed literature can either be static or dynamic. Static means that all decisions are made prior to the beginning of a clinic session, which is most common in health care. In the dynamic case, the schedule of future arrivals is continuously revised over the course of the day based on the state of the system at that time. The problem definition and formulation stage requires input data related to capacity (number of services, doctors, appointments per session) and to time distributions for arrival and service.

3.2.2 Performance indicators

A variety of performance indicators are used in the literature to assess appointment systems. A summary and categorization is made by Cayirli and Veral (2003), which is shown in Table 8. Most indicators listed show results in terms of the mean waiting time of patients, the mean idle time of doctors, and the mean overtime of doctors. Although patient flow time (the total time a patient spends in the clinic, including the service time) is also used as performance measurement in some studies, patients generally do not mind time spent in service as this is perceived as part of the treatment (as mentioned in the same study). Most of the literature therefore focuses on waiting time rather than flow time.

<u>Performance measurements used in the literature</u>

1. Cost-Based Measures
    1.1. Waiting time of patients
    1.2. Flow time of patients
    1.3. Idle time of doctor(s)
    1.4. Overtime of doctor(s)
2. Time-Based Measures
    2.1. Mean, maximum, and frequency distribution of patients' waiting time
    2.2. Mean, variance and frequency distribution of doctor's idle time
    2.3. Mean, maximum and standard deviation of doctor's overtime
    2.4. Mean and frequency distribution of patients' flow time
    2.5. Percentage of patients seen within 30-minutes of their appointment time
3. Congestion Measures
    3.1. Mean and frequency distribution of number of patients in the queue
    3.2. Mean and frequency distribution of number of patients in the system
4. Fairness Measures
    4.1. Mean waiting time of patients according to their place in the clinic
    4.2. Variance of waiting times
    4.3. Variance of queue sizes
5. Other
    5.1. Doctor's productivity
    5.2. Mean doctor utilisation
    5.3. Delays between requests and appointments
    5.4. Percentage of urgent patients served
    5.5. Likelihood of patients receiving the slots they requested
    5.6. Clinic effectiveness

Table 8: Performance measures used in the literature (Cayirli & Veral, 2003)

Cayirli and Veral acknowledge that the three most prevalent performance indicators need a ‘reasonable’ trade-off to decide between them, to be made by the decision-maker. In other words: the criteria are interrelated and form a multiple-criterion optimum as mentioned in section 1.4.

Elkhuizen et al. define two kinds of waiting time. Access time is the amount of days (period) between the doctor’s statement that some kind of facility is necessary for a patient, and the moment this patient is actually making use of this facility (Elkhuizen, Van Sambeek, Hans, Krabbendam, & Bakker, 2007). Waiting time is the time patients have to wait in the waiting room for their appointment, so the time between their appointment and the moment they are seen by a doctor or enter the CT scan. We adopt these formulations since access- and waiting-times are both perceived to be important in measuring performance.

Two practical concerns Cayirli and Veral give, is that it usually is desirable to evaluate waiting time, idle time, and overtime measures separately, as there may be a maximum acceptable level for each. Furthermore, in order to exclude waiting time prior to appointment time (because of voluntary early patient arrival), a common approach is to calculate the ‘true’ waiting time of patients by subtracting the greater of appointment time and arrival time from the consultation start time (Cayirli & Veral, 2003).

3.3 Open access and walk-in

Starting in 2000, a new discourse found its way to health care. In the quest of fighting issues of long waits, delays, and bottlenecks in their system (a large primary care department in northern California), Murray and Tantau (2000) proposed an access model which has one simple yet challenging rule: “Do today’s work today”. This theory is explained to be self-evident since backlog in physician practices generally is constant, where under-capacity argues for increasing backlog (Carlson, 2002). This model is also called ‘open access’, ‘advanced access’, or ‘same-day access’, a principle we believe lies at the heart of walk-in.

Since then, several authors have explored the promises of open access scheduling. Kopach et al. (2007) indicate that, if correctly configured, open access can lead to significant improvements in clinic throughput with little sacrifice in continuity of care. Kennedy’s conclusion on the implementation of this principle in a residency training program: “Open access has improved revenue, simplified office processes, decreased nursing work, and improved patient satisfaction without any increase in provider time or clinic expansion” (Kennedy & Hsu, 2003). Although Parente et al. did not find demonstrable significance in patient satisfaction comparing Open Access pre- and post-implementation, they did find that operational efficiency improved, the number of days between appointment scheduling and being seen by a physician decreased, and it allowed more patients to see their primary care physician (Parente, Pinto, & Barber, 2005). Perhaps most important of all: quality of care is concluded to improve due to the timely access offered (Carlson, 2002).

An important note is that open access does not let go of making appointments completely, they are just made the same day or the next (Gupta, Potthoff, Blowers, & Corlett, 2006). With a walk-in system, appointments are not made at all; patients just walk in when they need some kind of hospital service (after referral). This is a concept not unfamiliar in hospitals: most blood-puncture services work like this, and laboratory tests not always require making an appointment first (Plexus Medical Group, 2008). The goal here is to minimize costs versus achieving demonstrable high quality. Another difference between open access and walk-in is that one of the principles of open access is to increase the number of patients that is seen by his/her own primary care physician. For hospital services like the laboratory or for central diagnostic facilities however, this is not relevant.

Already, several hospitals in and around The Netherlands have started exploring the possibilities of shortening the access times of diagnostic modalities. For example, Gilles (2007) performed a quantitative research into same-day access on the ultrasound modality in the Netherlands Cancer Institute – Anthoni van Leeuwenhoek (NKI-AVL) hospital in Amsterdam. She showed that the number of patients seen on the same day as their request can strongly be improved by allowing minor extensions of (time) capacity while better balancing demand and capacity. The 'Alysis Zorggroep' in Arnhem, the 'Tweesteden' hospital in Tilburg and the 'Imelda' hospital in Bonheiden (Belgium) have started exploring the possibilities of implementing walk-in at their radiology department. However, still minor quantitative research has been done to evaluate the effects on patient logistics (waits and delays, e.g.) when implementing walk-in. Moreover, there currently is no indication if walk-in will be logistically beneficial for every patient category in central diagnostic facilities, or to what extent.

3.4 Mathematical considerations

To predict the effects of walk-in on waiting time and utilisation we employ queueing theory: the mathematical study of waiting lines. The performance depends on the interarrival and service time distribution of jobs, the number of servers, and the available buffer space (Zijm, 2003). An often-used measure of productivity in queueing theory is utilisation, commonly expressed as the interarrival time divided by the service time. Patient waiting time, average time in the system, and number of jobs in the system are performance indicators for efficiency that all can be determined relatively simple. We know from queuing theory that the (steady-state) average number in system increases exponentially for large utilisation factors (> 0.8) (Law, 2007). Thus, attaining high utilisation requires a relatively large number of patients that need to be present in the system. This however dramatically increases the chance of congestion due to service time variances. Increasing capacity utilisation -with clear cost benefits- hence contradicts with access and waiting time reduction which are an important factor for patient service.

The relation between utilisation and waiting time is studied by Kingman (1962). The formula shown below, as deducted by Zijm (2003), represents this relation for the M/M/1 queue where $\mathrm{E}W_q$ is the expected waiting time in queue, E*S* the expected service time, C^2 represent the squared coefficients of variance, and ρ represents utilisation.

$$\mathrm{E}W_q = \frac{C_A^2 + C_S^2}{2}\frac{\rho}{1-\rho}\mathrm{E}S \qquad \rho < 1$$

This approximation is reasonably accurate for typical manufacturing systems, except when C_a^2 and C_s^2 are much larger than one or when $\rho < 0.1$ (light traffic conditions), or $\rho > 0, 95$ (heavy traffic). In case the expected service times and coefficients of variance are presumed static, a linear relation between the expected waiting time and utilisation becomes even clearer. An increase in utilisation will cause the expected waiting time to increase as well. Vice versa, the expectation that higher waiting times are acceptable with walk-in (Scholtens, 2009) leads to the theoretical possibility to increase utilisation. For appointments that do not require to be planned in an appointment slot, no slack needs to be scheduled which also enables a theoretical increase in utilisation. Walk-in therefore shows to offer logistical benefit. However, since standard queueing theory focuses on the stationary long-run steady-state behaviour of a system, this implication needs further investigation for non-stationary arrival behaviour in case of walk-in (Green, Kolesar, & Whitt, 2007).

3.5 Promising interventions

In order to give direction to the development of possible useful interventions, we studied several methods of balancing demand.

Schedule at periods of low demand

Rising, Baron and Averill (1973) conducted a case study on the use of mathematical computer models in developing operating policies for a university-health-service outpatient clinic. Their aim was to balance supply and demand, by determining the expected demand. Demand was divided in what they called an 'uncontrollable' and a 'controllable component'. The uncontrollable component consisted of emergency patients that walk in at some unpredictable moment, where the controllable component represented the number of patients that could be controlled by making an appointment.

In order to smooth the overall daily arrivals, they scheduled appointment patients during periods of low walk-in demand which were forecasted based on historical data. A Monte Carlo simulation model showed the effects of various decision rules for scheduling appointment periods during the day to increase patient throughput and physician utilisation. Their method was concluded to be successful, as the number of patients seen be a physician increased with more than 13%, while the number of physician hours decreased with 5%. Although walk-in patients in this case particularly concerned emergency patients arriving at the clinic without an appointment, the argument for smoothing demand holds. Walk-in demand can thus be complemented by using fixed appointments for inpatients and examinations that are not suitable for walk-in at periods of low demand, while leaving the peak times open for walk-in.

Call-in

A second scenario found in the literature is a situation where inpatients are not scheduled at all, but are on a waiting list and called in on periods of quiet in the waiting room. Instead of working with forecasted periods of low demand, the timing is entirely fitted to real-time demand. This scenario is amongst others applicable to the radiology department of the Alysis hospital in Arnhem. Described by Blake and Carter, Hancock authors several papers describing the development and use of an inpatient bed planning model (called Admissions Scheduling and Control System or ASCS) aimed at both patient service and high hospital bed utilisation. Because service requests and length of stay are variable he argues that resource allocation decisions are difficult to make. He therefore proposes call-ins during periods of low demand to restore census (Blake & Carter, 1997).

Realtime visualization

A third option to smooth demand is by offering a real-time visualization of the waiting time, so patients can decide for themselves if the waiting time at the moment of arrival is acceptable or not. An example of this application is described by Jost, Rodewald, Hill, and Evens who (in the early 80's) developed a computer system at the Mallinckrodt Institute of Radiology (St. Louis, Missouri) that measured and showed indicators real-time such as patient waiting time, report production time, room use, etc. (Jost, Rodewald, Hill, & Evens, 1982). Offering real-time visualization to smooth demand is quite an uncertain measure since it is unknown if patients are sensible for this kind of information in terms of arrival. Can arrival behavior be influenced in this way, and to what extent? Besides, the definition of an acceptable waiting time might vary substantially per individual and is inherent to patient characteristics and personal situation, such as travelling distance to the hospital, obligations at work, and other appointments, making forecasts difficult to interpret. However, it is an option worth considering when smoothing demand is not achieved to full satisfaction.

3.6 Conclusions

Quite some researchers in health care have focused on implementing open access in their (outpatient) clinic. While open access lies at the basis of walk-in, it does not entirely let go of making appointments as is the case with walk-in. As far as we know, no articles exist that specifically aim at introducing walk-in; most researches mentioning walk-in consider it a disturbance. An area still underexposed in research is the possibility of a combination of the appointment system and walk-in, where appointments for some patients are specifically utilized to counterbalance non-stationary walk-in demand. Little is known regarding the implementation of walk-in at central diagnostic facilities. The implications found in queueing theory illustrate a balance between waiting time and system utilisation. Analyzing this effect however is not straightforward, as standard queueing theory focuses on the long-run steady-state behaviour of stationary models, whereas we aim to incorporate non-stationary arrival. The considerations in general are thought to offer a solid motivation for further analysis of implementing walk-in.

Discrete event simulation is a useful tool to consider various hypothetical interventions in system set-up, and has been applied widely. The performance indicators that are found to be most used in these studies are access time, patient waiting time, utilisation of the resources, and overtime. Utilisation is often measured by the idle time that indicates how much of the time the doctor is idle (waiting for a patient). As our study concerns a diagnostic modality, utilisation of the resource instead of utilisation of personnel seems a more appropriate measure, even more since utilisation of expensive equipment can be argumented to be more important than idle time of CT scan personnel.

Cayirli and Veral (2003) conclude that most studies analyze the environment of a specific clinic and hence lack generalized applicability. In their eyes the biggest challenge in future research is to develop easy-to-use heuristics which are applicable to individual situations.

4 Experiment approach

In Chapter 4, we first design the interventions we wish to analyse quantitatively. Section 4.2 describes the development of the conceptual model which is used to imitate real system behaviour. The appointment scheduling rules and system algorithm is covered, and model attributes are identified. The last paragraph explains the selection of the experimental model which we will use to investigate the logistical performance of each intervention.

4.1 Design of interventions

To determine promising interventions, the schedules, appointment- and patient types currently present are taken as point of reference. Aside from interventions only allowing appointments or assuming 100% walk-in, we aim to assess combinations of both. Combinations consist of using specific blocks for patients on appointment, while the rest of the capacity is left open for walk-in.

First, we simulate the situation as-is, where 100% of the patients receive an appointment by using the schedule as is currently the case (intervention i0_a). This intervention is considered purely for validation purposes. To be able to fully show the difference between planning and walk-in, we also show the logistical performance of a hypothetical situation where all patients are planned, but all blocks allow all patients (intervention i0_b). Next, we calculate the performance for the hypothetical situation where 100% of the patients are allowed based on walk-in. Two interventions are assessed: the first requires walk-in patients that are rejected by the system or who decide to go home to come back randomly somewhere the next two weeks (intervention i1_a), the second requires the patients to come back the next day (intervention i1_b) which relates to the principle of keeping the access time as low as possible. Then, we assess interventions in which the patient or examination types that are scheduled vary to show the impact of various degrees of walk-in. To this end we determined patient- and examination types of which the radiology department might decide to allow these patients only by making an appointment. We first assess a situation where only patients that require an appointment are planned because of the obligatory presence of third parties (intervention i2_a). Examinations with oral contrast require patients to be sober, which imply that patients have not eaten in the 4 hours prior to the examination. Because of the possible negative consequences when those patients walk-in, we assess an intervention where examinations that require soberness are scheduled (intervention i2_b). The third intervention incorporates the possibility of patients to prefer to make an appointment (intervention i2_c), as this corresponds to the idea of offering the highest service possible. Subsequently, we assess a situation which allows inpatients to be called-in from the ward (intervention i3) during times of low demand, instead of planning an appointment. The last intervention calculates the performance for the situation that the radiology department is able to spread demand by better informing patients when to come back, which is expected spread demand. To this end, the expected arrival pattern is smoothened (intervention i4). Summarizing, the interventions we will assess are defined as:

- i0) 100% appointment
  - a. All patients are scheduled and arrive at their appointment date
  - b. All patients are planned, but in similar slots (only one slot-type is used)
- i1) 100% walk-in: all patients arrive by walk-in, after their outpatient clinic appointment
  - a. All patients that are rejected return randomly in next 10 days
  - b. All patients that are rejected return randomly, but somewhere the next day
- i2) Fixed blocks only for various patient types:
  - a. For cardiac patients, colonography, and treatments with anaesthesia
  - b. For cardiac patients, colonography, treatments with anaesthesia and sober patients
  - c. Same as 'b', but outpatients' preference is considered as well (patients are offered the choice of walk-in or appointment). Preference is based both on natural preference and on expected waiting time
- i3) Inpatients are called-in prospectively on periods of low expected waiting time
- i4) Influence the arrival pattern of walk-in patients

A general remark on intervention i2 is that soberness is not checked for when patients report for their appointment. Besides, laboratory workers acknowledged never to have sent away a patient because he or she was not sober. This disputes the need for patients being absolutely sober, and for this reason we assess both a situation in which they are planned, as a situation that allows them on a walk-in basis.

4.2 Interventions and adjusted planning and control

Our interventions require some adjustments to be made with regards to scheduling of the appointments. Intervention i2 strongly reduces the number and types of blocks used in patient scheduling, as only specific patient groups will be scheduled. The effect of combining walk-in and appointments is the strongest when appointments are scheduled during expected low walk-in arrival. Optimal schedules that regard the amount and placing of schedule blocks unfortunately could not be used, as the analytical model which provides these is still in development by PhD candidates N. Kortbeek and M.E. Zonderland. The appointment schedule blocks are therefore reduced and shifted manually. We choose to allow overtime in all interventions with walk-in, as we assume that rejecting patients does not comply with a service that allows patients at any time. The appointment schedule contains appointment blocks that represent the capacity assigned per examination type. Based on the context analysis phase, we classify the blocks in our schedule open for appointment as follows:

b1) Appointment blocks for outpatients
   a. For patients with large preparation times due to oral contrast (soberness required)
   b. For patients that prefer an appointment
b2) Examinations needing anaesthetics
b3) Cardiac examinations
b4) Appointment blocks for inpatients.
b5) Appointment blocks for colonography examinations
b6) Appointment blocks for orthopaedic examinations
b7) Appointment blocks for patients without IV contrast

Sub-bullets 'a' and 'b' under b1 emphasize that both patient types are scheduled in the same block type b1. It is important to notice that not all blocks appear in every intervention, as not all patient types are scheduled. This is shown in Table 9. Furthermore, blocks b2, b3, b5, b6, and b7 are open to both inpatients and outpatients, depending on the intervention.

	Sober patients (b1)	Appointment Preferred (b1)	Examinations with anaesthesia (b2)	Cardiac examinations (b3)	Inpatients (b4)	Colonography examinations (b5)	Orthopaedic examinations (b6)	Examinations without IV (b7)
i0_a	yes	yes	yes	yes	yes	yes	yes	yes
i0_b	yes	yes	yes	yes	yes	yes	yes	yes
i1_a	-	-	-	-	-	-	-	-
i1_b	-	-	-	-	-	-	-	-
i2_a	-	-	yes	yes	-	yes	-	-
i2_b	yes	-	yes	yes	-	yes	-	-
i2_c	yes	yes	yes	yes	-	yes	-	-
i3	yes	yes	yes	yes	call-in	yes	-	-
i4	yes	yes	yes	yes	call-in	yes	-	-

Table 9: Patients and examination-types that are scheduled per intervention

4.3 Conceptual model

We use the work of Robinson (2004) as a guideline for developing a conceptual model. Robinson states that six elements should be present in any conceptual model: 1) Model objective, 2) Input, 3) Content, 4) Output, 5) Assumptions and 6) Simplifications. Although we primarily consider a specific case-mix, generalisation is a goal that will be taken into account in our modeling phase.

4.3.1 Model objective

We formulated the following model objectives:

- The model gives a reliable reflection (with a confidence interval of at least 90%) of the patient flow process of the CT scan department in AMC, including estimates on arrival times, service times, and patient characteristics
- The model allows to simulate the dynamical behaviour of the system (queueing due to varying service times and non-stationary arrivals)
- The model output is unambiguous, and offers an insight in access time, waiting time, utilisation, production, and number of rejected patients for various operating policies
- The model must be detailed, flexible, and user friendly, parameters must be easy to change in order to easily assess various interventions
- The model must remain generalized applicability for other CT scan departments

4.3.2 Input

Each intervention contains a choice how to deal with the access of certain patients to the CT, represented by a schedule and a set of parameters concerning the patient categories and their specific properties. To reliably analyze the effects of each intervention, we determine input variables based on the overview and definitions provided by Cayirli & Veral (paragraph 3.2.1).

Appointment scheduling

The decisions to plan an appointment are illustrated in Figure 4, but rules can be turned on or off for various interventions. The algorithm developed searches for the first open slot in the schedule that fits this patient type (for a colonography examination it for example searches for the first block b5) which has not already been assigned to another patient. The probability of a patient preferring an appointment is incorporated as $P_{preferred}$. We assume patients prefer an appointment if the expected waiting time is beyond a certain threshold $Z_{waitingtime}$. The expected waiting time is based on the number of patients currently in the system, but also considers planned patients. The more patients in the waiting room, the further ahead planned patients are considered. During scheduled appointments walk-in might occur simultaneously because of the availability of 2 CT scans.

Patients that have to drink oral contrast for 30 or 60 minutes are allowed until 4:00 PM and 3:30 PM respectively, because of the preparation time. During days of maintenance, we adhere to a maximum capacity of 30 walk-in patients for one CT scan to avoid large clustering in the waiting room.

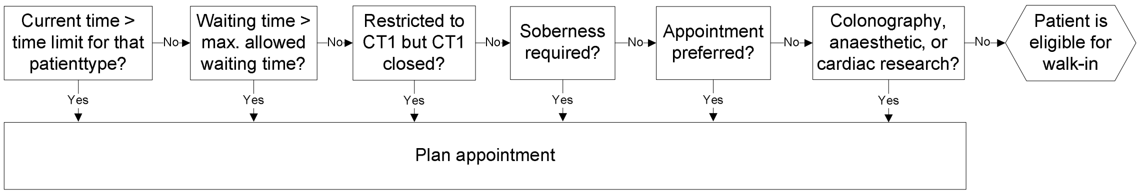

Figure 4: Decision rules to decide on walk-in eligibility

In our planning algorithm, we adhere to a maximum allowed access time for inpatients and urgent outpatients $Z_{maxATinpat}$, and patients without IV contrast $Z_{maxAToutpat}$ which is similar to practice. The maximum allowed access time enables the schedule to allow other blocks. For example for inpatients, if no inpatient blocks have been found available soon enough regular outpatient blocks and urgent blocks are verified as well. The maximum allowed access time for patients without IV contrast is required, since patients without IV contrast are preferably planned between 12:00 AM and 02:00 PM, but are also allowed in other slots if their access time exceeds the threshold value. In Appendix A, we describe the specific steps that the planning algorithm developed here follows.

A problem we encountered is that in practice, the planning department often does not actually check for the first available appointment, but selects an appointment slot manually. The selection criteria vary, and some employees plan in a backwards manner (e.g. two weeks prior to the next appointment at the outpatient clinic) and hence negatively influence the retrospective access time value measured. However, we adhere to the prospective access time as this represents the minimum attainable access time, which still can be compared among the interventions.

Patient class & queue discipline

There are two different patient classes upon which the queueing discipline applies: patients that are scheduled, and patients that walk in. Patients with an appointment acquire priority over patients that walk-in when their appointment time has passed, as we do not wish planned patients to encounter high waiting times because of walk-in patients. Before their appointment time, walk-in patients are preferred since they experience all waiting time as such (patients that are early only suffer *voluntary* waiting time). At last, patients who are restricted to CT1 are prioritized above others, since other patients can be served by CT2 as well.

Patient attributes

Arrival rate of requests

We incorporate time-dependent arrival averages in order to imitate an expected day-to-day, as well as a within-day fluctuation of CT scan request arrival at the CT department. We identify a time interval {t, t+h} (in our model h is set to 15 minutes). The number of visits λ per time interval h is assumed Poisson-distributed since they occur with a known average rate and are independent from each other. The total number of arrivals per day is then Poisson distributed too. The arrival average over the day varies and is based on the referring outpatient clinic daily consultation hours which are divided in quarters. The within-quarter interarrival time follows a uniform distribution.

Our simulation model handles the CT scan request arrival rate of inpatients and outpatients independently. At the planning department it is determined whether the patient can immediately proceed as walk-in or if an appointment needs to be made. The arrival distribution of inpatient requests could not be determined since no data was available on the time of origin of inpatient requests. After consulting several inpatient clinic departments, we chose to assume a Poisson-determined total number of inpatient requests per day based on historical data, of which the time of origin is spread over the day according to a uniform distribution.

Patient punctuality

Patients that have an appointment can be early or late according to a probability distribution $Punct_X$. Since we measured a different punctuality for inpatients and outpatients we adhere to this as well. No-show is only assumed for outpatients with a deterministic probability of P_{noshow}.

Request assessment time

The assessment of each application by a radiologist is an AMC-specific occasion. Because taking this into account might oppose the aim to create general applicability of our model, we choose to incorporate a switch to determine whether the assessment time by a radiologist is taken into account or not. The time the assessment takes into account is given by the distribution $Assessment_x$.

Preparation time

The setup process primarily considers the placing of an IV access line in case necessary, of which the time varies according to the distribution $Setup_X$. The setup process might also consider extra set-up time like determining kreatinine-values if unknown and time for applying anaesthesia.

Service time

The service time (CT scan time) per patient group is given by the distribution $Service_X$. Patient groups might vary from patient types; for example when service time depends on the need of IV contrast rather than patient type. The transportation time between locations at the CT scan department is included deterministically; transportation time from the inpatient ward to the department follows a distribution $Transportation_X$.

Preparation-related properties

There are several patient properties that influence the routing of patients, and the time each step takes. These are:

- The need for oral contrast, which either requires 30 minutes (P_{oral30}) or 60 minutes (P_{oral60}) preparation time (however, deviation of a couple of minutes is allowed)
- The requirement of soberness (P_{sober})
- The need for intravenous contrast (P_{iv}), which yields some optional exceptions:
    - Patients might be allergic to IV contrast ($P_{allergic}$); in this case the patient is planned
    - Patients' kreatinine values can be unknown or missing ($P_{kreatinine}$); if it is before 3:30 PM the patient is referred to the laboratory to test for these kreatinine values., otherwise an appointment is offered.
    - Problems can occur with placing an IV ($P_{ivproblem}$); when this occurs the help of a third party is called for, which can be another laboratory worker, doctor, or the like.

    A deterministic amount of time is assigned to these activities. An assumption we made in line with laboratory workers experience, is that these patient properties are equal for inpatients and outpatients.

Capacity

Number of servers

The number of servers is the number of CT scans at the department under scrutiny.

Server properties

The CT scans are not fully interchangeable; some examinations have to be done on the newest CT scan (CT1) while others can be performed on both machines (see Table 2, section 2.3). Planned patients are always served on the CT scan at which their appointment is planned, for walk-in patients it is assumed that they can be served by both CT scans as long as they are not restricted to CT1.

Variable server capacity during the day

Variable server capacity considers CT scan downtimes consisting of coffee breaks (one CT, 2x15 minutes per day), periodical maintenance (both CT scans 4 times a year, closed entire day), calibration (CT1: 1x 20 minutes every day around 12:45 pm which is somewhat flexible), and break-down. Break-down ($P_{breakdown}$) is the only capacity-restraining event that does not happen periodically, and is very hard to predict. Besides, only break-down is a pre-emptive interruption. Server capacity might furthermore increase when overtime is accepted. Maintenance (and closure due to personnel shortness) of both CT scans is always planned ahead. Appointments are not scheduled on CT scans that are planned to be closed; in case walk-in patients are restricted to CT1 but CT1 is closed at walk-in they are offered an appointment. If the patient is not restricted, he will be served by the other CT scan (if available). In case of breakdown, planned patients are called off and rescheduled. This policy might seem arbitrary, but is chosen to minimize the number of hospital visits for patients since walk-in patients are already present at the department.

Dynamic resource constraints

With dynamic resource constraints, we consider the constraints imposed by personnel. For example, administering IV contrast requires the supervision of a radiologist (which means he has to be in the adjacent room, at least). In the current situation, the radiologists have a meeting each day between 12:00 am and 02:00 pm, hence during this time only patients without IV are allowed. With walk-in, examinations with IV contrast need to be possible the entire day, hence requiring the continuous presence of a radiologist. Also, when patients walk in directly after referral from their outpatient clinic, the application assessment needs to happen immediately. This also stretches the need for a radiologist to be present.

Examinations that require the presence of a cardiologist or anaesthetist are assumed to be scheduled in fixed time-blocks under accordance with the concerned specialists. We assume that specialists are always present during these blocks and that they always arrive on time. Since these examinations cannot start before the medical specialist is present, patients that are early have to wait until the block has started.

Content

Figure 5 schematically simplifies the patient flow at the CT scan. The actions at each location are listed:

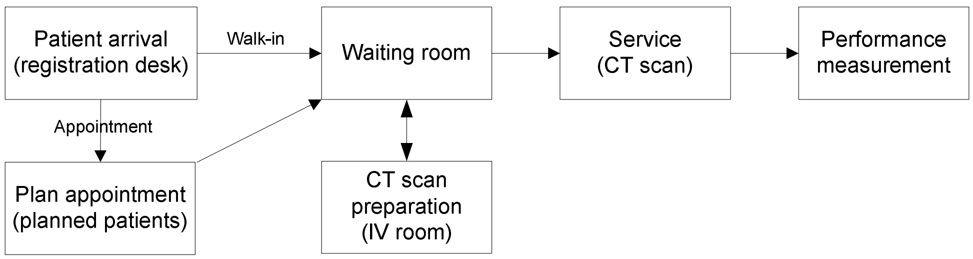

Figure 5: schematic process at the CT scan

Patient arrival

- Assign specific patient properties
- Route to registration desk

Registration desk

- Determine if appointment is required/preferred, following the criteria:
  - If arrival is later than 4:30 PM (for patients who have to drink contrast for 30 or 60 minutes, arrival is allowed until respectively 4:00 PM and 3:30 PM)
  - If expected waiting time > 1.5 hours
  - If restricted to CT1 but CT1 is closed (due to maintenance or breakdown)
  - If soberness is required
  - If an appointment is preferred
  - If examination is anaesthetic, cardiac, or colonography

  If one of these criteria is true, than plan an appointment.
- Else forward to waiting room as walk-in
  - Wait for the application assessment
  - Refer to waiting room for CT scan
- The number of patients that request an appointment because of high waiting times are counted, as well as the number of patients rejected because of system constraints:
- Assign priorities (based on queue discipline)
- Start waiting time measure

Planned patients

- 'Release' patient at the time of the appointment
- Include punctuality and no-show

Waiting room

- If oral contrast is needed → administer contrast and wait for 1 hr (If IVC is also needed, we assume this happens within the same hour as indicated in practice)
- If IVC is needed: route patient to the service setup (IV room)
- Queue according to priority and mandatory waiting time (see 'queue discipline').
- All planned patients are routed to the CT scan at which they were planned, walk-in patients can be routed to both CT scans unless the examination of the patient is restricted to CT1.

Preparation (IV room)

- The intravenous access line is placed
- Account for specific IV properties (allergic, kreatinine value unknown, call for backup in case of difficulties with placing); route to a third location if a problem occurs
- Route back to waiting room

Service (CT scans)

- Stop waiting time measure and correct for time spent drinking contrast and time in IV room
- Account for service time for making the scan
- In case of breakdown: all planned patients are cancelled and rescheduled

Output

- Register performance indicators: access time, waiting time, production and utilisation, and overtime.

4.3.3 Additional intervention rules

For some interventions, some additional rules were necessary. In case of 100% walk-in (intervention i1), patients also consider the expected waiting time. However, if they decide not to join the queue (the expected waiting time is larger than 1.5 hours), they are assumed to come back randomly somewhere during the next two weeks. It is kept how many times patients decide not to join the queue (number of revisits) rather than measuring the access times, since patients come back randomly. In case of inpatient call-in (interventions i3 and i4), the maximum number of patients on the list for call-in is limited to ten to avoid large clustering. Inpatients exceeding this maximum are offered an appointment. Patients are called-in when the expected waiting time is below a certain threshold $Z_{waitingtimecallin}$. We deterministically appointment a CT scan to all patients who are not restricted to CT1, to avoid extensive call-in in case one of both CT scans is closed. For example, when an inpatient is assigned to CT2 but CT2 is closed for maintenance that day, the inpatient waits an extra day.

4.3.4 Output

The output parameters for our model are equal to the parameters used for evaluating the performance of the CT department described in section 2.3.

Access time (for scheduled patients)

The access time is measured in days between making the appointment and receiving the actual CT scan. We measure both prospective access times which is determined each month for several patient types by searching the third slot available, as well as retrospective based on patients' realized access time in the simulation. The access time of rejected or rescheduled patients is the sum of the access time for both appointments.

Patient waiting time

For the performance measure, we only wish to determine the involuntary waiting time, which is imposed by the system. Set-up time and waiting due to earliness should not be included. Nevertheless, the model measures waiting time in minutes, from the moment patients register at the counter until they enter the CT scan room, including all voluntary and involuntary waiting. We choose this specific definition since it directly corresponds to the times that were registered during the 2-week time-measurement at the CT scan department and hence offers good comparison, useful for validation purposes. For the performance measurement, we subtract the preparation time for oral contrast and earliness afterwards. The time in the IV room stays incorporated in the waiting time as we did not specifically measure this during the time measurement and hence couldn't subtract these. Both average waiting times as the waiting time which holds for 90% of the patients ($Y_{waitingtime}$) is measured, representing the service level.

Utilisation and production

Daily utilisation is measured as the sum of scan time per CT scan in regular opening hours, divided by the total amount of minutes the department was open. We only count during regular opening hours as the utilisation in overtime per definition should be high and hence can skew the outcome. Production is measured as the amount of CT scans made per day.

Overtime

An opening time constraint related to hospital policy is the allowance of overtime. A hospital might for example decide to treat all patients that walk in the same day, where another policy might prescribe to refuse patients when the waiting time is above a certain threshold. Both policies obviously influence efficiency and patient service, and relate to the percentage of rejected patients. Overtime is measured as the time the last patient leaves the CT scan minus the closing time of the CT department (5:00 pm). Overtime hence can either be negative (indicating earliness) or positive (actual overtime). An important notion (which should be correctly modelled) is, that with walk-in negative overtime is limited since patients might still arrive. We both measure average overtime as well as the number of days the overtime exceeds the threshold value $Y_{overtime}$.

Patients rejected

Patients that encounter high waiting times might voluntarily decide to plan an appointment rather than joining the queue. Also, hospital policy might prescribe to reject patients. Rejections are system-imposed, for example because of CT scan breakdown or closure. A third category is the number of patients rescheduled, which is imposed because of treatment requirements for example when a patient is allergic to contrast. The amount of patients that decide to plan an appointment or that are rejected are recorded for every day.

4.3.5 Assumptions & simplifications

We provide a short overview of the assumptions and simplifications made in the conceptual model.

Assumptions

- Radiologists do not impose bottlenecks in the process and are always present during walk-in
- Walk-in only exists for the same day. If patients are rejected they always receive an appointment
- Transfer from the ward to the CT scan in case of inpatient call-in is exponentially distributed with a mean of 20 minutes, including the application assessment
- All patients allow a same expected waiting time of $Z_{waitingtime}$, and in case of violation decide to make an appointment
- Walk-in patients not restricted to CT1 are assumed mutually exchangeable on both CT scans.
- In case of planned patients, the request assessment is assumed to have taken place before the appointment in all cases.

Simplifications

- Laboratory workers are not modelled as dynamic resources. However, since they do impose bottlenecks resulting in capacity shortage in practice, we chose to stochastically determine what days to close the CT scans in a manner strongly representative of the current situation. The number of days the CT scans are closed and the day in the week are in consensus with practice.
- The waiting room capacity is infinite
- In our planning algorithm, CT1 is considered before CT2 (and hence creates a higher load on CT1)
- We use a single block schedule from 2008 for the entire year, which was verified by the department to be representative. However, in practice schedules might change over the year

- In case of breakdown of one of both CT scans, we limit the number of walk-in patients that are allowed (N = 30, which is the maximum capacity) and offer the rest of the patients an appointment. In practice, patients might be referred to the CT scan at the trauma department

4.4 Selection of experimental method

A model is a tool used for managerial purposes to predict the consequences of various alternative interventions, without actually changing the system (Law, 2007). Three types of models for the design and control or patient flow processes are commonly used in healthcare: descriptive models, analytical models, and computer simulation models (Van Sambeek, 2009). This review showed that descriptive models are only applied to process design problems as they lack quantitative properties, while we are dealing with a scheduling problem. Analytical models are exact and quantitative, but often require making a lot of assumptions and simplifications. Computer simulation models can endlessly be tailored to increase accuracy, but are very data-intensive and development can be time-consuming. Our context analysis has shown that this particular system has quite some specific issues to take into account that we would like to study in detail, like the fact that scheduled appointment blocks for specific patient types are soft blocks, where walk-in might still be allowed once not scheduled fully. We must assume non-stationary queues, since the arrival rate probability fluctuates over the day and over the week. The servers are not identical, creating multiple queues. Servers can suffer from both periodical and probabilistic downtime and various patient types, paths, and disturbing events exist. An analytical model which combines planned appointments and walk-in for the CT is developed concurrently by N. Kortbeek and M.E. Zonderland (two PhD candidates), simultaneously to this research. Their research can offer valuable input on determining the optimal number of blocks necessary, and how they should be spread over the week. Our study however aims to give a more accurate insight in the day-to-day implications described above for the logistical performance. To this end, we decide to develop a discrete-event simulation model which is used to assess the various interventions set forth in section 4.1. The model is developed using the medical simulation software MedModel Professional, ©2005 by ProModel Corporation.

5 Computational experiments and results

This chapter describes the results from our experiments. First, the basic scenario is constructed from the input data gained, in which we make an assumption on the expected arrival rate, and fit distributions on specific patient properties.

5.1 Construction of scenarios from input data

In order to create useful input data for our simulation model we quantify the input parameters determined for our case. Quantification of data is based on the data analysis described in section 2.3, attribute chances of all patients are assumed to be representative for both inpatients and outpatients. Input data modeling is achieved by fitting standard probability distributions to observed data using the statistical software Stat::Fit©. Distributions are fitted using Sturges' rule for the number of intervals k.

Arrival rate

To describe the arrival rate of planned outpatients and inpatients, the data analysis over 2008 is presumed to be a reliable representation. We calculated specific properties like punctuality and no-show, and adhere to the length of appointment slots: 15 minutes for outpatients, 30 minutes for inpatients. Regarding walk-in, it is unknown what the arrival rate will be since walk-in currently does not exist, which requires a plausible assumption to be made. We assume a walk-in pattern (amount of patients that are expected to arrive per time interval) that would be attained when a patient is directly referred to the CT scan after his consult at the outpatient clinic. This policy theoretically increases patient service by eliminating access time as much as possible and thus enabling the possibility of a one-stop-shop, and by offering outpatients free choice. To predict the arrival pattern, we evaluated the clinic agendas of the eight most-referring specialties to determine the amount of consultation hours, which together account for 81.6 % of all outpatients CT scan requests. Given the specialty reference ratios (based on the amount of CT scan applications of that specialty divided by the total number of patients seen on that outpatient clinic), and by including 30 minutes of transfer-time to the average end-time of each consult, we deducted an expected arrival rate for each quarter of the day, as illustrated in Figure 4. The resulting pattern of these eight referring clinics has been extrapolated to match the total number of arrivals.

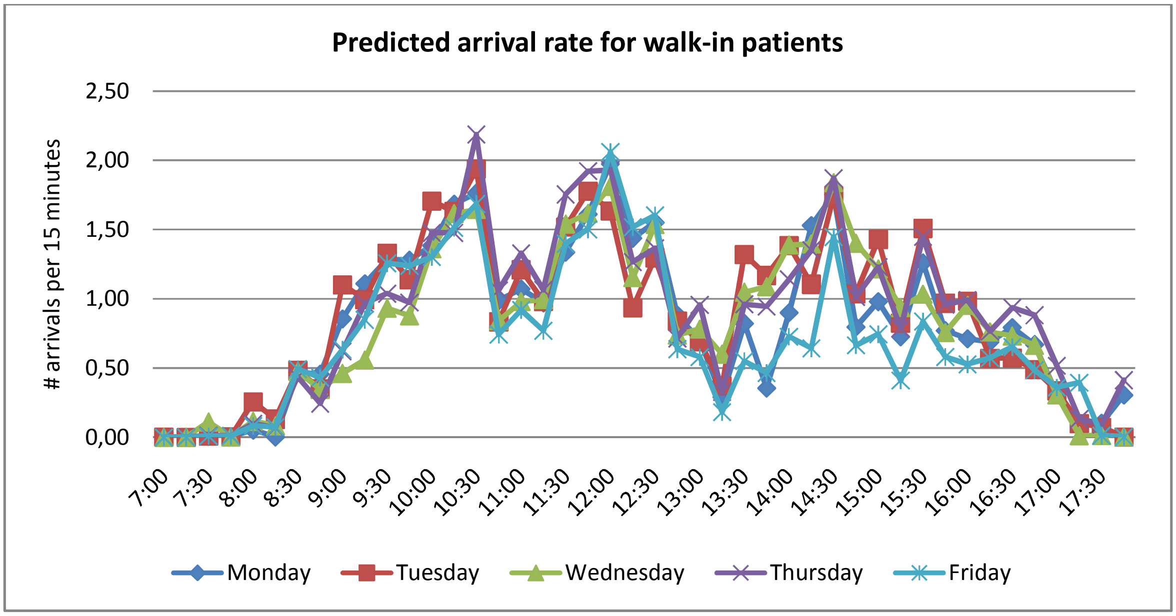

Figure 6: Expected arrival rate for walk-in patients

Patient punctuality (only for scheduled patients)

A distribution is fitted on patient punctuality on the data over the two-week time measurement. A statistical significant difference has been found between inpatient and outpatient punctuality (t-test value = 4.41 > 1.96, d.f. = 361, α=.05). The inpatient punctuality is found to follow a Beta distribution (N = 36) with parameters α = 6.35, β = 18.31, minimum value = -48 and maximum value 168.44. (KS-stat: 0.104, AD-stat: 0.264). On average, inpatients were somewhat over 6 minutes late. Outpatient punctuality is found to follow a Weibull distribution (N = 327) with parameters α = 7.10, β = 163.21, and minimum value -166 (KS-stat: 0.070, AD-stat: 2.68). Outpatients are a little over 13 minutes early on average. No-shows are assumed to follow a binomial probability of p = 0.031 for not showing up.

Preparation time

A measurement is conducted over several days in July and August 2009 in which the time is recorded it took to place the intravenous access line. Secondly it was recorded whether the kreatinine-values of a patient were not available, if back-up was requested, and if problems with allergy surfaced while placing the IV. These were used to update the estimates by the expert laboratory workers. The service setup time was found to follow an Inverse Weibull distribution (N = 86) with minimum = 2, and parameters α = 1.29 and β = 0.33 (KS-stat: 0.129, AD-stat: 1.2). On average, the service setup takes just under 9 minutes.

Service time

The data of our time measurement showed minimal differences in the mean scan time (time the CT scan room is occupied) of inpatients (13.25 minutes) and outpatients (11.34 minutes). A t-test analysis of the means (N=36, N=302) was performed to test this hypothesis, and no statistical difference in service time could be found. This is remarkable since 30 minutes are reserved for inpatients while only 15 minutes are reserved for outpatients. Further analysis did show a significant difference in service time between patients needing intravenous contrast and patients who did not. This difference was acknowledged and explained by an expert laboratory worker, who recognized that when using IV contrast, more images often need to be made. Distributions therefore are fitted on the service time data for both patients with and without IV contrast. Service time without contrast has an average of 9.32 minutes, and is found to closely resemble a Pearson-5 distribution with parameters $\alpha = 2.732$, $\beta = 17.387$, and $\gamma = 0$ (KS-stat = 1.008 with $\alpha = .05$, N = 183). The service time for patients with IV contrast is on average 14.03 minutes, and is found to follow a loglogistic distribution with parameters $\alpha = 3.198$, $\beta = 10.676$, and $\gamma = 2$ (KS-stat = 0.062 with $\alpha = .05$, N = 203).

Specific properties

To determine whether a patient needs oral and/or IV contrast, we assume a probability $P_{Oral30} = 0.083$ if oral contrast needs to be administered for 30 minutes, $P_{Oral60} = 0.149$ if oral contrast needs to be administered for 60 minutes, and a probability $P_{IV} = 0.536$ if intravenous contrast is necessary. These probabilities are determined based on PACS data over 2008. The probability for being restricted to CT1 is assumed binomially distributed with $P_{ct1} = 0.4$. Furthermore, we estimated the probabilities $P_{allergic}$, $P_{kreatinine}$, and $P_{ivproblem}$ based on laboratory worker experience.

Number of servers

Our simulation model adheres to the current situation at the AMC radiology department. The model hence accounts for two CT scan modalities since the trauma-CT is not included in this study.

One general remark on all properties and attributes just described is that caution was applied when defining them. For example, the time-measurement that was conducted allowed for human mistakes, as the researcher was not present during the measurement and there was no reminder or incentive which motivated participants to be strict with regards to the measurement. To this end, we eliminated registrations that had a deviation over 10 minutes from the registration in the picture archiving system PACS, which records a time that corresponds to the time the system was ready for the next patient.

Correlation

All input parameters are summarized in Table 10. Values can depart from the data analysis, because of the correlation between the parameters. The values in the table hence represent the input value in the model.

The patient properties IV contrast (IV), drinking contrast 30 minutes (Oral30), drinking contrast 60 minutes (Oral60), examinations restricted to CT1 (Restricted) and the need for soberness (Sober) are tested for correlations to eliminate the effect of overrepresentation in case of linear relations. The matrix below shows the results of the bivariate correlations procedure where the correlation significance is tested at the 5% level. Significant correlations are indicated with an asterisk. The significant correlations have to be accounted for when modelling input data.

Correlations

		Oral30	Oral60	Restricted	Sober
IV	Pearson Correlation	,198*	,129	,304**	,249*
	Sig. (2-tailed)	,044	,191	,002	,011
	N	104	104	104	104
Oral30	Pearson Correlation		-,056	,310**	,794**
	Sig. (2-tailed)		,571	,001	,000
	N		104	104	104
Oral60	Pearson Correlation			-,089	,420**
	Sig. (2-tailed)			,367	,000
	N			104	104
Restricted	Pearson Correlation				,323**
	Sig. (2-tailed)				,001
	N				104

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Input parameter	Input type	Description	Value
$Punct_x$	Inpat: Beta distribution Outpat: Weibull distribution	Patient punctuality	$\alpha_1 = 6.35$, $\alpha_2 = 18.31$ $\alpha = 7.1$, $\beta = 163.21$
P_{noshow}	Binomial probability	No-show	p = 0.031
$Arrival_\lambda$	Poisson distribution	Arrival time	λ changes per h = 15 min.
$P_{preferred}$	Deterministic probability	Appointment Preferred	p = 0.200
$Assessment_x$	Lognormal distribution	Request assessment time	$\mu = 5$, $\sigma^2 = 2$
$Preparation_x$	Pearson5 distribution	Preparation time for IV	$\alpha = 1.58$, $\beta = 5.25$ (- 2)
$Service_x$	With IV: user defined distr. Without IV: Pearson5 distr.	Service time	$\mu = 9.32$, $\sigma = 9.19$ $\alpha = 2.73$, $\beta = 17.39$ (-2)
$Transportation_x$	Exponential distribution	Inpatient transportation time	$\beta = 20.00$
P_{oral30}	Deterministic probability	Oral contrast (30 minutes)	p = 0.098
P_{oral60}	Deterministic probability	Oral contrast (60 minutes)	p = 0.195
P_{sober}	Deterministic probability	Soberness required	p = 0.029
P_{iv}	Deterministic probability	IV contrast required	p = 0.612
$P_{allergic}$	Deterministic probability	Allergic to IV contrast	p = 0.023
$P_{kreatinine}$	Deterministic probability	Kreatinine values unknown	p = 0.075
$P_{ivproblem}$	Deterministic probability	Problem with placing IV	p = 0.038
$P_{restricted}$	Deterministic probability	Patient restricted to CT1	p = 0.331
$Y_{waitingtime}$	Performance measurement	Waiting time	90%
$Z_{waitingtime}$	Maximum threshold value	Waiting time	1.5 hours
$Z_{waitingtimecallin}$	Threshold value	Threshold for releasing inpatients for call-in	20 minutes
$Y_{overtime}$	Performance measurement	Overtime	90%
$Z_{maxATinpat}$	Maximum threshold value	Maximum threshold for access time inpatients	2 days
$Z_{maxAToutpat}$	Maximum threshold value	Maximum threshold for access time outpatients w/o oral contrast	4 days

Table 10: Input parameters defined

5.2 Verification and validation of the simulation model

To illustrate the difference between verification and validation, we adhere to the definition given by Balci (1998): "*Model verification is substantiating that the model is transformed from one form into another, as intended, with sufficient accuracy. Model verification deals with building the model right* [...]. *Model validation is substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives. Model validation deals with building the right model.*"

Verification of the process and model

To verify and validate simulation models, various techniques exist. They generally can be divided in qualitative and quantitative techniques. Qualitative techniques employed in this study contain data gathering and -analysis from hospital databases, system observations, and the study of existing literature. Various conversations with the head of the radiology department, the laboratory workers and employees of the planning department helped to gain an understanding of the way the radiology department operates and hence should be modelled. Structured walk-troughs of the simulation model have been performed, and with the assistance of knowledgeable individuals formed a conclusive view on the CT scan department. A pilot run of one year helped to determine the validity of the programmed model. After sufficient coherence was obtained on the pilot model, we employed various quantitative techniques to test the statistical similarity between the real world system and the simulation model. Since the input parameters (e.g. patient punctuality and service time) have been verified in the previous section, we now focus on the verification and validation of output parameters: access time (both pro- and retrospective), waiting time, production & utilisation (per day, per year) and overtime.

Warm-up period

Effectively, we have two systems that are interwoven: a non-terminating system that represents the planning process, and a terminating system representing the day-to-day imaging process in the CT scan department. Both can be validated independently. The non-terminating simulation converges to a status quo over some time but, since we begin with an empty system, requires the determination of a warm-up period defined as the time to reach this steady state. Data from the warm-up period is then omitted from the actual data analysis. The warm-up period is determined both for intervention i0 and i1 by using Welch's method, based on the calculation and plotting of moving averages (Robinson, 2004). To determine whether the system has reached steady state we look at the number of patients that are on the list with planned patients, i.e. patients that have received an appointment and are awaiting the occurrence. The graph flattens after 40 days, which is the warm-up period.

Run-length and number of replications

To ensure that enough output data have been obtained from the simulation in order to estimate the model performance with sufficient accuracy, we select an appropriate run-length and determine the number of replications. Since we have multiple interventions, we estimate and later verify the run-length and number of replications separately for two interventions: i0 and i1, since these are expected to carry the most variability. The run-length (in number of days) is determined by using the convergence method proposed by Robinson (2004). This method inspects the cumulative mean averages for multiple periods (days) and replications until a convergence of typically less than 5% is obtained. We chose to take the average waiting time per day as convergence measure, which is below 5% after 117 periods (days) and hence should provide a sufficient run-length. However, an entire year (50 weeks of 5 days) is simulated because of seasonal influences we perhaps wish to include in a later stadium.

We determined the number of replications by determining the width of the confidence interval for an increasing number of replications until a probability of 95% is gained that the value of the true mean lies within the confidence interval. The estimation on average waiting times in intervention i0 achieve this probability after 6 replications of one year ($\alpha = 4.02$). We again tested the confidence interval on the same values in intervention i1, and achieved sufficient confidence after 5 replications ($\alpha = 4.54$). We chose to run all interventions with 10 replications, and verified afterwards that in all other interventions, 10 replications yielded sufficient confidence.

Validation of the planning process

The only available performance indicator which can be used for validation of the planning process is the access time gained for each patient type, as no other performance indicator is influenced directly (see). However, since the retrospective access times of patients were not reliable (see section 2.3.3.), it only proved possible to use the prospective access times determined by the third available slots. We performed independent t-tests for equality of means to test for significant difference in access times between the real system and the simulation model, for each patient type. We found a significance of 0.53 for orthopaedic patients, 0.33 for patients without IV contrast, 0.55 for patients with IV contrast, and 0.51 for inpatients which all indicate similarity in data. The 95% confidence interval on the difference also includes zero in all four cases, indicating that no significant difference in real system and simulation model access times could be identified. However, as the number of observations is small (N = 12) as access times are only determined monthly these results should be interpreted with caution.

Validation of the imaging process

To verify the day-process, the waiting time is used as independent performance parameter to assess the similarity between our model and the real situation. An independent-sample t-test is used to compare two separate independent and identically distributed samples, in our case the real world system sample (2 week measurement with N = 386) and the simulation model sample (1 run of 1 year with N = 10910) of the waiting time. As large sets of data are available, a confidence-interval approach is applied. The t-test value of 0.772 is measured with a significance of 0.441. The 95% confidence interval includes zero {-1.35, 3.10} and hence we reject the hypothesis of the two samples being significantly different.

5.3 Analysis of interventions in the current situation

We now turn to the results of our interventions, which are presented in an overview per performance measure for all interventions to allow for easy comparison. The interventions are placed in columns; the rows indicate the specifics of the parameter measured. Table 11 shows the access times found for the interventions employed. Orthopaedic patients represent 10.7% of all patients, without IV 29.0%, with IV 45.5%, and inpatients 14.8%.

Access Time (days)

		i0_a	**i0_b**	**i1_a**	**i1_b**	**i2_a**	**i2_b**	**i2_c**	**i3**	**i4**
% planned		*100%*	*100%*	*0%*	*0%*	*16.1%*	*45.3%*	*47.8%*	*55.5%*	*55.4%*
Prospective	Orthopaedic	3.77	1.30	-	-	4.98	1.43	2.58	2.73	2.60
	Without IV	3.64	1.30	-	-	3.71	2.77	3.08	2.98	2.89
	With IV	2.33	1.30	-	-	1.32	1.12	1.18	1.16	1.12
	Inpatients	2.17	1.26	-	-	1.10	1.43	1.35	1.93	1.84
Retrospective	Orthopaedic	3.47	1.37	Random	1.00	2.78	1.51	1.64	1.69	1.68
	Without IV	3.57	1.60	Random	1.00	3.02	2.61	3.02	2.97	2.96
	With IV	2.72	1.61	Random	1.00	2.67	2.67	1.62	1.53	1.52
	Inpatients	2.36	1.57	Random	1.00	1.53	1.59	1.60	6.19	4.46

Table 11: Access time per intervention

The appointment schedule that is applied naturally has great influence on the access times of planned patients. Access times for various patient groups can easily be controlled by changing the number of slots. An optimum hence is expected to exist, not only in terms of the amount of slots and slot types, but also in terms of clever scheduling during periods of low expected demand. Schedule optimization lies outside the scope of this research, but a research conducted concurrently focuses exactly on this topic and could provide valuable input. The most important implication is that the access time imposes no problems for planned patients as the access times for all patient types remain below the access times in the current situation (i0_a). More blocks for inpatients should be allowed, as access times exceed the maximum allowed access time of two days. Caution should be applied when interpreting these numbers because the prospective access time always is determined at the same moment each month, and therefore might deviate from actual (retrospective) access times.

Waiting time (minutes)

	i0_a	i0_b	i1_a	i1_b	i2_a	i2_b	i2_c	i3	i4
Planned inpatients	12.22	10.76	-	-	7.78	4.08	6.01	-	-
$Y_{waitingtime}$ *(90%)*	44.00	39.00	-	-	26.00	28.00	31.00	-	-
Planned outpatients	10.95	9.84	-	-	7.99	5.20	6.58	8.01	7.64
$Y_{waitingtime}$ *(90%)*	44.00	41.00	-	-	34.00	37.00	35.00	41.00	40.00
Walk-in inpatients	-	-	27.37	28.84	27.21	29.48	28.69	14.62	13.43
$Y_{waitingtime}$ *(90%)*	-	-	83.00	84.00	81.00	75.00	72.00	42.00	39.00
Walk-in outpatients	-	-	33.37	33.85	34.84	35.04	34.83	35.42	35.38
$Y_{waitingtime}$ *(90%)*	-	-	92.00	93.00	94.00	82.00	83.00	84.00	83.00

Table 12: Waiting times for planned patients and walk-in patients per intervention

The waiting time (Table 12) is independently measured for planned patients and walk-in patients, and as well for inpatients and outpatients. Table 11 shows the percentages of planned patients, which is between 45% and 55% in interventions combining walk-in and appointments. Interventions i3 and i4, where inpatients are called in, consider inpatients as walk-in patients. The indicator $Y_{waitingtime}$ indicates that 90% of the patients have a shorter waiting time than value Y for that intervention. In interventions where walk-in is combined with walk-in, the average waiting time for planned patients lies between 4 to 8 minutes, and between 26 to 41 minutes for 90% of the patients which is lower than the basic situation (intervention i0_a). Waiting time for walk-in patients is between 27-35 minutes, and lies between 39 to 94 minutes for 90%. When calling-in inpatients, the waiting time for these inpatients drops to around 14 minutes. Waiting times are quite stable for both planned patients and walk-in patients, independent of the intervention chosen. We subscribe this to the explicit priority we give to planned patients over walk-in patients, which is equal over all interventions.

Overtime (minutes)

	i0_a	i0_b	i1_a	i1_b	i2_a	i2_b	i2_c	i3	i4
Average overtime	19.58	22.09	32.16	35.59	28.59	27.21	25.71	25.09	24.87
Overtime occurence (% days)	26%	26%	64%	63%	49%	52%	42%	43%	44%
Average undertime	-30.11	-30.73	-18.15	-18.07	-21.11	-20.57	-22.77	-23.69	-22.89
Undertime occurence (% days)	74%	74%	36%	37%	51%	48%	58%	57%	56%
Overall average	-17.43	-17.00	14.11	15.77	3.06	4.14	-2.27	-2.71	-1.91
$Y_{overtime}$ *(90%)*	18.00	20.00	56.00	63.00	45.00	44.00	38.00	36.00	38.00

Table 13: Overtimes per intervention in minutes

Overtime performance data is shown in Table 13. The average overtime and undertime show the amount of overtime in minutes, and the percentage of days in which overtime occurs. The overall average is measured, as well as the measure $Y_{overtime}$ which indicates that in 90% of the days, the overtime is below this value *Y*. Overtime occurs more often when allowing walk-in (from 26% of the days to around 45%), but decreases with each intervention. Remarkably, intervention i4 where demand is smoothened does not affect the overtime. The current situation (intervention i0_a), shows an average of 17 minutes undertime, which is a structural loss in capacity.

Production & Utilisation

	i0_a	i0_b	i1_a	i1_b	i2_a	i2_b	i2_c	i3	i4
Production									
CT1	5560	5976	6088	6124	5982	5805	5824	5988	5985
CT2	5281	5024	5122	5104	5107	5243	5186	5037	5069
Utilisation									
CT1	53.2%	57.1%	57.4%	57.4%	56.6%	54.8%	55.8%	57.3%	57.2%
CT2	50.9%	47.2%	48.5%	48.1%	48.9%	50.7%	49.2%	47.8%	48.0%
No-shows	295.0	294.3	0.0	0.0	47.9	111.4	149.2	147.0	144.1
Rejections	0.0	0.0	193.6	185.1	157.9	152.8	157.0	137.1	128.9
Patients gone home	0.0	0.0	599.4	817.4	556.9	482.7	466.0	335.7	297.4
Patients rescheduled	37.0	14.3	8.1	5.8	5.1	12.3	12.1	6.9	6.4

Table 14: Results on production and utilisation

Table 14 shows the performance data on production and utilisation. The production shows the average number of patients that was served per CT scan over multiple replications, and stays equal under same demand. However, a higher load is noticed on CT1 in the interventions allowing walk-in (around 5900 yearly against 5560 in intervention i0_a). The utilisation measured is the overall utilisation over the year, in which total scan time is divided by the time capacity was available. Utilisation in overtime is not counted as this would skew the actual utilisation. We accounted for calibration time as this is perceived obligatory, but maintenance, downtimes, closure due to personnel shortness, patient changing times and other planning inefficiencies are all included in the utilisation measure as this is recognised as time that capacity was available. Likewise to the production, the utilisation stays the same for equal demand. The no-show *percentage* does not change, but changes with a changing *amount* of planned patients and hence decreases when patients are allowed to walk in. In case of breakdown or late arrival, patients are rejected. Rejections are system-imposed, and decrease with each intervention to around 129 on a yearly basis. However, in the current situation patients are never rejected. 'Patients gone home' indicates the amount of patients that encounter a waiting time higher than the threshold value $Z_{waitingtime}$, and hence chose to make an appointment. This occurs less often with each subsequent intervention, from around 600 patients under full walk-in (i1) to around 300 under intervention i4. If planned patients are assigned to a CT scan that is closed due to breakdown, they are rescheduled and they are offered a new appointment.

5.4 Additional experiments

In the current situation, the average overtime is negative which implicates an inefficient use of available capacity. Nevertheless, the schedule is quite full and growth will be hard given the current schedule and available capacity (something which we tested in our simulation model). We therefore assess the logistical performance of walk-in in case the CT department is able to attract growth in demand. We take intervention i4 as starting point and recalculate this intervention for a 10% growth in demand. Besides, we are curious towards the influence on performance of the planned downtime. Planned downtime includes closure due to maintenance during the daily schedule as well as closure due to personnel shortness on the overall performance. Intervention i4 is also recalculated without having planned downtime. To show the effect when both are combined, we determine the performance including growth, but without planned downtime in the third experiment. The results of the experiments are listed per performance indicator, and show a deviation in percentage with respect to the results under intervention i4.

Access Time (days)

		i4	i4 + 10% growth	% vs i4	i4 w/o downtime	% vs i4	I4 + 10% growth w/o downtime	% vs i4
% planned		*55.4%*	*56.5%*	-	*41.5%*	-	*42.0%*	-
Prospective	Orthopaedic	2.60	2.90	*+11.5%*	1.00	*-61.5%*	1.00	*-61.5%*
	Without IV	2.89	2.92	*+1.0%*	1.00	*-65.4%*	1.00	*-65.4%*
	With IV	1.12	1.38	*+23.2%*	1.00	*-10.7%*	1.00	*-10.7%*
	Inpatients	1.84	1.88	*+2.2%*	1.00	*-45.7%*	1.00	*-45.7%*
Retrospective	Orthopaedic	1.68	2.03	*+20.8%*	1.01	*-39.9%*	1.06	*-36.9%*
	Without IV	2.96	2.98	*+0.7%*	1.25	*-57.8%*	1.31	*-55.7%*
	With IV	1.52	1.72	*+13.2%*	1.25	*-17.8%*	1.30	*-14.5%*
	Inpatients	4.46	5.87	*+31.6%*	3.75	*-15.9%*	3.98	*-10.8%*

Table 15: Access times in case of growth in demand

Table 15 shows that under a growth of 10%, access times of planned patients can be kept low as they are still under the access times of the current situation. Furthermore, these results show the tremendous influence planned downtime has on the access time. Almost all access times (except for inpatients) reduce to the minimum of one day without having planned downtime. The scenario where growth is combined with a schedule without planned downtime does not show very significant deviations compared to the scenario of regular demand.

Waiting time (minutes)

	i4	i4 + 10% growth	% vs i4	i4 w/o downtime	% vs i4	I4 + 10% growth w/o downtime	% vs i4
Planned inpatients	-	-	-	-	-	-	-
$Y_{waitingtime}$ *(90%)*	-	-	-	-	-	-	-
Planned outpatients	7.64	9.22	*-31.3%*	3.43	*-55.1%*	3.89	*-49.1%*
$Y_{waitingtime}$ *(90%)*	39.00	44.00	*+12.8%*	36.00	*-7.7%*	38.00	*-2.6%*
Walk-in inpatients	13.43	16.39	*+114.5%*	9.80	*-27.0%*	9.76	*-27.3%*
$Y_{waitingtime}$ *(90%)*	40.00	48.00	*+20.0%*	32.00	*-20.0%*	30.00	*-25.0%*
Walk-in outpatients	35.38	42.99	*+21.5%*	28.36	*-19.8%*	33.07	*-6.5%*
$Y_{waitingtime}$ *(90%)*	83.00	100.00	*+20.5%*	66.00	*-20.5%*	75.00	*-9.6%*

Table 16: Waiting times in case of growth in demand

Table 16 illustrates that increasing the production without changing other constraints (like the available capacity) results in a slight increase in waiting times, especially for walk-in patients as waiting time rises from 35 to 43 minutes on average for walk-in outpatients, and even doubles for walk-in inpatients. Without planned downtime, the waiting time of planned outpatients reduces drastically to about 3.4 minutes which could be expected since demand can be spread as more capacity is available. The waiting time of walk-in outpatients decreases with about 20% to 28.36 minutes on average. When allowing for growth under a scenario without planned downtime, waiting times only increase slightly compared to the situation under regular demand, but still decrease compared to the basic scenario of i4.

Overtime (minutes)

	i4	**i4 + 10% growth**	***% vs i4***	**i4 w/o downtime**	***% vs i4***	**I4 + 10% growth w/o downtime**	***% vs i4***
Average overtime	24.87	27.30	*9.8%*	22.11	*-11.1%*	24.07	*-3.2%*
Overtime occurence (days)	43.9%	56.2%	*27.9%*	36.4%	*-17.1%*	45.9%	*+4.6%*
Average undertime	-22.89	-19.45	*15.0%*	-21.70	*+5.2%*	-19.78	*+13.6%*
Undertime occurence (days)	56.1%	43.8%	*-21.8%*	64.6%	*+13.4%*	54.1%	*-3.6%*
Overall (min)	-1.91	6.80	*456.0%*	-5.75	*-201.0%*	0.35	*+118.3%*
$Y_{overtime}$ *(90%)*	38.00	46.00	*21.1%*	30.00	*-21.1%*	37.00	*-2.6%*

Table 17: Average overtime and percentage within threshold in case of growth in demand

On average, an overtime of 6.8 minutes is the result if demand increases with 10% under constant capacity (see Table 17). 90% of the days then encounter an overtime of less than 46 minutes. In case no planned downtime exists, the overall overtime drops to -5.75 minutes on average. In that case, in 90% of the days overtime is below 30 minutes.

Production & Utilisation

	i4	i4 + 10% growth	*% vs i4*	i4 w/o downtime	*% vs i4*	I4 + 10% growth w/o downtime	*% vs i4*
Production							
CT1	5985	6396	*+6.9%*	6198	*+3.6%*	6570	*+9.8%*
CT2	5069	5709	*+12.6%*	4874	*-3.8%*	5500	*+8.5%*
Utilisation							
CT1	57.2%	60.7%	*+6.1%*	59.4%	*+3.8%*	62.7%	*+9.6%*
CT2	48.0%	54.0%	*+12.5%*	47.3%	*-1.5%*	53.3%	*+11.0%*
No-shows	144.1	163.8	*+13.7%*	108.4	*-24.8%*	106.1	*-26.4%*
Rejections	128.9	127.8	*-0.9%*	5.2	*-96.0%*	4.0	*-96.9%*
Patients gone home	297.4	606.7	*+104.0%*	38.2	*-87.2%*	89.2	*-70.0%*
Patients rescheduled	6.4	10.4	*+62.5%*	2.6	*-59.4%*	5.0	*-21.9%*

Table 18: Production and utilisation performance in case of increased demand

The production and utilisation data in case of increased demand (shown in Table 18) illustrate an increase in average utilisation of both machines. This is not surprising as the capacity remains constant. Especially the number of patients that decide to go home due to high waiting time increases, hence indicating that waiting time at peak times will be higher with 10% growth. Without downtime, a significant decrease is seen in the amount of patients rejected, patients that decide to go home, and rescheduled patients. In fact, these patient-unfriendly events are almost negligible. When combining the increased demand with a schedule without planned downtime, only the amount of patients gone home changes considerably compared to the situation without growth, but with planned downtime.

5.5 Sensitivity analysis

A sensitivity analysis is performed on various estimated values, to determine the effect they have on the outcome and to test the robustness of the solution (see Table 19). Since sensitivity analysis is a very time-consuming process if performed for all parameters, it should be restricted to the analysis to a few key inputs that carry a relatively great deal of uncertainty (Robinson, 2004). We are especially interested in the effects on waiting time and overtime, of estimated values we couldn't measure. The threshold values of 4 and 2 for the maximum accepted access time for respectively outpatients and inpatients have been validated under intervention i0_a, but are left out from further sensitivity analysis as these estimators only influence access time. We selected four estimated indicators that directly affect waiting time:

- The maximum accepted waiting time for patients to decide to join the queue or go home
- Patient changing time; the set-up time necessary for each patient
- Request assessment time; the average time for reviewing the request by a radiologist
- The transfer time; the average time between calling-in inpatients and their actual arrival

To provide a concise overview we choose only to show the effects on waiting time for walk-in outpatients, and the average overtime. For both, the indicator Y (the 90% performance indicator) is included. The column 'Chosen value' shows the input values as chosen under intervention i4, the column 'Overestimation' shows the values for the performance indicators in case of overestimation, and the column 'Underestimation' in case parameters were underestimated.

	Overestimation	**Chosen value**	**Underestimation**
Maximum accepted waiting time	1 hour	1.5 hours	2 hours
• waiting time	• 29.17 (Y = 65.00)	• 35.38 (Y = 83.00)	• 35.59 (Y = 82.00)
• average overtime	• -2.25 (Y = 30.00)	• -1.91 (Y = 38.00)	• 1.16 (Y = 40.00)
• patients gone home	• 772.4	• 297.4	• 200.8
Patient changing time	2.0 minutes	3.7 minutes	5.5 minutes
• waiting time	• 27.19 (Y = 64.00)	• 35.38 (Y = 83.00)	• 44.19 (Y = 100.00)
• average overtime	• -7.12 (Y = 26.00)	• -1.91 (Y = 38.00)	• 10.10 (Y = 58.00)
Request assessment time	2.5 minutes	5 minutes	7.5 minutes
• waiting time	• 31.96 (Y = 78.00)	• 35.38 (Y = 83.00)	• 35.74 (Y = 79.00)
• overtime	• -1.30 (Y = 37.00)	• -1.91 (Y = 38.00)	• 0.77 (Y = 38.00)
Transfer time from the ward	15 minutes	20 minutes	25 minutes
• waiting time	• 33.45 (Y = 78.00)	• 35.38 (Y = 83.00)	• 33.91 (Y = 78.00)
• overtime	• -2.30 (Y = 31.00)	• -1.91 (Y = 38.00)	• -0.66 (Y = 35.00)

Table 19: Sensitivity analysis on model parameters

The changing time between two patients is found to carry a great deal of uncertainty. The changing time is determined to be 3.7 minutes under all interventions. However, when set to 2 minutes, the average patient waiting time and average overtime decrease firmly. The opposite is also true: if patient changing time is 5.5 minutes on average, average waiting time increases with 10 minutes on average as well as the average overtime. This result is subscribed to the piling effect of patients that are waiting: since 15 minutes per slot are reserved, 5.5 minutes of changing time per patient results in a slack of almost zero causing to increase the average waiting time. However, as patient changing time is a parameter somewhat in control by the department, it should hence be subject of investigation when implementing walk-in. Remarkably, the maximum accepted waiting time, request assessment time, and transfer time from the ward all show a larger impact in case the values were overestimated, compared to when they were underestimated.

6 Conclusions & Recommendations

In our problem statement, we emphasized the critical position CT scans often have in patient service processes. Short access times and the possibility to combine appointments are important indicators in patient satisfaction, but logistical performance for the CT scan when allowing walk-in remained unknown. Our context analysis shows, that walk-in for 100% of the patients is not feasible from a practical point of view, as some examinations require the presence of other medical specialists, because large preparation times are required, or simply because some patients will prefer to make an appointment. Our various interventions offer options to deal with the fluctuating demand in case of walk-in, by deliberately using appointment blocks, inpatient call-in, and informing patients on the expected waiting times over the week to smoothen the expected arrival pattern.

This research demonstrates that by introducing walk-in in combination with appointments, patient service can significantly be improved. It enables patients to combine multiple appointments on the same day, while lower access times for planned patients can be achieved. Simultaneously, the logistical performance indicators do not exceed the threshold values set. We have shown that under various ratios of walk-in, access times for planned patients remain low. Simultaneously, a waiting time of 35 minutes on average for walk-in patients (for the interventions combining walk-in and appointments) is below the maximum allowed waiting time and will, based on former studies, definitely cause patients to consider combining the CT scan with their earlier appointment at the outpatient clinic. Moreover, patients always have the choice to make an appointment which is an important addition in terms of patient service. As prudence is applied in the data analysis, the results will probably be better.

The interventions employed in this research proved particularly useful in decreasing the average overtime gained. Calling-in inpatients from the ward at times of low expected waiting time reduces the number of rejections and patients that decide to leave because of high expected waiting times, which are important secondary indicators on patient service. This indicates that although the average waiting time does not change, peaks in demand are decreased by our interventions and hence the expected waiting time less often exceeds the maximum threshold set. The utilisation does not change with various interventions, which is easily explained since demand is equal as well. However when demand is increased, walk-in offers the option to deal with this higher demand while not changing the capacity available: something that is not accomplished under the current process and schedule. In short, we are able to increase patient service, while simultaneously being able to expand production and serve more patients under the same capacity indicating a higher attainable efficiency.

Only one hospital in the Netherlands has implemented walk-in at their radiology department, and one is starting a pilot aimed at doing so (Tweesteden hospital Tilburg, Alysis hospital Arnhem). This research provides the scientific guidelines for such a system, and creates a deeper understanding of the effects of introducing walk-in on patient logistics.

6.1 General recommendations

This research contributes to the awareness of other access systems besides the traditional appointment-system. Based on the results of this research, implementing walk-in should receive serious consideration for radiology departments that value to provide more timely access to their patients. Implementing walk-in provides a strategic advantage as short access times and combined appointments on the same day are valued the most by patients in terms of patient service. Also, we have shown that by implementing walk-in, efficiency can be increased as more patients can be served under the same capacity. On a hospital-wide level, introducing walk-in can significantly reduce internal waiting lists between departments, and hence eliminates at least a part of the disruptive effect on patient flow often incurred in diagnostic modalities. The interventions proposed in this research are generally applicable in other hospitals, and as we demonstrated are able to reduce some of the variability inherent for walk-in. Chapter 7 provides a more elaborate perspective on the organisational and practical implications of implementing walk-in.

6.2 Recommendations for further research

There are several recommendations for further research to be made. The workload can be divided more equally between both CT scans which will further increase operational efficiency. To this objective, more blocks should be scheduled on CT2 since only CT1 allows all patient types. The appointment schedule should be optimized as is the objective of the study of N. Kortbeek and M.E. Zonderland. They are working on an analytical model to optimize the various schedules for each intervention separately. Optimizing the schedule will further decrease fluctuation, and is expected to offer shorter waiting times especially for walk-in patients. Besides, the results proved quite sensitive to interference with the schedule which emphasizes the need for optimization. The strictness in our priority rules in the waiting room (planned patients are always prioritized over walk-in patients after the beginning of their appointment) causes most interventions to primarily have effect on planned patients while waiting time for walk-in patients stays fairly constant. These priority rules might be reconsidered in order to divide waiting time more equally between planned patients and walk-in patients. Calling in inpatients can further be investigated and optimized by for example investigate the number of patients to call in at once, or the decision exactly when to call in patients.

Our results show a higher workload on CT1, while the load of both CT scans might be divided more equally. In practice this is easily achievable, but more equally dividing workload should also be considered for further improvement of the planning designing the schedules

By allowing (some) more waiting time for planned patients, overall waiting time can be divided much more equally over all patients. For example, one can choose to give priority to planned patients some time after the beginning of their appointment and not directly at the start. The effects however of changing priorities stay subject to further investigation.

The approach chosen, where walk-in and appointments are combined to balance non-stationary demand is new in literature. It might find application in areas wider than health care alone, for example in call-centres and bank tellers. Walk-in especially is useful when service times are short, which should be considered before implementation.

7 Managerial implications

This chapter focuses on the practical implications of walk-in for the CT department. We first consider several organisational, higher-level implications. Section 7.2 illustrates the implications for the day-to-day process. The third section draws some preconditions for success which should be considered for application in practice.

7.1 Organisational implications

An important organisational implication lies in the financial aspects of introducing walk-in. As allowing walk-in requires less planning, the planning department which currently consists of about 3 fte can downsize. Dependent on the policy adopted, patients that need an appointment can simply be offered the first available appointment automatically to reduce access times.

Another financial aspect lies in the increased capacity that is allowed with walk-in, as planned slack only exists over the day and planned slots, instead of every slot. As we saw, growth in demand is maintainable which yields implications for reimbursements as long as higher demand exists. However, it very well is imaginable that growth is created since implementing walk-in has an implication in terms of marketing as well, as more patients might choose to visit the AMC radiology department because of their patient friendliness. The Alysis hospital also expects rising demand because of general practitioners that are allowed to refer patients for a CT scan without the intervention of a medical specialist in the hospital, as walk-in might lower the threshold for referral. Referral by general practitioners is currently not the case in AMC, but it emphasizes the implications in terms of marketing.

7.2 Practical Implications

Currently, all CT scan applications are reviewed by an attending radiologist. This only happens periodically since patients typically have an access time of multiple days and the application only needs to be reviewed before this date. When introducing walk-in, this process will change. If AMC adheres to the practice of radiologists reviewing each application (this is not general practice in all hospitals), continuous presence of the radiologist is required at least during walk-in hours. Besides, in AMC no scans using IV contrast are planned between 12 pm and 2 pm each day as the radiologists attend to their daily meeting. With walk-in it is required to offer the same service the entire day (or at least while walk-in is allowed) and hence can compromise with the restriction of being able to offer examinations with IV contrast in this time. This requires the need of a radiologist who is present continuously.

In the situation we draw, the triage at the registration desk is an important step in the patient process as is decided whether patients can be referred as walk-in, or if they need to schedule an appointment. This triage brings more responsibility for the 'hostess'. Besides, he or she needs to coordinate the process as patients have to start drinking contrast, the routing towards the IV room, and the routing to the CT scans while adhering to the (computer-determined) priority of each patient. A computer-controlled system can be used to efficiently control the priority of patients waiting. Since we expect that most patients would not wait without an indication of the expected waiting time, an electronic sign can be implemented together with the computer-controlled system to estimate the expected waiting time in the waiting room which walk-in patients can base their decision on.

During our time-measurement, we discovered that two slots for inpatients seemed unnecessary as we could not discover a significant difference in scan time between outpatients and inpatients. We did discover different service times for patients with and without IV contrast, which perhaps should be allowed for in a new appointment schedule. However, a more elaborate measurement is recommended before taking action as the amount of observations was not very high.

As the Alysis hospital already put a lot of effort in starting a pilot where patients without preparation are required to walk-in, we can draw various practical success factors from their experience so far. For example the introduction of a new guideline called the 'CNP protocol' which starts nationally from 1 January 2010 requires some practical additions to the walk-in process at the Alysis hospital. For example, GFS-values (an abbreviation of 'glomerulaire filtratie snelheid' in Dutch) may not be older than 6 weeks, and is required for all patients with IV contrast. Additionally, at least 1 litre of fluid needs to be administered before the examination but this is consistent with current practice. A safety form needs to be filled out which can be done prior to the examination, which is then checked by a laboratory worker.

7.3 Preconditions for success

In this final paragraph, we determine general success factors of implementing walk-in with broad applicability. For a walk-in system to work effectively, it should be known to the patient what the expected waiting time would be at the time of arrival. To this purpose, one could use a similar algorithm as proposed in this study, which is then displayed real-time in the waiting room. Broad support from the radiology department at all levels is indispensable, especially since work can be perceived as stressful by laboratory workers because of the fluctuations in demand. However, trials in the Tweesteden and Alysis hospitals showed that most laboratory workers perceived their work as more dynamic and fun. The increased responsibility of 'managing the process' is experienced as a positive effect. A flexible working attitude is required, especially for laboratory workers and radiologists.

The communication with patients must be clear, especially about what walk-in means, when patients can walk-in and what requirements they should meet. Clear communication with referring inpatient and outpatient clinics is essential as well, as the referring process should be very clear and CT scan requests need to be unambiguous and complete. Referring clinics should be enabled to determine whether walk-in is possible (based on type of examination, time of request, etc.) by using a standardized protocol similar to what Alysis offers their departments. Several interventions that combine appointments during low demand with walk-in have been shown to be effective in smoothing the process. Clear protocols need to be in place, and the idea of mutually exchangeable CT scans to divide the workload equally needs to be given some time to land. At least one radiologist must be present (or present on call) at all times, and experiences might be shared with other hospitals, especially hospitals who are simultaneously discovering the benefits of walk-in like the Alysis Zorggroep and the Tweesteden hospital.

Appendix A: Planning algorithm

In our planning algorithm, urgent outpatients have the same urgency as inpatients. We adhere to a maximum allowed access time for inpatients and urgent outpatients $Z_{maxATinpat}$, and patients without IV contrast $Z_{maxAToutpat}$ which is similar to practice. The maximum allowed access time enables the schedule to allow other blocks. For example for inpatients, if no inpatient blocks have been found available soon enough regular outpatient blocks and urgent blocks are verified as well. The maximum allowed access time for patients without IV contrast is required, since patients without IV contrast are preferably planned between 12:00 AM and 02:00 PM, but are also allowed in other slots if their access time exceeds the threshold value.

The figure below gives a simplified impression of the planning algorithm, and illustrates how first an allowable slot is searched, it subsequently is verified if this slot is already assigned to another patient, and at last considers the maximum allowed access time. In case of violation of the latter other slots are allowed. Each CT scan has its own schedule, and an important consideration is that the two CT scans are not identical as some examinations have to be performed on one CT scan. When searching for an available slot, all allowable slots in the coming 5 days are considered for availability. If no slot is found, we increase the week and search for an allowed and available slot in the next week.

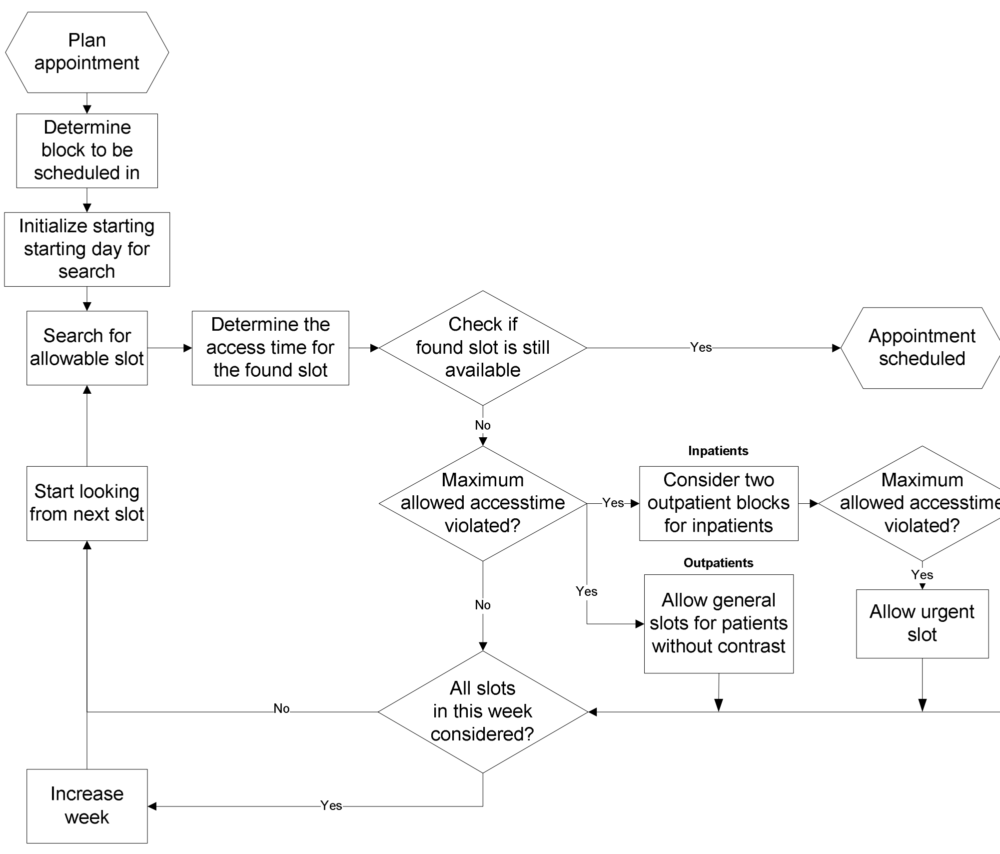

Figure: Planning algorithm

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