Reducing lead time for acute MRI examinations

Improving a healthcare diagnostic process

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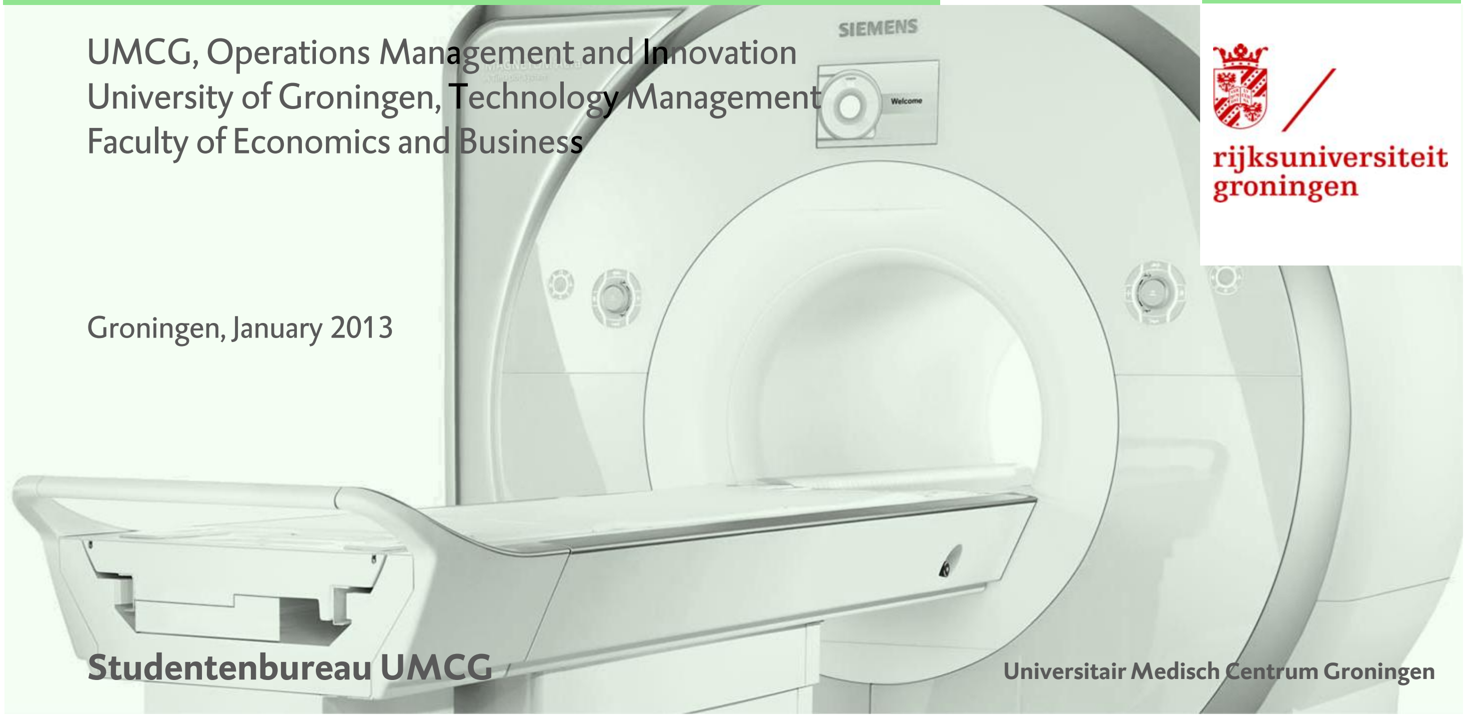

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FOREWORD

This master's thesis marks the end of my life as a student and in particular the end of my study Technology Management at the University of Groningen. I started my student life in September 2004 in Zwolle where I studied Mechanical Engineering at Windesheim University of Applied Sciences. After finishing this study in four year I started at the Technical University in Delft. After a couple of months I stopped the study and started working as an engineer in January 2009. However, a sense of dissatisfaction and the gut feeling that I could do more made my decide to quit my working career and start a masters study again in September 2009. I am very glad I made this decision. The three years in Groningen have shaped me further relationally, intellectually, religiously and socially. Now, at the beginning of 2013, I can start my working career again, but this time with a satisfied feeling that I have fully used my talents.

I would like to thank Peer Goudswaard as my main supervisor within the UMCG. With his help this study stayed in the right direction. Furthermore, I would thank Igor van der Weide and Tjibbe Hoogstins for their valuable assistance. They gave valuable feedback on my written texts, built a Monte Carlo simulation and helped with statistics when needed. The participation within the department made me feel as one of them. I participated the yearly department activity and the Friday afternoon drinks for example. I would thank Jan Kooistra (manager radiographers), Peter Kappert (system specialist MRI) and the radiographers and radiologists for giving me insight in the MRI process and answering all my questions. I thank Taco van der Vaart and Jos Bokhorst (my first and second supervisors from the University) for their valuable support, feedback on my thesis and helping me to maintain the academic level. The visits to Taco (sometimes with the presence of Jos) were valuable because they helped me to keep focussed and stay critical to where the study was heading.

I would thank my parents for supporting me in this period and for making it possible for me to finish this study. I thank my beautiful girlfriend Rianne for wanting to listen to my experiences and supporting me with love in this period.

As a last I would thank God for giving me my talents and for keeping me focussed on the things in life that really matter.

Gerben Brandsema
Groningen, Januari 2013

CONTENTS

MANAGEMENT SUMMARY

This study deals with the lead time reduction of acute MRI examinations on the three whole body MRIs. Currently, 55% of the acute MRI examinations are performed within 24 hours. Furthermore, extra demand for MRI will arise through a change in the diagnostic standard for acute stroke patients. The current diagnostic standard for these patients is a CT scan, but this will change in favour of MRI. The defined acute patients population has to be examined within 24 hours.

2011 data is analysed and two of the three MRIs are observed for two weeks to get more insight in the MRI process. During the two week observation 224 MRI examinations are observed and timed.

Reduction of the lead time of acute MRI examinations can be accomplished by reducing the protocol times of HH45, CV60, MSK45 and Ma40 protocols with 5 minutes (HH45 are e.g. all head/neck protocols with an examination time of 45 minutes). The insertion of intravenous access lines takes places in the MRI room when a patient lies on the scan table. This activity can be conducted outside the MRI room to reduce the variability in examination time and hence, reduce the average examination time. The supply chain can be improved to reduce e.g. the time that is lost by waiting on patients or the extra activities that are needed when a patient is delivered in the wrong conditions. A continuous improvement board can be used to identify problems in the supply chain or other issues in the MRI process. A culture of continuous improvement and problem recognition must take shape in addition to the implementation of a continuous improvement board. Without the right culture and organizational structure an improvement board loses its improvement potential. The MRI schedules can be improved to improve fast access for e.g. acute stroke patients (acute stroke patients need an MRI scan within 15 minutes after arriving at the hospital). Access for acute patients within 15 minutes is possible. Improving the MRI schedules is more feasible when one team is responsible for the whole schedule of the three MRIs. Currently, three teams are scheduling examinations. The access time improvement can be combined with the planned changes in the MRI organization.

With the implementation of the proposed solutions 60 minutes of capacity can be unlocked per day in the current elective capacity. This 60 minutes of unlocked capacity can be used for emergency examinations. Currently, 90 minutes per day is reserved for emergency examinations. With the unlocked time the total emergency capacity will be 150 minutes per day. This will be enough to examine the defined acute patient population within 24 hours with a performance in refusal rate of 9% and a utilization of 66%, based on the Monte Carlo simulation that is used.

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Main entrance UMCG – ca 1950 and present

1 INTRODUCTION

1.1 UNIVERSITY MEDICAL CENTER GRONINGEN

The University Medical Center Groningen (UMCG) is one of the largest hospitals in the Netherlands and it is the biggest employer in the North of the country. A staff of over 10,000 people work in patient care and in leading medical research, focusing on 'healthy ageing'. For its research and educational function the hospital has close ties with the University of Groningen. Some 3.400 students are currently enrolled in degree courses to become physician, dentist or movement scientist and over 450 are trained as medical specialists. Patients come to the UMCG for basic care, but also for highly specialized diagnostics, examinations or treatment. All patients in the North of the country with complicated or rare conditions are eventually referred to the UMCG. Excellent care is always based on the latest insights and given by the best doctors and nursing staff. Together with the support services they always focus on that one common goal: building the future of health.

This study is conducted at the department Operations Management & Innovation. The department was founded in 2009 to improve logistical processes of various natures at the UMCG and is part of sector E (see

Figure 1).

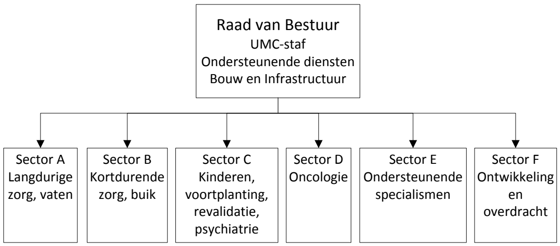

Figure 1 Organizational structure of the UMCG

1.2 RADIOLOGY

The radiology department (part of Sector E) is an integral part of the top clinical and top referral care and research, education and training activities of the UMCG. Also for hospitals and general practitioners from the region radiologic examination is conducted. The department is located in a central location where all the state of the art radiologic techniques are present. In addition, there are radiologic modalities at the emergency department, endoscopy center and urology department. Furthermore, mobile equipment is available at the operative care center, center for day treatment and for radiologic examinations on the nursing wards.

At the emergency department, there are two trauma rooms with one X-ray device each, five mobile ultrasound devices and a CT scanner located in a separate room. MRI examinations are done at the central radiology department.

1.3 STRUCTURE OF THE REPORT

This report is structured as follows. The next chapter will present the research framework. Chapter three discusses relevant literature. The methodology of this study will be explained in the subsequent chapter. Results of the analysis are presented in Chapter 5. The redesign is covered by chapter 6. After the redesign, discussion is covert by chapter 7. The last chapter will present the conclusions, recommendations for implementation of the solutions and suggestions for further research.

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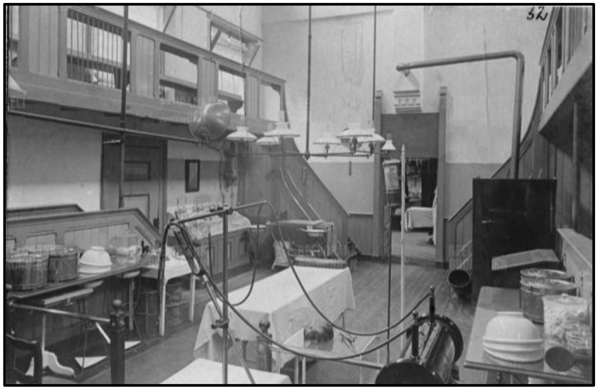
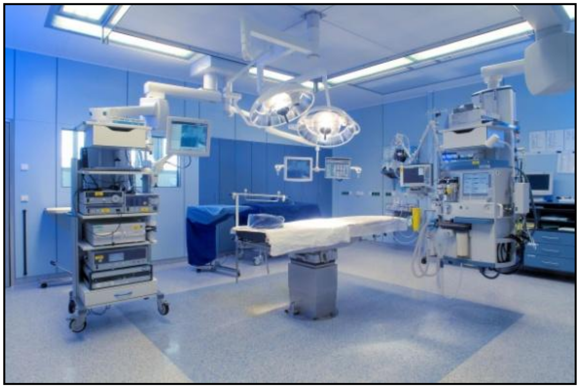




Operating room – ca 1900 and present

2 RESEARCH FRAMEWORK

2.1 INTRODUCTION

In this chapter, the conducted study will be introduced. First, the background and motivation will be elaborated. Secondly, Magnetic Resonance Imaging will be introduced. After that, the changing diagnostic standard for acute stroke patients is introduced. As a last, the research objective, research question and sub questions will be formulated.

2.2 BACKGROUND AND MOTIVATION OF THIS STUDY

The department Operations Management & Innovation (OM&I) aims to provide the right affordable care at the desired place at the desired time with a focus on improving logistical processes of various natures at the UMCG. Tools/methods that help them to achieve this aim are i.a. Lean, Six Sigma and TOC (theory of constraints).
The radiology department of the UMCG performs amongst others MRI examinations. MRI faces two patient groups. Plannable elective patients and acute patients who arrive randomly. Currently capacity is reserved for acute patients on one whole body MRI scanner every working day from 15:00 till 16:30 hours (90 minutes per day). From 2011 data it appears that 54,6% of the emergency requests was conducted within 24 hours. The aim of the OM&I department is to study the possibility to perform all acute MRI diagnostics within 24 hours.
Furthermore, extra demand for MRI will arise through a change in the diagnostic standard for acute stroke patients. The current diagnostic standard for these patients is a CT scan. The radiology department of the UMCG assumes that the diagnostic standard will change in favour of MRI because of current studies and trials in the medical world, concluding that MRI is a better alternative for these patients than CT (Schellinger et al., 2010). This change results in a larger demand for MRI, more specific, a larger amount of acute examinations for which MRI capacity must be available in a very short time (within 15 minutes after arrival of the patient).
The fact that not all emergency requests are conducted within 24 hours and the extra demand for MRI (acute stroke patients) are reasons for the OM&I department to study the MRI process to secure a good MRI performance in the future.

2.3 MAGNETIC RESONANCE IMAGING

Magnetic Resonance Imaging (MRI) is a medical imaging technique used in radiology to visualize internal structures of the body in detail. MRI makes use of the property of nuclear magnetic resonance to image nuclei of atoms inside the body.
MRI provides good contrast between the different soft tissues of the body, which makes it especially useful in imaging the brain, muscles, the heart and tumors compared with other medical imaging techniques such as Computed Tomography (CT) or X-rays. Unlike CT scans or traditional X-rays, MRI does not use ionizing radiation.
The UMCG has four MRI scanners. One extremities scanner of 1 Tesla and three whole body scanners of 1,5 Tesla each. This study focuses on the three whole body MRI scanners.

2.4 CHANGING DIAGNOSTIC STANDARD FOR STROKE PATIENTS

Cardiovascular diseases are the second leading cause of death in The Netherlands (cancer is no. 1) with 38.132 deaths in 2011. Cerebrovascular accidents (CVA, stroke) accounts for 22% of the cardiovascular deaths with 8.440 cases (Central Bureau of Statistics). A CT scan is the current diagnostic standard for acute stroke within the UMCG. This standard is probably going to change in the future, because MRI is becoming a better alternative for diagnosis of acute stroke (Schellinger et al., 2010). Patients that enter the hospital with suspected stroke need to get a scan within 15 minutes after arrival to keep the possible further deterioration of the patient to a minimum. Availability of MRI in a short time is of vital importance when the shift is made from CT to MRI as diagnostic standard.

2.5 Research objective and research question

The objective of this study is to give advice on how diagnosis of acute patients who need an MRI can be performed within 24 hours and how access within 15 minutes for acute stroke patients can be achieved. The research question is:

How can future acute patients who need an MRI scan be diagnosed within 24 hours and how can access within 15 minutes be achieved for acute stroke patients, with a minimal impact on the elective capacity?

To be able to answer the research question relevant theory is studied and a separation is made into an analysis and redesign phase. In the analysis phase the current MRI process and part of the future process will be studied. Improvements are suggested in the redesign phase to be able to diagnose the future acute patients within 24 hours.

2.5.1 Sub questions

The sub questions are divided into the analysis and redesign phase. The first step in the analysis phase is to study the current acute patient population and the increase in number of acute patients in the future. The amount of acute MRI examinations that are performed within 24 hours has to improve and the acute stroke patients that will have an MRI scan as diagnostic standard in the future will increase the demand. The first sub question is divided in two parts:

1 (a) How many acute patients demand MRI in the present situation and how much capacity do they need?
  (b) How many acute patients demand MRI in the future and how much capacity do they need?

Now that the current and future acute population is known, the current MRI process can be further analysed. This is done by first looking at the different steps in the MRI process and how much time is spend per step. The second sub question corresponding to the above, is:

2 How much time is spent per step in the MRI process?

Knowing in which way time is consumed by the process, gives insight in possible improvement directions. Further insight in possible improvements is obtained by studying the causes of variability in the process. Knowing the causes of variability sheds light on possible ways to reduce variability in the process. the third sub question is:

3 What are causes of variability within the process?

Fast access is required for acute stroke patients (<15 minutes). Knowing to which extent fast access is already possible in the current process gives insight in the improvements that might be needed. Hence, the fourth sub question is:

4 To what extent is fast access for acute patients possible in the current process?

The last subject is the reporting of acute MRI examinations. With fast diagnosis fast reporting is essential. The last sub question of the analysis phase is:

5 What is the current performance of radiology reporting of acute examinations?

With the preceding sub questions the current situation is analysed. In the redesign phase improvement suggestions are made. First, suggestions are made on how to unlock extra time within the current capacity that is needed to diagnose the future acute patient population within 24 hours. The first sub question of the redesign phase is:

6 How can extra time be unlocked in the current capacity and how much?

Now that is clear in what way time can be created and how much time can be unlocked within the current capacity, the question arises how to allocate the emergency capacity. The corresponding sub question is:

7 How should the emergency capacity be allocated within the elective schedule?

Fast access time for acute stroke patients is required. Suggestions to realize fast access for acute stroke patients are made. The sub question here is:

8 How can fast access for acute stroke patients be realized?

The last sub question of the redesign phase concerns the radiology reporting of acute MRI examinations and is:

9 How can the lead time of reporting of acute examinations be improved?

With the above sub questions the research question will be answered. The next chapter gives an overview of literature that is relevant to this study.

Nursing ward – ca 1900 and present

3 LITERATURE REVIEW

It is a waste of time to reinvent the wheel in scientific research. Scientific knowledge is stored in scientific literature. This knowledge can be of great help in understanding the subject under research and finding possible solutions for the problem dealing with. Hence, this chapter will present relevant literature that will help to improve the MRI process. First, the subject of process variability will be dealt with. The second part is about the allocation of emergency capacity in an elective program. The last part deals with improving access time for acute patients.

3.1 VARIABILITY IN HEALTH CARE

What exactly is variability? A formal definition is 'the quality of nonuniformity of a class of entities' (Hopp and Spearman, 2008). In daily life everyone encounters variability. For example, travel time of commuters. The distance between home and work is the same but travel time can change every day, because of traffic jams, a traffic lights, road conditions, etc. These factors represent potential sources of variability in the system.

Health care delivery systems also encounter variability. The simple, but elusive goals in health care services are to deliver the right care, to the right patient, at the right time (Long et al., 2006). According to Long et al. (2006) variability is the enemy to efficient, quality health care delivery. They present two types of variability. Namely, (I) Natural and (II) artificial variability. The first one is divided into three types of natural variability. Patients have many types of disease and even patients with the same disease exhibit major differences in their degree of illness, their choice of therapeutic alternatives and their response to therapy. This type of natural variability is called clinical variability. In addition, they usually appear randomly for care, which is the second type (flow variability). In addition to these components of normal variability on the demand side, medical practitioners and health care delivery systems are not uniform in their ability to provide the best treatment. This is the third type of natural variability (on the supply side) and is called professional variability.

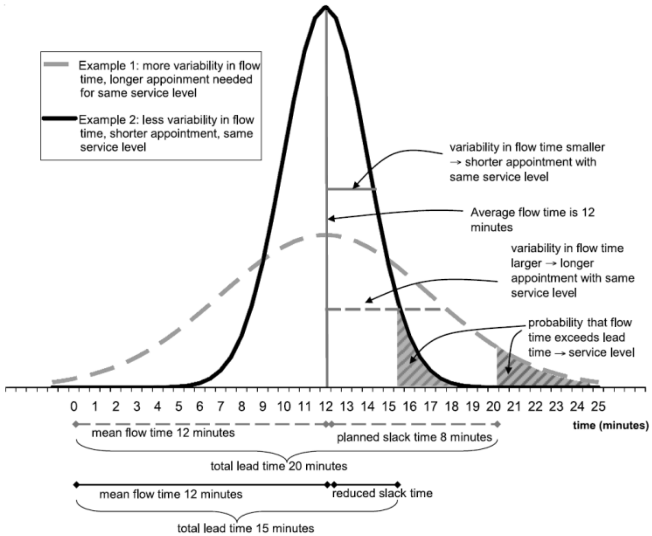


Figure 2 Flow time variability and lead time (from Elkhuizen et al., 2007)

The goal is to optimally manage natural variability. However, dysfunctional management often leads to the creation of artificial variability (the second type of variability). This type of variability unnecessarily increases cost and inefficiency and negatively impacts the quality of care that is tried to deliver. Variability in health care systems should be measured (Long et al., 2006; Elkhuizen et al., 2007). Variability should be measured as deviation from an ideal, stable pattern. Elkhuizen et al. (2007) performed a study in which they reduced the variability of the time needed for the CT scanning process. Due to the enormous variation in types of scans, it was hard to get reliable results and hence, they did not perform a quantitative measurement of the variability in flow times. Instead, they gained insight into the most variable parts of the whole scanning process by observation and by relying on the radiographers' expertise. **Figure 2** on the previous page shows the effect of variability reduction on lead time when the same service level is maintained.

Besides the variability in process time there is variability in the supply chain of health care organizations. According to Lapierre et al. (1999) the improvement of on-time performance is one major challenge that health care organizations have to face in order to improve the quality of services they provide to their customers. A visit to a physician's office can be delivered on-time when the physician and the patient are both available at the scheduled appointment. The on-time process is usually more complex if it is considered that a physician will typically schedule a series of appointments with different patients and that each patient has another series of activities before and after the physician's visit. Any variation of the predicted time for one of these activities can affect the schedule of any other. In other words, the resources are highly interdependent (Manansang et al. 1996)

3.2 Allocation of emergency capacity

To be able to examine acute patients, emergency capacity can be allocated within the elective MRI program. Allocation of emergency capacity can be done in several ways. Wullink et al. (2007) tackle this problem in the light of allocating emergency capacity to twelve operating rooms (ORs). They compare two options in which emergency capacity can be allocated: (I) concentrating all emergency capacity in dedicated emergency ORs and (II) evenly allocating capacity to all elective ORs (see **Figure 3**). A discrete event simulation model is used to test both situations. The main output of the simulation is: (I) waiting time, (II) staff overtime and (III) OR utilization and are evaluated for the two options.

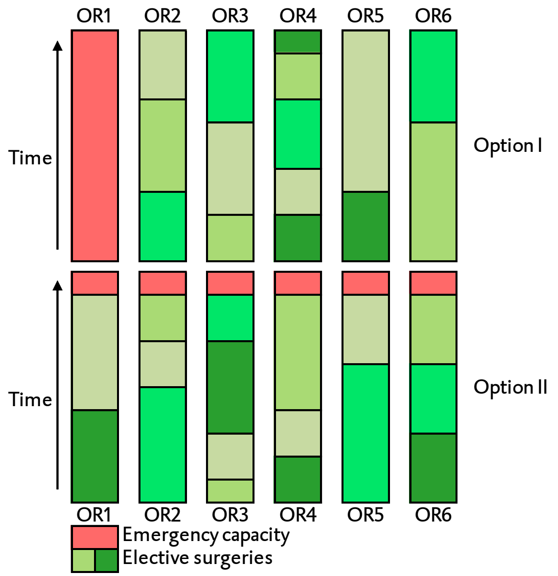


Figure 3 Two options for allocating emergency capacity (Wullink et al., 2007)

The results of the study indicate that the policy of reserving capacity for emergency surgery in all elective ORs (option II) leads to an improvement in waiting times for emergency surgery from 74 (±4,4) minutes to 8 (±0,5) minutes, working in overtime is reduced by 20% and overall OR utilization can increase by around 3%. These results are obtained by using data of the OR department of the Erasmus Medical Center (The Netherlands).

In contrast to the study of Wullink et al., Tancrez et al. (2009) argue that a dedicated OR is preferable. They have studied a hospital with seven ORs. When one OR is dedicated to emergency surgeries instead of none, waiting time reduces. Overtime on the other hand, increases with more dedicated ORs. The latter one corresponds with the study of Wullink et al. Waiting time on the other hand is in stark contrast with the study of Wullink et al. The reason for this could be the number of ORs (seven instead of twelve). With more ORs, the number of moments to break-in in the elective schedule (the moment an elective surgery ends and an acute one can start) will also increase and hence, waiting time for emergency surgeries will decrease.

3.3 Improving access time for acute patients

When a patient needs an MRI scan (almost) immediately, it is preferable that the scan can start in between two elective scans (a so called break-in-moment) instead of interrupting an elective scan. To reduce the chance of interrupting an elective scan, break-in-moments (BIMs) need to be spread as equally as possible over the day given the fact that an acute MRI has a maximum time it can wait (Van der Lans et al., 2006). The article of Van der Lans et al. focuses on optimising operating room schedules. Here, a translation is made to MRI rooms to let it better fit with this study.

The BIM optimisation problem is NP-hard in the strong sense. This means that there is no mathematical method to solve the problem optimally. For an extensive proof of the above statement, see Van der Lans et al. (2006).

To cope with the BIM optimisation problem, Van der Lans et al. (2006) introduce three constructive heuristics that sequence the set of examinations for each MRI room at a given day. The first one is known as the Shortest Processing Time (SPT) heuristic and schedules the examinations in an MRI room from shortest to longest duration which leads to short intervals in the beginning of the day and larger intervals at the end of the day.

The second and third heuristic aim to sequence the examinations such that every break-in-interval (BII) approaches lower bound λ. This lower bound λ reflects the distance between two subsequent BIMs if all BIMs would be distributed evenly over the day. Than each BII would be of equal length λ.

The second heuristic (called heuristic C1) schedules examinations forward and backward, trying to avoid large BIIs either at the beginning or at the end of the day. By forward scheduling is meant the scheduling of examinations in an MRI room one after another from the start of the day towards the end of the day. With backward scheduling is meant the scheduling of examinations in an MRI room one after another from the end of the day towards the start of the day. Backward scheduling is possible, since the number and the durations of examinations in an MRI room are known and thus completion times per MRI room.

The third heuristic (C2) also strives the avoid large BIIs by using λ. Heuristic C2 is based on the SPT heuristic and schedules one whole set of examinations in an MRI room at a time from shortest to longest duration, starting with the MRI room with the highest number of examinations and ending with the MRI room with the lowest number of examinations. With this heuristic large BIIs will be at the end of the day. In this study heuristic C1 is chosen to improve the access time for acute patients, because it tries to avoid large BIIs at the beginning and at the end of the day. An example will be used to further explain heuristic C1. The example starts with the initial schedule shown in **Figure 4**. The three MRI rooms (M1, M2 and M3) are filled with (elective) examinations.

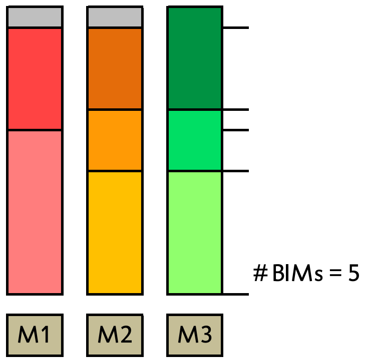


Figure 4 Initial schedule

The starting position is a blank schedule, keeping in mind that the examinations need to be scheduled in their original MRI room (in this case, the red examinations can only be scheduled in the M1 room). Heuristic C1 schedules examinations forward and backward with the aim that all BIIs are as close to λ as possible. The first step in the heuristic is to calculate λ. In this simplified example, the computation of λ is omitted. The next step is the forward scheduling move. If no examinations are scheduled forward so far, the unscheduled examination from one of the MRI rooms is selected for which the completion time will be closest to the latest starting time of all MRI rooms plus λ and this examination is scheduled forward in MRI room *j*. If examinations are already scheduled, an unscheduled examination from one of the MRI rooms *j* is selected for which the completion time will be closest to the latest completion time of all already forward scheduled examinations plus λ. The third step is the backward scheduling move. If no examinations are scheduled backward so far, an unscheduled examination is selected from one of the MRI rooms *j* for which the starting time will be closest to the earliest closing time of all MRI rooms minus λ. If there are already backward scheduled examinations, the unscheduled examination from one of the MRI rooms *j* is selected for which the starting time will be closest to the earliest starting time of all already backward scheduled examinations minus λ and is scheduled backward in MRI room *j*.

Step four says to repeat step two and three until all examinations are scheduled. First the shortest examination from M1 is forward scheduled (step two). Thereafter, the shortest examination from M2 is backward scheduled (step three). Subsequently the shortest examination from M3 is again forward scheduled (step two). The shortest examination of the remaining examinations from M2 is than backward scheduled (step three). The remaining examination from M1 is scheduled forward (step two) and so on. Following the steps of heuristic C1 can result in the schedule shown in **Figure 5**. It can be observed that the number of BIMs has increased from five to seven.

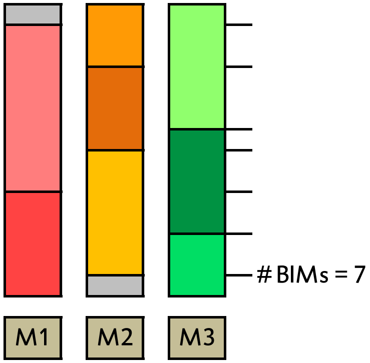
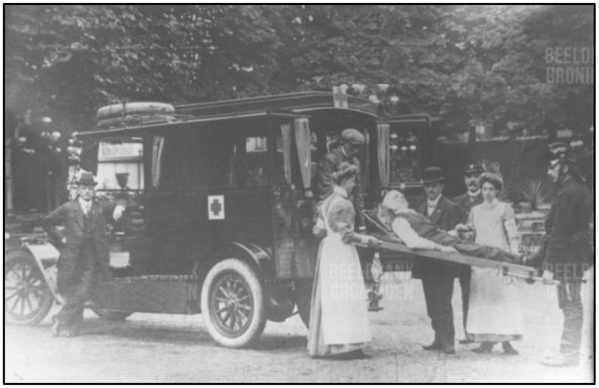


Figure 5 Schedule with the use of the C1 heuristic

The schedule could possibly be further improved. For that, Van der Lans et al. (2006) introduce improvement heuristics. They propose four heuristics that make use of the so called “2-change neighbourhood structure” of the problem. This structure defines for each schedule a neighbourhood consisting of the schedules that can be obtained from the given schedule by exchanging two examinations from one single MRI room. This step is repeated until no further improvements are possible. The improvement heuristics are not further elaborated here, because the MRI setting (with three MRI rooms) is a lot easier to oversee than a schedule with e.g. 25 operating rooms (for which the heuristics are used in the study of Van der Lans).



Ambulance – 1925 and present

4 METHODOLOGY

The term methodology is derived from the Greek words meta (after), hodos (way) and logos (doctrine) and literally means doctrine of the covering way. Nowadays, the concept has different meanings:

1. The analysis of the principles of methods, rules, theories and principles used by professional disciplines
2. The development of methods, which are used within disciplines
3. Methods used in research or development
4. A specific procedure or set of procedures

In this chapter the third meaning is used. This chapter describes which research methods are used to answer the formulated problem statement. The chapter is divided in a qualitative and quantitative part.

4.1 QUALITATIVE METHODS

Qualitative properties are observed and can generally not be measured with a numerical result. Three types of qualitative methods are used in this study. Namely: (I) literature, (II) interviews and (III) observation.

4.1.1 LITERATURE

Scientific literature forms the palpable body of knowledge that is created and is still growing through the exercise of science. Chapter 3 entirely covers the theory that is used in this study. It gives insight in the already existing scientific knowledge about subjects that are relevant for this study. Theory is used to get more insight in variability (sub questions 3 and 6), the allocation of emergency capacity (sub question 7) and improving access time (sub questions 4 and 8).

4.1.2 INTERVIEWS

Several interviews are held to get more insight in the research subject and MRI process.

To get more insight in the research subject and MRI activities at the UMCG the system specialist of MRI and the manager of radiographers are interviewed. This is done in a more or less informal, conversational interview. Some subjects that have to be covered are clear before the interview starts, but no predetermined questions are formulated.
This is done to keep the interviews as open and adaptable as possible.
More insight in the activities of radiologists, more specific radiology reporting of MRI examinations, is obtained by interviewing three radiologists (sub questions 5 and 9). The interviews are open-structured. Five questions, each about a specific subject, are formulated to guide the interviews. The further course of the interviews within the specific subjects is open.

4.1.3 OBSERVATION

Observation in the qualitative sense is conducted to observe the process of MRI examinations. Behaviour of radiographers, the process itself and relevant influencing factors that come from outside the process are observed. Sources of variability could be discovered in this way (sub questions 3 and 6). The observation period takes two weeks (ten working days) from 8:00h till 16:30h.
When interesting behaviour or influencing factors are observed, radiographers are asked for further explanation or their opinion. This is done ad hoc and in an informal, conversational interview setting within their own comfortable work environment. In this way it is tried to give them the feeling that they do not have to give the desired answers, but can actually express their own opinions.

4.2 QUANTITATIVE METHODS

The term quantitative refers to a type of information based in quantities or else quantifiable data (objective properties), as opposed to qualitative information which deals with apparent qualities (subjective properties). In this research three types of quantitative methods are used. Namely: (I) data analysis, (II) observation and (III) simulation. With the first one is meant analysing existing data, with the second one is meant obtaining data that was not available.

4.2.1 Data analysis

Existing data from several sources is used, i.a. RADI, X-care and Cognos. RADI is an appointment database for radiology, X-care is a more general hospital appointment database and Cognos is an overarching data warehouse. MRI data of 2011 is used to determine the current acute patient population and the duration of scheduled examinations (sub question 1a). CT data of 2010 till 2012 is used to determine the acute stroke population. The two together form the future acute patient population (sub question 1b). Furthermore, data is used to get insight in the performance of radiology reporting (sub questions 5). The data also serves as input for the Monte Carlo simulation.
Existing MRI schedules are analysed to study the performance of fast access (sub question 4 and 8).

4.2.2 Observation

In the quantitative sense, observation is used to gather data about the MRI process. More specific, it is about the different process steps and about the time it was performed. The data obtained in this way can be used to perform a time study, i.e. an analysis of the time that is spent on different activities (sub question 2). It gives insight in for example the actual time spent per patient compared to the scheduled time that is available per patient (sub question 6). **Figure 6** below shows the steps in the process that are timed. Other data items collected are: patient number, scheduled examination duration and the type of protocol that is scanned. The quantitative observation is done simultaneously with the qualitative observation mentioned in paragraph 4.1.3 (two weeks, ten working days).

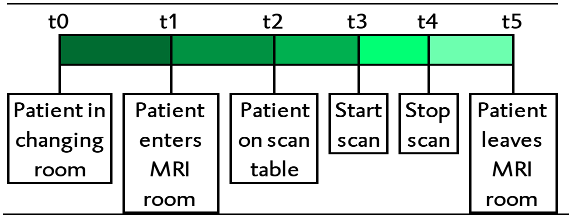


Figure 6 Defined steps in MRI process

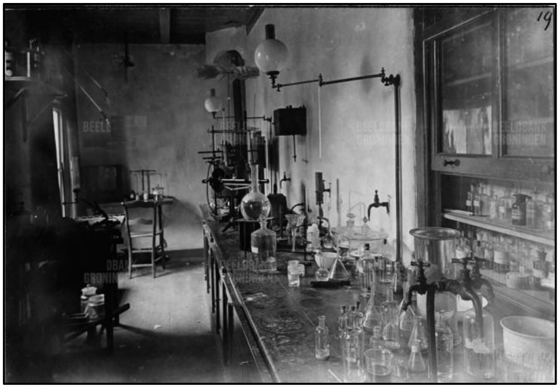
4.2.3 Simulation

To get more insight in the MRI process regarding emergency capacity and the subsequent refusal rate and utilization, a Monte Carlo simulation is developed in Excel (sub questions 1a, 1b, 6 and 7). A Monte Carlo simulation is a simulation technique in which a physical process is simulated many times, every time with different starting conditions (variability in starting conditions is known). The result of the collection of simulations is a distribution function of the solution space.
The simulation used in this study fills a predefined MRI capacity (in minutes) with emergency patients. The starting condition of every simulation (one of many simulations in a run) is a number of patients and each patient having a certain examination duration (in minutes). The number of patients is Poisson distributed (the arrival of emergency patients per day is Poisson distributed) and the duration per patient is randomly chosen with the probabilities of the actual durations derived from MRI data. The output of the simulation is a distribution function of refused patients and the refusal rate and utilization of the emergency capacity. For more info see Appendix I.

Table 1 shows the used methods per sub question to get an even better view of the relationship between the sub questions and the methods that are used to answer them.

		Qualitative methods			Quantitative methods		
		Literature	Interviews	Observations	Data	Observations	Simulation
Sub questions	1				x		x
	2					x	
	3	x		x			
	4	x			x		
	5		x		x		
	6	x		x		x	x
	7	x					x
	8	x			x		
	9		x				

Table 1 The individual sub questions with the methods used to answer them



Laboratory – 1900 and present

5 ANALYSIS OF CURRENT PROCESS

This chapter analyses the current MRI process. The first paragraph analyses the current acute patient population and how the population will change with the introduction of acute stroke patients. The second paragraph presents a time study of the current MRI process. Paragraph 5.3 describes the causes of variability that are observed in the process. Subsequently the performance of fast access for acute patients in the current process will be analysed. Finally, the radiology reporting of acute examinations is examined.

5.1 ACUTE PATIENT POPULATION

The first step in this research is to identify the acute patient population. In paragraph 5.1.1 and 5.1.2 the current acute patient population and the future acute stroke population will be analysed respectively. In the last sub paragraph the total future acute patient population will be analysed.

5.1.1 CURRENT NUMBER OF ACUTE PATIENTS

The current acute population is derived from MRI data of 2011. Every MRI request is prioritised according to the priorities shown in **Table 2**.

Anders nl. (datum wijzigen)	Otherwise, namely
Binnenlopers (datum aanvraag)	Walk-in patients
Over 2 week (+ of - 3 werkdag)	In 2 weeks
Over 4 week (+ of - 1 week)	In 4 weeks
Over 6 week (+ of - 1 week)	In 6 weeks
Over 3 maand (+ of - 1 week)	In 3 months
Over 6 maand (+ of - 1 week)	In 6 months
Over een jaar (+ of - 1 week)	In a year
Spoed=vandaag (altijd bellen)	Acute=today
(leeg)	(empty)

Table 2 Priorities for MRI requests

The priority 'otherwise, namely' is used by requesting physicians when they prefer a different date than is possible with the available priorities. Walk-in patients are outpatients who have an appointment with a physician and get an examination that day because it is more convenient to make the scan or photo (x-ray) directly instead of going home and come back later. However, for MRI this is not common. In practice the physician would have oral consultation with radiology with the question if there is room for a scan. A scan within 24 hours after a request with priority 'walk-in patients' would therefore probably be necessary. It is likely that the patient is acute, but the wrong priority is given. MRI requests with priority “acute” are by definition acute[1]. Furthermore, there are examinations in the data where no MRI order could be coupled to (priority ‘empty’). Acute patients could be hidden in this group. All examinations that are performed within 24 hours after the examination was scheduled are defined as acute. This definition is chosen because there is no data about the moment an examination is requested (see **Figure 7**).

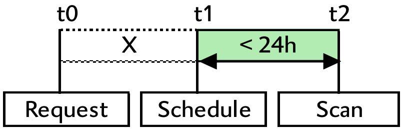


Figure 7 Visualisation of definition acute for priority (empty)

Priority	Number
Acute=today	781
(empty)	161
Walk-in patients	5
Total	947

Table 3 shows the number of acute patients in 2011 per priority according to the chosen definition of acute.

Priority	Number
Acute=today	781
(empty)	161
Walk-in patients	5
Total	947

Table 3 2011 acute population

Further analysis reveals that not all emergency requests with priority acute=today are examined within 24 hours. **Table 4** on the next page shows the time between request and examination for the whole acute population. The ‘(empty)’ patients are also included, but their definition is within 24 hours after the examination was scheduled. The data of this group of patients is used as ‘within 24 hours after the request’.

[1] For emergency patients that need a surgery, the UMCG uses three sub categories: (I) Urgent (within 24 hours), (II) Spoed (emergent, within 6 hours) and (III) Acute (ASAP) (Prikker, 2011). At the radiology department the acute patients are not further divided into sub categories.

Within [h]	Number	%	Cumulative #	%
Same day	509	53,7	509	53,7
24	84	8,9	593	62,6
48	75	7,9	668	70,5
72	42	4,4	710	75,0
96	39	4,1	749	79,1
120	23	2,4	772	81,5
144	30	3,2	802	84,7
168	21	2,2	823	86,9
192	26	2,7	849	89,7
216	5	0,5	854	90,2
240	8	0,8	862	91,0
>240	85	9,0	947	#####
Total	947	#####		

Table 4 Hours between request and examination of acute patients

The Radiology department has no hard criteria formulated with respect to which proportion of acute patients has to be examined in a certain amount of time. Therefore, the Operations Management & Innovation department has defined a criteria for this study. The aim is that all acute examinations that are done within 96 hours after the corresponding request must be performed within 24 hours. MRI examinations with priority acute and who are performed later than 96 hours after the request are not considered to be acute. This means that 79,1% of the acute examinations should be performed within 24 hours. Hence, the total size of the current acute population is 749 patients per year. Furthermore, this criterion is fairly arbitrarily chosen.

5.1.2 Capacity for current acute patients

The capacity that is needed for the acute patients depends on the duration of the individual examinations and the acceptable chance to refuse patients. The current demand of acute patients is 749 examinations per year. Supply can be problematic during times where the three whole body MRI scanners are fully occupied. This is the case on working days from 8:00h till 16:30h. In the evening on working days only one MRI scanner has an elective program scheduled from 16:30h till 23:30h. The other two scanners have no program scheduled. In the weekend all three scanners are free. In the evening, night and weekend radiographers are present to provide radiologic diagnostics (MRI, CT, etc.) for acute patients. The staffing of these radiographers in the evening should be seen separately from the radiographers who perform the elective program in the evening (for a detailed overview of staffing, see Appendix II).
To determine the demand for an MRI scan of the current acute patients from 8:00h till 16:30h, all examinations on working days from 7:00h till 20:00h are selected. Examinations conducted after 20:00h are more likely to be really acute on medical grounds. On the other hand, examinations between 16:30h and 20:00h and between 7:00h and 8:00h could be examinations that had to be performed between 8:00h and 16:30h, but because of a lack of time they are shifted to the evening or early morning.
The population of acute patients on working days between 7:00h and 20:00h is 570 patients. 70 examinations per year are done before 7:00h and after 20:00h on working days and the rest (109 patients) are done in the weekends.

Duration [min]	Frequency	Percentage
10	2	0,4

15	14	2,5
20	4	0,7
30	227	39,8
40	2	0,4
45	189	33,2
60	66	11,6
75	4	0,7
85	1	0,2
90	5	0,9
Unknown	56	9,8
Total	570	100

Table 5 shows the examinations done on working days between 7:00h and 20:00h and their duration. From 56 of the examinations no data about the duration could be found. To be able to match a duration to these examinations, the average duration of the known examinations is used. The average duration is 40 minutes (39,88 minutes exactly).

Duration [min]	Frequency	Percentage
10	2	0,4
15	14	2,5
20	4	0,7
30	227	39,8
40	2	0,4
45	189	33,2
60	66	11,6
75	4	0,7
85	1	0,2
90	5	0,9
Unknown	56	9,8
Total	570	100

Table 5 Number of examinations per duration between 7h and 20h on working days

Table 6 shows the average time of 87 minutes that is needed per day assuming 260 working days per year.

	duration [min]	# examinations
Known	20.500	514
Estimated	2.233	56
Total	22.733	570
Average time/day	87 minutes	

Table 6 Total time per day needed

Currently there is 90 minutes of emergency capacity reserved on the M1 (the MRIs are called M1, M2 and M3) every working day from 15:00h till 16:30h. The currently used 90 minutes correspond to the 87 minutes of emergency capacity that is on average needed according to the current acute population in this study. However, the acute population in this study contains patients who are scanned max. 96 hours after a request for a scan. This means that the total of 90 minutes is not always sufficient to guarantee access within 24 hours and hence, patients are refused and postponed to a later time. A reason for this is that 90 minutes is only sufficient when emergency patients come in evenly divided amounts per day. Due to variability in arrivals per day and duration of examinations the 90 minutes are not always sufficient. Postponing of emergency patients not always has negative consequences for the medical condition of the patient, but could disturb processes downstream (e.g. a surgery). Therefore, reducing the lead time of emergency patients, with minimal impact on the elective program, improves efficiency.
Currently the radiology department has no criteria regarding the refusal rate of emergency patients. Depending on the severity of the patient a decision is made when to scan the patient.

5.1.3 Number of acute stroke patients

Acute stroke patients form a new group of acute patients. 2011 data is analysed to identify the acute stroke population. Patients with suspicion of an acute stroke are triaged under SNEP (Spoed NEurologie Poli, acute neurology outpatient department). All CT examinations that are triaged under SNEP on the emergency department (ED) are screened for acute stroke patients. This screening resulted in a population of 589 patients in 2011. Data of 2010 and 2012 is analysed to check whether there is an in- or decreasing trend noticeable (see **Table 7**). There is a light decreasing trend noticeable, but the data of 2011 is a proper estimation of the expected patient population. See appendix III for a more extensive overview.

Year	CTs
2010	595
2011	589
2012	578

Table 7 Number of acute stroke CTs per year

5.1.4 Capacity for acute stroke patients

The capacity for MRI examinations that is needed to scan the stroke patients depends on the time the radiographers require per patient. Room time (time a radiographer spends on a patient) is estimated to be 30 minutes. This time includes i.a. shifting a patient from a gurney to an MRI proof bed (because of the high magnetic field within the MRI room) to the scan table and vice

versa. The actual scan time is estimated at a maximum of 15 minutes[1]. 589 patients with a room time of 30 minutes results in an extra demand of 589*30=17.670 minutes (294,5 hours) per year (± 6 hours per week).
However, demand that has to be performed between 8:00h and 16:30h on working days is only a problem, because then all three MRI scanners are fully occupied. The future demand during full occupy time amounts 202 examinations (all acute stroke CTs on working days between 8:00h and 16:30h of 2011). 50% of the CTs on working days are performed between 8:00h and 16:30h (for detailed information, see Appendix IV). The criteria 'between 7:00h and 20:00h is not applicable for acute stroke patients, because acute stroke patients need a scan within 15 minutes. 202 examinations times 30 minutes results in an average capacity per working day of 24 minutes (260 working days per year).

5.1.5 Future number of acute patients

The acute population that MRI will encounter in the future and that has to be examined within 24 hours is estimated to be 1.338 patients per year. The composition is shown in **Table 8**.

Acute group	Patients
Current acute	749
Acute stroke	589
Total	1.338

Table 8 Future acute patients per year

It is highly desirable that the arrival of emergency patients, which is expected to be random, can be predicted in some way. This will help e.g. to predict the required capacity per day. Since the arrival of emergency patients occurs randomly, the number of emergency patients per day could be Poisson distributed. To see if this is true in this particular case, 2011 data is analysed (see **Figure 8**).

[1] Estimated by a radiologist.

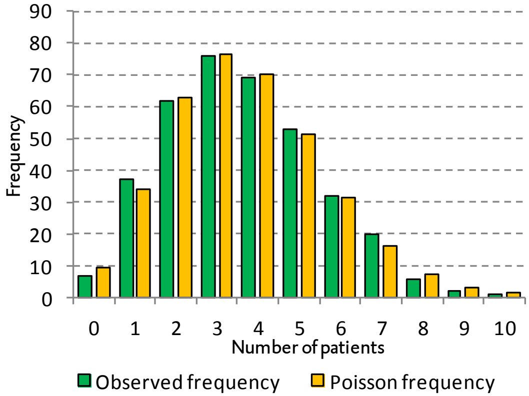


Figure 8 Emergency patients per day (data 2011,)

The graph clearly shows that the observed frequency follows the Poisson frequency closely. To check if the observed data is really Poisson distributed, a chi-square test is conducted. The of the observed data is 2,61. The of the Poisson distribution is 16,92 (α=0,05; DOF=9) and hence, . This means that the hypothesis H_0=*The form of the distribution is Poisson* cannot be rejected and hence, the data is Poisson distributed. Often the assumption dominates that the flow of emergency patients cannot be predicted because of its random nature, but the probability for the number of arriving patients per day is known. On the other hand, the exact number of acute patients that will arrive per day cannot be predicted.

Furthermore, the distribution over the weekdays is analysed. **Figure 9** shows a box plot of the number of emergency patients per weekday and

	Mo	Tu	We	Th	Fr	Sa	Su
Total/yr	203	220	218	197	205	146	149
Ave.	3,90	4,23	4,19	3,79	3,94	2,75	2,87
St.dev.	1,86	2,08	1,68	1,81	1,97	1,56	1,55

Table 9 shows the corresponding numbers. The first thing that can be noticed is the lower average on Satur- and Sundays. An explanation for the lower number of acute patients in the weekends can be that ‘logistic acute’ appears more on working days. ‘Logistic acute’ patients are patients who need an MRI scan quickly before the next step in their treatment process but where their physical condition is not immediately at risk. Such treatment steps are often scheduled on working days and hence, the needed MRI is also scanned on working days.

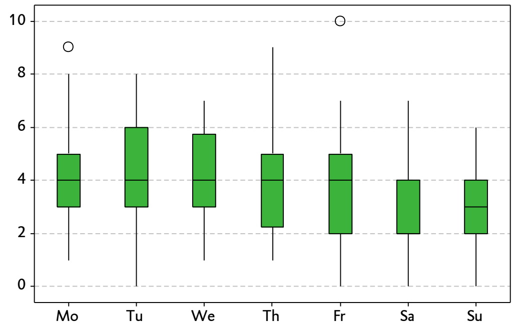


Figure 9 Box plot of emergency patients per weekday (2011)

	Mo	Tu	We	Th	Fr	Sa	Su
Total/yr	203	220	218	197	205	146	149
Ave.	3,90	4,23	4,19	3,79	3,94	2,75	2,87
St.dev.	1,86	2,08	1,68	1,81	1,97	1,56	1,55

Table 9 Emergency requests belonging to the boxplot

Another observation is the slight peak on Tuesdays and Wednesdays. The observed peak is not significant when it is compared to the other working days. However, the difference between the working days and weekend is significant. A Two-Sample T-Test between Thursday (lowest working day) and Sunday (highest weekend day) results in a p-value of 0,006. Hence, the null hypothesis that the sample means are equal has to be rejected.

5.1.6 Capacity for future acute patients

Capacity problems occur on working days between 8:00h and 16:30h, as stated earlier. For both the current acute patient population and the acute stroke patient population the number of patients in this 'problem area' is known and amounts 772 patients per year (570 current acute + 202 acute stroke). The average required emergency capacity per day is 111 minutes (see

Patient group	Duration [min]	
Current acute	22.73 3	570 exam. (see table 5)
Acute stroke	6.060	202 exam. * 30 min.
Ave. time/day	111	260 working days/yr

Table 10 on the next page).

Patient group	Duration [min]	
Current acute	22.73 3	570 exam. (see table 5)
Acute stroke	6.060	202 exam. * 30 min.
Ave. time/day	111	260 working days/yr

Table 10 Average emergency capacity per day

The average required capacity per day will not always be enough to examine all acute patients. Due to variability in the arrival of acute patients per day some patients will be refused and postponed to a later time. The required emergency capacity per day depends on the performance that radiology wants to reach. However, radiology has no criteria formulated regarding a refusal rate or utilization. Because of this, the effects of emergency capacity on refusal rate and utilization is studied. The outcome gives the management of radiology insight into the effects of emergency capacities on refusal rate and utilization which can help to make a justified decision.

A Monte Carlo simulation is used to get insight in the performance of different emergency capacity sizes. A simulation run consists out of many simulations (in this study a run contains 1.500 individual simulations). In each individual simulation a number of acute patients is generated (Poisson distributed) with each patient having an examination duration of 30, 45 or 60 minutes (according to

Duration [min]	Frequency	Percentage
10	2	0,4
15	14	2,5
20	4	0,7
30	227	39,8
40	2	0,4
45	189	33,2
60	66	11,6
75	4	0,7
85	1	0,2
90	5	0,9
Unknown	56	9,8
Total	570	100

Table 5 on page 20). The chance for a particular duration is derived from the real planned durations. The acute patients are then scheduled in the available capacity. To fill the capacity as much as possible, the best fitting patient is chosen. For example, when 15 minutes of capacity are left, a 30 minute patient is removed from the schedule and a 45 minute patient is scheduled. In either way one patient is refused, but with the 30 minute patient removed and the 45 minute patient scheduled, the capacity is better utilized. From the refused patients, a maximum of two are examined in the evening. Any remaining refused patients are postponed to the next day and are scheduled with priority over the acute patients that are generated for that particular day (iteration). The output of the simulation is the refusal rate and utilization. The capacity is a multiple of 15 minutes (for the sake of the simulation). 15 minutes of overtime is used to reduce the effect of patients that would be refused in the simulation while they would be examined in real life because the overtime is small. For example, if 45 minutes are left in the simulation and there is a 60 minutes patient, that patient will be refused (without overtime). In real life such a patient would probably be examined, because 15 minutes of overtime is incalculable. Utilization is computed without overtime, because this could lead to a utilization of more than 100%. **Figure 10** shows the results of the analysis.

Refused patients are in practice postponed to the evening or to one of the next days (see **Table 4**). Postponing all patients to the evening may not be desirable, because of lower staffing in the evening. Hence, in this simulation a maximum of two patients are postponed to the evening and the rest are postponed to the next day. In the end, management of Radiology has to decide which policy they will implement and which utilization and refusal rate is appropriate.

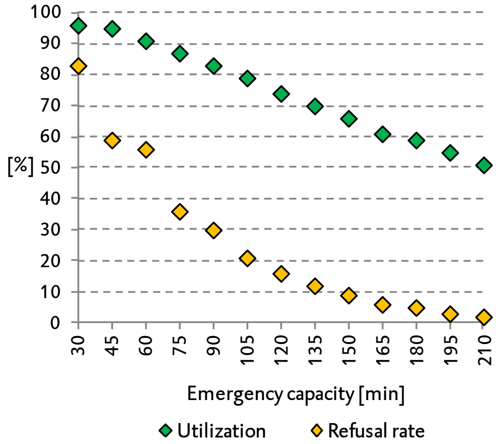


Figure 10 Output of Monte Carlo simulation with respect to emergency capacity

5.1.7 Sub conclusion

The present and future acute patient populations are analysed. The current acute patient population amounts 749 patients per year of which 570 need an MRI scan on working days between 8:00h and 16:30h. The average capacity that is required for the latter group is around 90 minutes.

202 patients per year of the acute stroke population require MRI capacity on working days between 8:00h and 16:30h. The future acute patient population is made up of the current acute population and the acute stroke population. The total number of acute patients that require MRI capacity in the future on working days between 8:00h and 16:30h amounts 772 patients per year. This equates to an average of 111 minutes of emergency capacity per day (assuming 260 working days per year). Refusal rate and utilization depends on the actual capacity that is chosen. The average required capacity of 111 minutes will result in a refusal rate of around 21% and a utilization of 78%. Which performance is acceptable is up to the management of radiology. This analysis only shows the effect of different choices.

5.2 Time study

This paragraph presents a time study of the MRI process. The analysis is conducted to gain more insight into the process. The available data of the UMCG was not sufficient to get insight in the performance of the MRI process. The only way to get reliable data was to collect it manually. During a two week observation of two of the three MRIs (M2 and M3) the process was observed and data (times) was collected to get insight in the MRI process. During the observation period 224 MRI examinations were conducted and it was the best possible way to get a view of the process in a reasonable period of time.

5.2.1 Methodology

During the observation several process steps are timed and listed per patient. See **Figure 6** in chapter 4 for the steps per examination that are timed. Besides that, patient number, scheduled examination duration and type of protocol that is scanned are listed.

The collected data is analysed and arranged according to the following time blocks:

- Patient in MRI room
- Scan time
- Setup time internal
- Setup time external
- Waiting for patient
- Started late – Stopped early
- Breakdown

Patient in MRI room is the total time a patient spends in the MRI room. *Scan time* is the time the scanner truly operates. *Setup time internal* is the time a patient is in the MRI room but no scanning occurs. Activities that are done in this block are i.a. reassuring and informing the patient, inserting of intravenous (IV) access lines for the contrast agent and removal of the access lines after the scan and attaching and removing the coils. *Setup time external* refers to the setup time whereby no patient is in the MRI room. This time includes i.a. changing the scan table (e.g. when changing from a breast scan to a scan of the brains) and waiting for a patient who is still in the changing room. *Waiting for patient* is the time the radiographers have to wait because the patient is not yet arrived in the waiting room. *Started late – Stopped early* is the time the program started later or stopped earlier then 8:00h and 16:30h respectively. Breakdown is time when the MRI scanner is not functioning, e.g. when the computer would not start (happened once during the observation).

5.2.2 RESULTS

The result of the analysis is a time distribution in percentages and depicted in **Figure 11**. The total time (100%) corresponds to a workday of 8,5 hours (510 minutes) from 8:00h till 16:30h. The analysis reveals that two-third of the available time (5:46h) the scanner is truly operating. Another 16,5% (1:24h) of the time the radiographers are busy preparing the patient before and after the examination and the remaining 15,7% (1:20h) is spent on external setup, waiting, starting late or stopping early and breakdown. By only reducing waiting time and external setup time[1] already 55 minutes can be saved on average per day, theoretically (5,9%+4,8%=10,7%. 510*0,107≈55 minutes). All in all the time study shows that there is room for improvement in the current MRI process.

5.3 CAUSES OF VARIABILITY

Several causes of variability in the MRI process are observed during the two week observation. They can be classified into three categories, namely:

- Scheduled vs. actual examination time
- Process design
- Supply chain management

[1] In this setting external setup time is time where no patient is examined. It should not be confused with the positive effect of external setup time as used in the SMED approach.

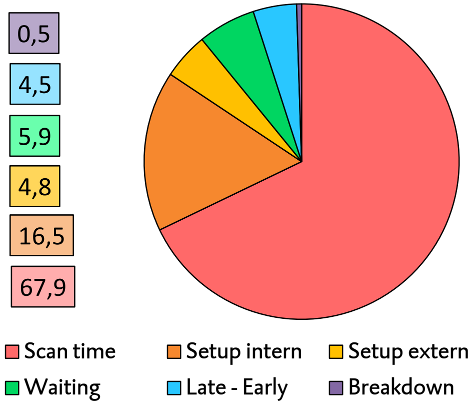


Figure 11 Time distribution of MRI process [%]

5.3.1 SCHEDULED VS. ACTUAL EXAMINATION TIME

The first cause of variability in the process is the discrepancy between the scheduled and actual examination time. The scheduled time is the time of the protocol[1] that has to be scanned.

The first reason why the actual time differs from the protocol time is the simple fact that for some protocols the time is not determined properly. This results in both running in front of schedule and behind schedule.

Another reason is the radiologist who sometimes adds extra series to a protocol while the planned protocol time stays the same. All requests for an MRI are judged by a radiologist before a request is scheduled. The radiologist decides which protocol is appropriate for the specific medical question. Adding extra series without increasing the protocol time leads to a standard scheduled protocol time but an examination that can take longer.

The last reason is that during a scan extra series are conducted. This can occur when a patient moves and hence, images are of bad quality which makes it necessary that that series is done again. It can also occur that a radiologist asks for more series because he/she needs more images to be able to diagnose the patient correctly. In the latter situation the opinion of which type of series are necessary could differ between the radiologist who selects the protocol and the radiologist who is on duty during the actual examination of the patient.

Figure 12 on the next page shows the observed examination times according to category and protocol time. The numbers in the category correspond with the protocol time and the abbreviations used in the categories represent:

- HH Head/Neck - Hoofd/Hals
- CV Cardiovascular
- MSK Musculoskeletal
- Ma Mammography
- Abd Abdominal

[1] An MRI examination is scanned according to a certain protocol. A protocol is made up of different series (scans) and every protocol has a specific length of time.

on the next page shows the difference between the mean examination time and the protocol time. The table shows per category the protocol time (t), the number of observations (N), the standard deviation (σ), the average duration (μ), the percentage of observations that are below the protocol time and the deviation of the average from the protocol time in minutes and percentage. The green and red numbers represent lower and higher average examination times respectively. Five categories have a higher average time. However, four have a low N and four have a negligible deviation of the mean from the protocol time. Hence, this data gives no significant evidence that examinations take on average longer than scheduled. Twelve categories have a lower mean than the corresponding protocol time. From that twelve, six have an N>10. And of those six, another four have a significant deviation of the mean from the protocol time. These four are: HH45, CV60, MSK45 and Ma40. The box plot reveals that HH45 and CV60 have a large variability in examination time. However, for HH45 this means that even when the upper whisker is above 45 minutes 84% of the observations are below 45 minutes and 50% of the observed examinations take less than 32 minutes. For CV60 this means that 80% of the observations are below one hour and 50% of the observations take even less than 47 minutes. Ten of the categories have an N<10. More observations are needed here to get more reliable results. In summary, it can be noted that the results below give a first indication of where improvements could be possible. With reducing protocol times slack is also reduced. This topic will be discussed in paragraph 6.1.5.

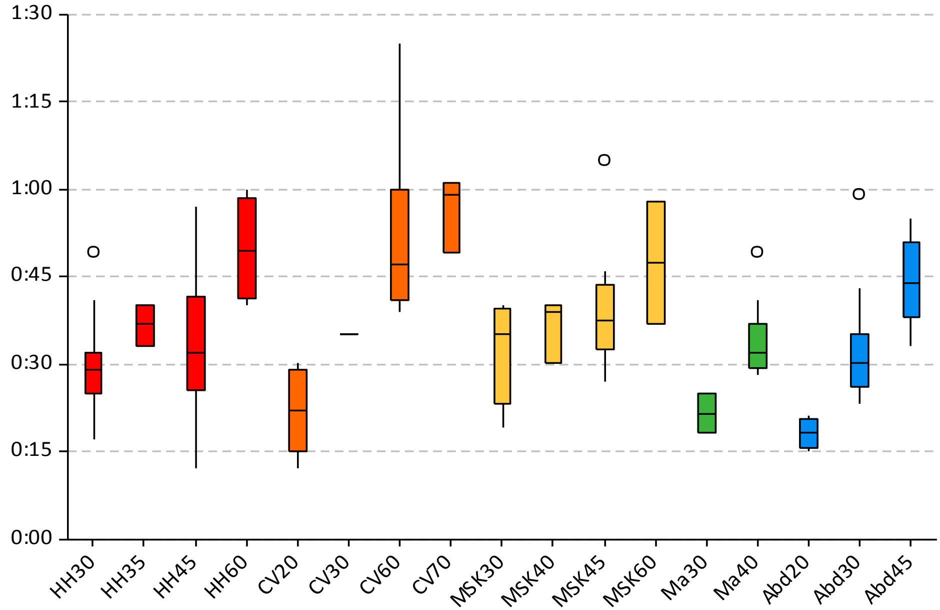


Figure 12 Boxplot of actual examination time per category

	HH				CV				MSK				Ma		Abd		
Protocol time t	30	35	45	60	20	30	60	70	30	40	45	60	30	40	20	30	45
# observations N	71	3	25	4	5	1	15	3	9	3	12	2	2	16	4	19	13
Ave. of obs. μ	29	36	33	49	22	35	51	56	31	36	39	47	21	33	18	32	43
St. dev. of obs. σ	5	3	11	8	7	0	12	6	8	5	9	14	4	5	2	8	7
% observ. ≤ t	64,8	33,3	84,0	100	40,0	0,0	80,0	100	44,4	100	83,3	100	100	87,5	75,0	57,9	64,5
t-μ	1	-1	12	11	-2	-5	9	14	-1	4	6	13	9	7	2	-2	2
(t-μ)/t [%]	3,3	-2,9	26,7	18,3	-10,0	-16,7	15,0	20,0	-3,3	10,0	13,3	21,7	30,0	17,5	10,0	-6,7	4,4

Table 11 Data corresponding to the boxplot in Figure 12

5.3.2 Process design

The second cause of variability in the MRI process is Process design. Within the process of MRI examinations one observation was conspicuous. When a program runs behind schedule some radiographers insert the intravenous (IV) access lines when the patient is in the changing room. This is done to gain some lost time and is possible because patients are asked to arrive 15 minutes before their scheduled appointment. Patients are asked to arrive 15 minutes before their scheduled appointment, because in case the preceding examination ends earlier the next examination can start earlier and hence, time loss is reduced. Insertion of IV access lines in the MRI room increases variability because sometimes insertion is difficult and hence, takes more time. A contrast agent is needed in approximately 50% of all the examinations. The normal procedure is to insert the IV access lines when the patient lies on the scan table. IV therapy is needed when patients receive a contrast agent during the examination. When the question was asked to the radiographers why not all patients get their IV access lines outside the MRI room while the current patient is still under examination, the answers were diverse. Opponents of the idea say:

- Time saving is negligible
- Not enough workspace in changing room
- Insertion when patient lies on a table is safer in case the patient is passing out or becomes unwell
- Simultaneously when the patient lies on the scan table and IV access lines are added the radiographer can talk to the patient and let them feel at ease
- A patient has to walk into the MRI room with IV access lines attached to his/her arm and that could be a risk

Proponents of the idea say:

- It saves time
- There is an infusion chair available
- All the necessary components should be available in an infusion trolley
- During insertion of IV access lines outside the MRI room a patient can be reassured
- When insertion is difficult and e.g. three attempts are needed, the risk of losing valuable time is lower
- One radiographer had experience with inserting IV access lines outside the MRI room at the UMC Utrecht and that experience was positive

5.3.3 Supply chain management

The third and last cause that can result in a delayed schedule are the effects of the supply chain. Three sources are observed. The first one is the delivery of inpatients. Inpatients come from a nursing ward. Sometimes nursing staff is not on time when they transport a patient to the MRI facility. An example seen during the two weeks observation shows this nicely. An inpatient was scheduled for 12:30h. At 12:25h the radiographer noticed that the patient had not arrived yet, so he/she phoned to the ward asking whether or not they knew the patient had an appointment. The answer was:"Yes we know, we leave at 12:30h." The radiographer told that the examination should start at 12:30h. "Ok, than we are coming right now.", was the reaction of the nursing staff. The patient arrives at 12:37h and at 12:43h the patient entered the MRI room. 13 minutes of valuable time was lost because of a failing supply chain.

The second source is delivering the patient in the wrong conditions. Again an observed example will illustrate this source. At 8:00h in the morning a baby is delivered by nursing staff. A baby should be swaddled because of the uncontrolled motions that the baby could make during the scan. Feeding the baby before the examination also helps to make the baby calm. In this particular case, the baby was swaddled wrong. The head was not swaddled allowing the baby to move his/her head. The baby needed to be swaddled again. Valuable time was lost. When the scan was in progress a radiographer gave an A4 paper with swaddle instructions to the nurse. When the question was asked whether all the nursing wards already had this information the answer was "No". No further actions were taken on this event (no use of e.g. a continuous improvement board).

The last source of delayed schedules through the functioning of the supply chain is the alignment of different processes that a patient is subjected to. An example of this are patients who need to go to the echo center to get a contrast agent injected right in one of their joints before the MRI examination starts. When the contrast agent is injected the MRI examination should start within one hour, otherwise the working of the contrast agent decreases. In this particular example a patient was scheduled at the echo center 15 minutes before the scheduled MRI examination. The schedule at the echo center was delayed which resulted in a delayed MRI schedule because two patients from the echo center were too late. This is an example of the effect of interdependent resources (Manansang et al., 1996). Radiographers indicate that there is some communication between the echo center and MRI. Often the echo center calls MRI with the question if they are on schedule before they start their procedure. However, this does not completely prevents the snowball effect to happen.

5.3.4 Sub conclusion

Three sources of variability were observed. (I) The actual examination time differs from the scheduled time. The analysis shows that improvement is possible by better estimating the protocol times. (II) The MRI process can be improved. Inserting of intravenous access lines is done within the MRI room. This results in longer examination times and higher variability. Moving this activity outside the MRI room will reduce variability and examination time. (III) The supply chain is the last source of variability. Late delivery of inpatients leads to delayed examinations. Delivery of inpatients in the wrong condition also leads to delayed examinations. The wrong alignment of different processes results in waiting for patients. Improving these supply chain sources will reduce the disturbance of MRI schedules. The amount of time that can be saved by improving these three sources will be discussed in chapter 6.

5.4 Access time in current process

When an acute patient needs a scan as soon as possible, it is preferable that the scan can start in between two elective scans instead of interrupting an elective scan. To reduce the chance of interrupting an elective scan break-in-moments[1] (BIMs) need to be spread as equally as possible over the day (Van der Lans et al., 2006). In the current process schedulers are not explicitly scheduling examinations with as much BIMs as possible. When the acute stroke patients will demand MRI capacity in the future, the need for fast access further increases.

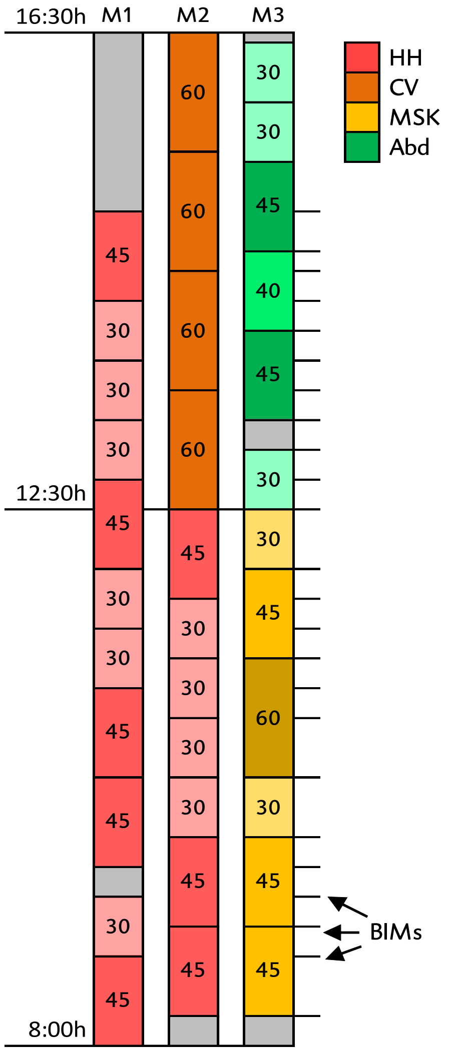


Figure 13 Example of MRI schedule with break-in-moments

[1] A break-in-moment occurs at the end of an examination

Therefore, it is interesting to see how the current process is performing.

Figure 13 shows an example of a schedule and its BIMs. In the current situation the planning is made by three different teams. Team 1 schedules CV and MSK examinations, team 2 Abd and Ma examinations and team 3 HH examinations. Teams can see each other's schedules but they just deal with their own planning. In the future (time period not known) the organisation of MRI scheduling will change which will result in i.a. the elimination of the different scheduling teams. When one team is responsible for the complete schedule, sub schedules can be better synchronised.

Seven schedules are analysed to see how the current schedules without BIM optimisation perform. **Figure 14** shows the average break-in-interval (BII) per number of BIMs and it can be observed that when the number of BIMs increase, the average BII will decrease. Hence, optimizing schedules by increasing the number of BIMs will increase fast access for acute patients.

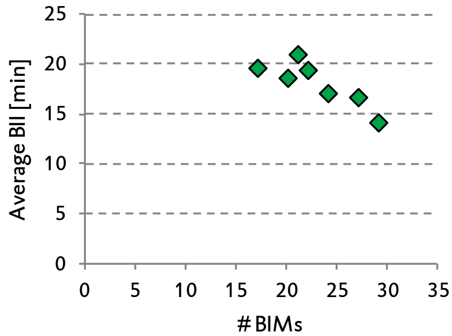


Figure 14 Average BII per number of BIMs

Break-in-intervals are a multiple of 5 minutes, because examinations are scheduled per 5 minutes. 31% of the intervals are larger than 15 minutes (see **Figure 15**). Intervals of 15 minutes or less are no problem, because the aim of radiology is to give acute stroke patients access within 15 minutes.

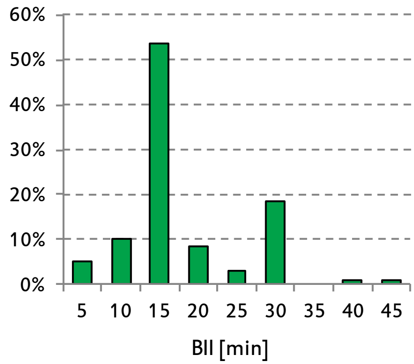


Figure 15 Distribution of break-in-intervals

The MRI department is informed when an acute stroke patient is on transit to the hospital, so there is even more time to be prepared for the patient.

Some nuance should be made because the BIMs deviate in practice, due to the variability in examination duration and other disturbing factors.

Breaking in in the elective program results in postponed elective examinations and possible overtime. This is a negative effect of examining acute patients within an elective schedule.

5.4.1 Sub conclusion

The results that are obtained without BIM optimisation (average BIIs of 15 to 20 minutes) are rather good, only the number of 30 minute intervals are relatively high (see **Figure 15**). Optimising the BIMs could reduce the variability in BIIs (reducing 30 minute intervals). Chapter 6 will discuss the impact of optimising the BIMs.

5.5 Reporting of acute examinations

Completing the MRI examination does not end when the patient leaves the MRI room. The produced images have to be interpreted by a radiologist who then makes a report. It is therefore also necessary to look at the reporting process and its effect on the lead time of the patient. First, the activities of radiologists will be analysed. Secondly, the relation between radiology reports and acute examinations will be studied.

5.5.1 Activities of the radiologist

The interpretative reports rendered by radiologists are the only tangible manifestation of their expertise, training and experience. These documents are very often the primary means by which radiologists provide patient care (Sistrom et al., 2005). Radiologists are assigned to a radiology modality (e.g. MRI or CT) per daypart. During their shift they could have been assigned to report emergency patients from all radiology facilities. However, besides this main task the radiologists have a lot of other activities that prevents them from making reports. These are among others; the discussion of examinations in MDOs (multidisciplinary consultations), assisting resident physicians, looking at images together with a physician when the latter one asks for further explanation, accompanying difficult examinations and performing scientific research.

This results in a workday with diverse activities for the radiologist which could lead to good work ethos, but what decreases the throughput of radiology reports.

Part of the examinations is first interpreted by resident physicians. Those reports have to be supervised by a radiologist to check the work of the resident physician. If the report is of insufficient quality, the report has to be adjusted. When the report is correct, the report is authorized by the radiologist. This process ensures that every examination is seen by a radiologist, whether a resident physician has made a report or not. Hence, in part work is done twice. However, this is part of the training of resident physicians and hence, is insurmountable (education is a core task of the UMCG).

5.5.2 Radiology reporting of acute examinations

Acute examinations differ from elective ones in the sense that time is more important. A fast diagnosis reduces the risk of further medical complications. When a report is needed as soon as possible, the radiologist passes on the report orally by phone to the referring physician. There is no data of phone calls. Hence, it is not possible to get a clear view on reporting performance of acute examinations. The data that is available is the time at which a written report is available and authorized. With this data the time between scan and report can be computed. That data is depicted in **Figure 16**. Examinations are used that were conducted within 96 hours after their request and who had priority acute=today.

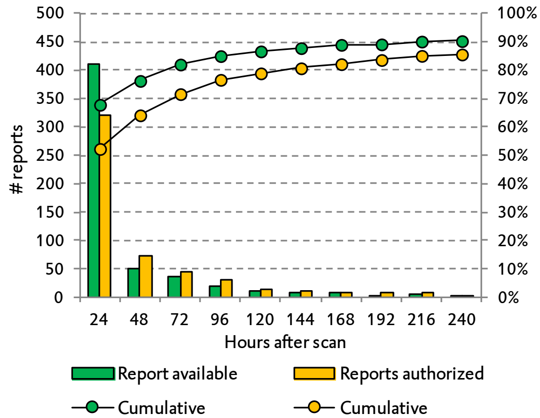


Figure 16 Hours between scan and report of examinations performed within 96h after the request and with priority acute=today

Both the radiologist and the resident physician renders reports. However, only the radiologist is in general allowed to authorize reports. Available and authorized reports are both visible for physicians in poliplus (e-patient record). **Figure 16** shows that 68% of the reports is available within 24 hours and 52% of the reports are authorized within 24 hours.

5.5.3 Sub conclusion

As mentioned earlier, the data does not reveal the performance completely, because the oral reports are not included. There is no possibility to track the past performance of oral reports and hence, no sound analysis can be made with the available data.

5.6 CONCLUSION

Now that the current process is analysed, the first five sub questions can be answered.
The current acute patient population comprises 749 patients per year of which 570 need to be examined on working days between 8:00h and 16:30h. This comes down to an average required emergency capacity of 87 minutes per day. The future acute patient population consists of 1.338 patients per year of which 772 need an examination between 8:00h and 16:30h. The average capacity that is required for the future acute population amounts 111 minutes per day. The Monte Carlo simulation shows the effect of different capacities on utilization and refusal rate. This can help management of radiology to make a justified decision about performance. Up till now radiology has no criteria regarding MRI performance.
A time study is conducted to get insight in the steps of the MRI process and the time it takes. The total available time amounts 8,5 hours of which 5:46h (67,9%) is spent on actual scanning, 1:24h (16,5%) per day radiographers are busy preparing patients, 0:24h (4,8%) are spend on changing of the scanner, 0:30h (5,9%) on waiting for patients and 0:26 (5,0%) on starting the day too late or ending early, or breakdown. The time study shows that improvements are possible.
Three causes of variability were observed within the process. Namely: (I) scheduled vs. actual examination time, (II) process design and (III) supply chain management. All three causes give possibilities to reduce variability. The amount of time that can be saved and the effect of reducing variability will be discussed in chapter 6.
Fast access for acute patients is measured to look at the break-in-moments (BIMs) in current schedules. The analysis revealed that the average break-in-interval (BII) lies around 15 to 20 minutes and 30% of the BIIs are 20, 25 or 30 minutes. Acute stroke patients need to be scanned within 15 minutes after arriving in the hospital. Knowing that the MRI department is informed when an acute stroke patient is on transit to the hospital there is even more time to be prepared for the patient. Reducing the amount of 30 minute intervals will increase the performance of access time (less variability in BIIs). Chapter 6 will discuss the amount of improvement that can be accomplished. The question if the effort it takes to improve the schedules outweighs the amount of improvement than is obtained will thereafter be discussed.
It is not possible to say something founded about the reporting of acute examinations. Real acute examinations are orally reported by telephone and oral reports are not recorded. Hence, no conclusion is made about the performance of reporting of acute examinations.

Pharmacy – ca 1906 and present

6 REDESIGN OF MRI PROCESS

In the previous chapter the MRI process is analysed and improvement opportunities are suggested. In this chapter the ways to improve the MRI process are proposed and the amount of improvement is determined. With improving the MRI process time can be unlocked in the elective capacity which can be used to increase the emergency capacity. The first paragraph will suggest possibilities to unlock extra time in the current capacity. The second paragraph will give advice on how to allocate emergency capacity to the elective schedule. Subsequently, suggestions are done for further increasing fast access for acute stroke patients. Lastly, possibilities to improve the lead time of radiology reporting of acute examinations will be proposed.

6.1 UNLOCKING EXTRA TIME IN CURRENT CAPACITY

Extra time can be unlocked by looking at the sources of variability and to try to reduce their effects. Three sources of variability were observed in this study. Namely, (I) scheduled vs. actual examination time , (II) process design and (III) supply chain management. The three sources are discussed below.

6.1.1 SCHEDULED VS. ACTUAL EXAMINATION TIME

Variability occurs when the actual examination time does not correspond with the scheduled time. Main reasons are: (I) the simple fact that some protocol times are not determined properly, (II) the fact that radiologists do not adjust the protocol time when they add extra series to a planned protocol and (III) the decision during an examination to scan extra series. Also see paragraph 5.3.1.

First, the first reason is looked at. The observed examination times during the two week observation give insight in possibilities to adjust protocol times (protocol times are the scheduled times) to make a better fit between scheduled and actual examination times. In paragraph 5.3.1 it is suggested that the protocol times of the categories HH45, CV60, MSK45 and Ma40 can be reduced. It is determined that more than 60% of the examinations should take less time than the suggested protocol time to avoid structural overtime. To (partly) absorb the variability in examination duration, 60% instead of 50% is chosen. Protocol times can be changed in steps of 5 minutes, because with the scheduling software examinations can be scheduled in blocks of 5 minutes. **Table 12** shows the percentages of examinations that are lower than the suggested protocol time (ts).

Category and protocol time tp	ts = tp - 5 min % < ts	ts = tp - 10 min % < ts
HH45	72,0%	60,0%
CV60	73,3%	53,3%
MSK45	66,7%	41,7%
Ma40	62,5%	25,0%

Table 12 Percentage of observations lower than suggested protocol time

It can be observed that the protocol times of all four categories can be reduced with a maximum of 5 minutes. To see the effect of the new protocol times, **Figure 17** on the next page shows per category the probability that x subsequent examinations (E) take longer or shorter than the suggested protocol time and the corresponding extra and saved time. **Fout! Verwijzingsbron niet gevonden.** on the page thereafter shows the corresponding data. The first five rows show the current protocol time, number of observations, average duration of the observed examinations, standard deviation of the observed examinations and the new suggested protocol time, respectively. The sixth and seventh row show the percentage of observations that take less time than the new suggested protocol time and the corresponding average saved time. The percentage is the probability that an examination takes less than the suggested protocol time. The last two rows show the percentage of examinations that take longer than the suggested protocol time and the corresponding average extra time that is needed. The percentage of examinations that take longer is the probability that an examination takes longer than the suggested protocol time.

Both from **Figure 17** and **Fout! Verwijzingsbron niet gevonden.** it can be observed that the probability that subsequent examinations take longer than the suggested protocol time is significantly lower than the probability that subsequent examinations take less time than the suggested protocol time. Furthermore it can be observed that (logically) the extra and saved time decreases when the variability in examination duration decreases (compare for example HH45 with Ma40).

It applies for all four categories that the shorter examinations probably level out the effect of longer examinations.

More detailed information can be found in Appendix V. To get an even better view on the process more observations are needed and the process can be simulated. Furthermore, more research is needed to get more insight in the exact causes of variability. For example, some CV60 examinations were used for a research project of patients with heart defects. These examinations were quite new and sometimes more time was needed to get the right images. This increased the examination time and hence, variability increased. Ma40 examinations (breast scan) are rather straightforward and hence, there is less variability.

	HH45	CV60	MSK45	Ma40
Protocol time, t [min]	45	60	45	40
Number of observations, N	25	15	12	16
Average duration of observed examinations, μ [min]	33	51	39	33
Standard deviation of observed examinations, σ [min]	11	12	9	5
Suggested protocol time, ts [min]	40	55	40	35
Percentage of observations < ts [%]	72,0	73,3	66,7	62,5
Average time saving of observations < ts [min]	12,5	6,2	6,1	4,9
Percentage of observations ≥ ts [%]	28,0	26,7	33,3	37,5
Average extra time of observations ≥ ts [min]	7,9	12,3	9,3	4,3

Table 13 Suggested protocol time

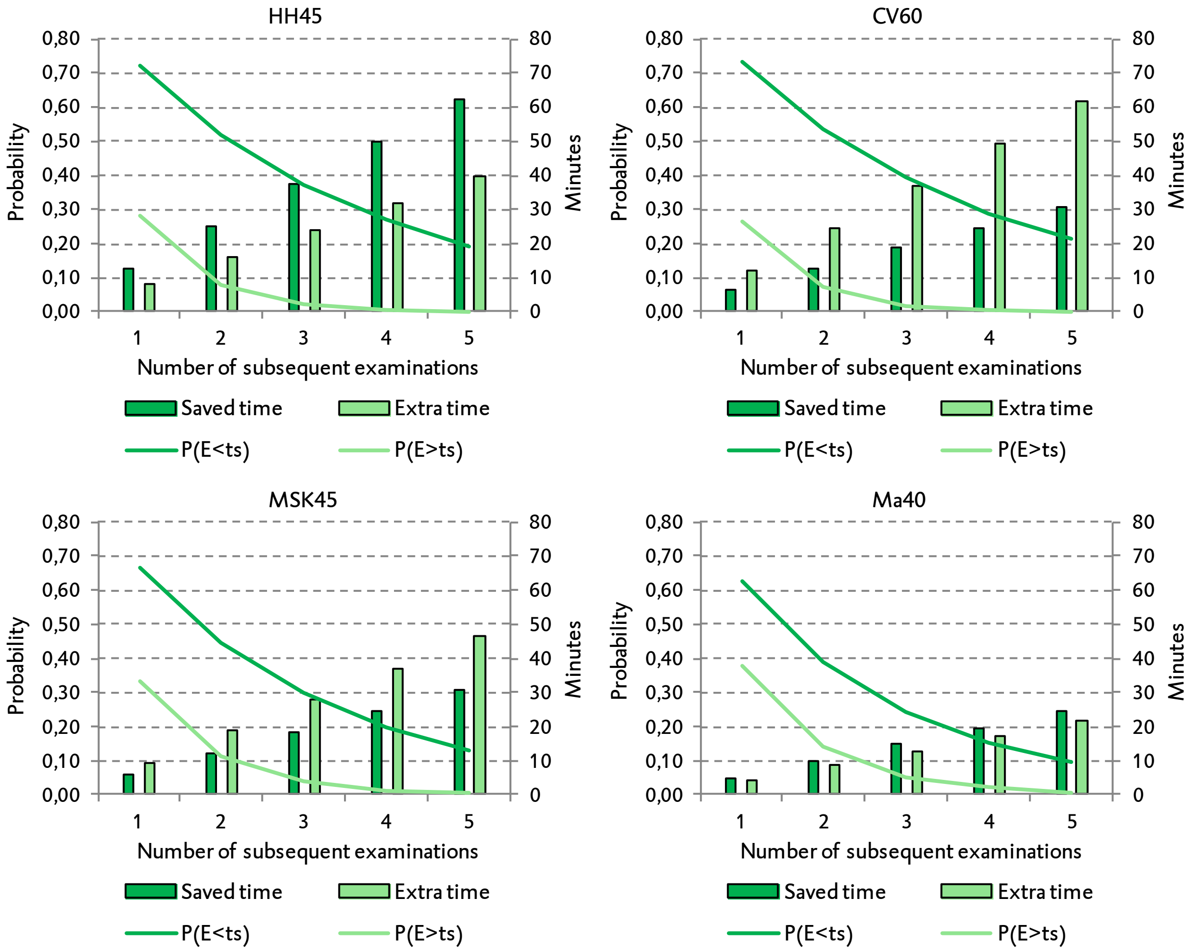


Figure 17 For all four categories the probability per number of examinations (E) that they take longer or shorter than the sug gested new protocol time (ts) and the corresponding average extra and saved time in minute

To see what the effect can be when the protocol times of those four categories are adjusted, the MRI schedules of the two weeks during the observation are adjusted. All the HH45, CV60, MSK45 and Ma40 examinations are reduced with 5 minutes. **Fout! Verwijzingsbron niet gevonden.** and Figure 18 on the next page show the results of reducing the protocol times. Per day, on average 56 minutes can be saved.

Now the last two reasons are analysed. The first one is the fact that radiologists do not adjust the protocol time when they add extra series to a planned protocol in the planning phase (before the actual examination). When protocol times better fit to the real examination times less slack is available to absorb the extra time that could be needed when extra series have to be scanned. Therefore, extra added series during the planning phase should result in an adjusted protocol time (the protocol time is the scheduled time). Protocol times can be adjusted in steps of 5 minutes, because the planning software schedules examinations per 5 minutes, so when the extra needed time is only 1 minute, adding 5 minutes is not really necessary. The decision that extra series have to be made can also be done during an examination (the second of the two reasons). This may be necessary because an image is of bad quality or extra series are necessary on medical grounds. In these cases, no extra time can be planned and slack is needed to absorb the extra time. Therefore, some slack in the system is useful. The decision that the majority of the examinations (more than 60%) have to take less time than the new suggested protocol time keeps some slack in the system that can be used for this kind of variability (and other ones).

Table 14 Reduction in examination time per day

	M1	M2	M3	Total
Day 2	20	15	25	60
Day 3	10	30	5	45
Day 4	5	25	40	70
Day 5	25	20	5	50
Day 6	0	20	20	40
Day 7	15	5	40	60
Day 8	10	40	15	65
Day 9	15	20	35	70
Day 10	20	25	0	45
Average	13	22	21	56,1

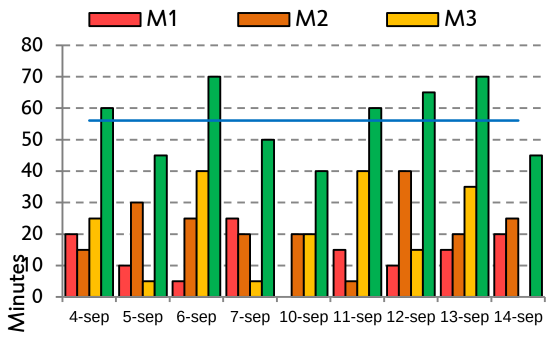


Figure 18 Reduction in examination time per day

6.1.2 Process design

As stated in chapter 5, during the two week observation one thing was conspicuous with respect to the design of the MRI process; The insertion of intravenous (IV) access lines in the changing room when the MRI program ran behind schedule. Some radiographers did this to catch up lost time. The pros and cons that radiographers see when inserting the lines outside the MRI room are mentioned in paragraph 5.3.2. By shifting the insertion of IV access lines outside the MRI room, variability within the process is reduced, because the variability in that task has almost no effect on the examination anymore (Elkhuizen et al., 2007). Patients are asked to arrive 15 minutes before the scheduled examination time. In case the preceding examination ends earlier the next examination can start earlier. The 15 minutes could also be used to insert the IV access lines outside the MRI room. In that case, no valuable examination time is lost. Using 15 minutes for two purposes may sound contradictory, but in general inserting access lines takes less than 15 minutes and when a previous scan stops earlier it is not always exactly 15 minutes too early. Hence, the extra 15 minutes can be used both for insertion of IV access lines and starting earlier. Furthermore, when the insertion of the IV access lines is difficult the radiographer is under less time pressure and is able to try it again calmly without the direct risk of running behind schedule. In the same time the radiographer can have a conversation with the patient and let them feel at ease. At the end of an examination the lines could also be removed outside the MRI room. In the current process the lines are removed when the patient lies on the scan table. When removing them outside the MRI room a patient leaves the table with the lines still inserted. The patient then waits in the changing room. When the radiographers have started the scan of the next patient one radiographer can come to the patient in the changing room and remove the lines. A study done by Elkhuizen et al. (2007) resulted in a reduced lead time for CT examinations by 5 minutes. The study was done at the Academic Medical Center in Amsterdam. At the University Medical Center Utrecht the IV access lines are also inserted outside the MRI room.

Inserting IV access lines outside the MRI room while the current patient is still under examination requires two radiographers. More general, performing activities parallel to increase utilization and reduce variability is only possible with two radiographers per MRI modality.

Preconditions for insertion of the IV access lines outside the MRI room are:

- Two radiographers per MRI modality
- The availability of a suitable infusion chair
- The availability of an infusion trolley with all the necessary equipment

Currently two radiographers are allocated per MRI modality and one infusion chair is available.

Looking at the study of Elkhuizen et al. (2007) the time savings are in minutes per examination. This seems to be little, but when 5 minutes can be saved per examination and there are e.g. six examinations per MRI per day that require a contrast agent, 30 minutes can be saved per MRI modality, which equals one examination (approximately 50% of the MRI examinations are with a contrast agent). The fact that access lines are inserted outside the MRI room at the UMC Utrecht and outside the CT room at the AMC Amsterdam indicate that there are probably no medical reasons on which insertion outside the MRI room is not possible.

6.1.3 Supply chain

The supply chain is the last source of variability in the process. Paragraph 5.3.3 mentions three examples of variability in the supply chain. To improve the supply chain, communication between the processes should improve. When (in)patients arrive on time less time is lost due to waiting for patients. In the example of the patients coming from the echo center, better alignment of the two processes would reduce the risk of waiting for patients. When the appointment at the echo center is scheduled 15 minutes before the MRI appointment (as was observed during the two weeks observation), there is a high probability of late arrival at the MRI facility.

To reduce the risk of arriving of inpatients in the wrong condition (the example of the wrong swaddled baby in 5.3.3) information about the right preparations should be known and available in the preceding processes. In the case of the wrong swaddled baby, swaddle instructions had to be available at the nursing ward.

When it is assumed that all waiting time in the process can be eliminated by better alignment of the supply chain, a maximum of 30 minutes can be saved per day (waiting time accounts for 5,9% of the total MRI time per day).

6.1.4 Continuous improvement board

The previous three paragraphs show the causes of variability in the MRI process. During the observation in this study it was noticed that no direct action was undertaken to reduce variability in the long term. This can be done with the use of a continuous improvement board. The observed problems are written on this board and people get the task to solve the problem. Each problem is a little project and with all the small incremental steps, the MRI process improves continuously. The problem with such a board is not the availability of the board itself but rather the change in attitude towards problem recognition and problem solving within the department. This study does not further deepen out the continuous improvement board, it just mentions it as an improvement possibility.

6.1.5 Total unlockable time

The paragraphs above suggest improvement possibilities which should unlock time in the current elective program. With unlocking extra time the current amount of elective patients can be maintained and the unlocked time can be used to expend the emergency capacity. Better estimated protocol times can save 56 minutes per day. Inserting IV access lines outside the MRI room can save up to 90 minutes per day (30 minutes per MRI) and improving the supply chain can in theory result in another saving of 30 minutes per day. Squeezing out all the variability in a system is not possible. Hence, some slack is useful to be able to absorb some variability in the process. Therefore, it is wise to make a conservative estimation of the time that can be unlocked within the current capacity. The estimation of the time saving due to better protocol times is grounded on data gathered during a two weeks observation. The estimation of the time savings due to insertion of access lines outside the MRI room is made with information of a study done at the AMC Amsterdam and not with data gathered during the two weeks observation. The time saving due to the improved supply chain assumes that all waiting time can be eliminated. Because the latter two sources of improvement are less well-founded than the first one and practice is often more recalcitrant than theory the estimated unlockable time will be less than 176 minutes (56+90+30 minutes). The estimation will be that 60 minutes of extra time can be unlocked in the current capacity. With the already 90 minutes of emergency capacity per day in the current process, the total emergency capacity will become 150 minutes. **Figure 18** shows the performance in utilization and refusal rate that are obtained using a Monte Carlo simulation. The simulation shows that with 150 minutes of emergency capacity the utilization will be 66% and the refusal rate will be 9% (performance of emergency capacity). As mentioned earlier, 15 minutes of overtime is used to reduce the effect of patients that would be refused in the simulation while they would be examined in real life because the overtime is small. A maximum of two refused patients is examined in the evening, the remaining refused patients are postponed to the next day.

6.1.6 SUB CONCLUSION

The improvement suggestions done above show that extra time can be unlocked in the current capacity. When protocol times are better estimated on average 56 minutes can be unlocked per day in the current capacity. Inserting IV access lines outside the MRI room will also unlock extra time, because examination time is reduced. This can amount to a saving of 30 minutes per MRI per day. Improving the performance of the supply chain can in theory unlock around 30 minutes per day. With a conservative estimation of 60 minutes that can be unlocked in the current process, emergency capacity can increase to 150 minutes per day (current 90 minutes + unlocked 60 minutes). According to the results of the Monte Carlo simulation, this will result in a refusal rate of 9% and a utilization of 66%. Which performance is desirable depends on the management of radiology, but it can be seen that improvements are possible and extra emergency capacity can be unlocked without the use of extra capacity outside the normal opening hours.

Furthermore, a continuous improvement board could help the radiology department with continuously improving the MRI process.

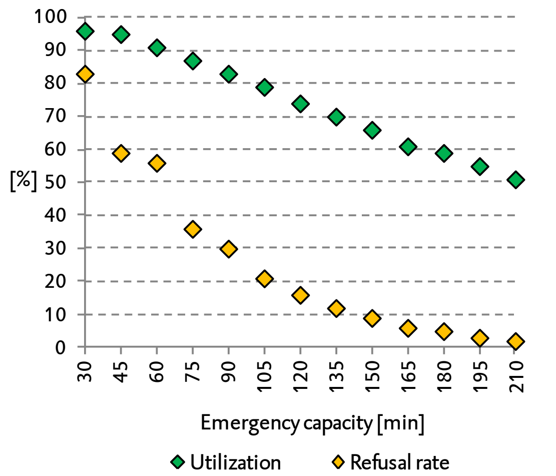


Figure 18 Utilization and refusal rate of future acute population, using a Monte Carlo simulation

6.2 ALLOCATION OF EMERGENCY CAPACITY

The allocation of emergency capacity can be done in three ways: (I) allocating all emergency capacity to one dedicated emergency MRI, (II) allocating all emergency capacity to one MRI where elective capacity is also allocated to, or (III) allocating the emergency capacity evenly over all MRIs (options I and III are from Wullink et al., 2007 and Tancrez et al., 2009). A dedicated emergency MRI results in a capacity of 510 minutes (from 8:00h till 16:30h) and hence, dedicating one MRI solely to emergency examinations would be a waste of valuable MRI capacity. The options that remain are, (II) allocation of emergency capacity to one MRI with that MRI also having capacity reserved for elective examinations, or (III) allocating the emergency capacity evenly over all three MRIs (see **Figure 19**).

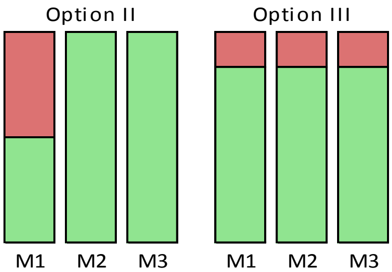


Figure 19 Two options to allocate emergency capacity (red)

The elective capacity is the same in both situations. Allocating all emergency capacity to one MRI (option II) has no negative effect on the elective capacity, while dedicating one MRI solely to emergency examinations does, because in the latter case elective capacity is reduced. The way in which emergency capacity is allocated influences the performance of the emergency capacity. When, for example, 150 minutes of emergency capacity is divided over all three MRIs in blocks of 50 minutes, the performance of the emergency capacity will decline compared to one block of 150 minutes (refusal rate and utilization), because examination times fit less well in smaller blocks.
With the use of the Monte Carlo simulation the effect of smaller emergency capacity blocks can be studied. The flow of arriving emergency patients can be divided into three separate flows (one flow for every capacity block, see **Figure 20**).

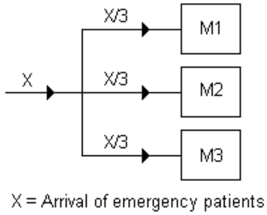


Figure 20 flow of arriving emergency patients divided per MRI

When the average number of patients per day (Poisson) is divided by three and the capacity is set to 50 minutes, the results of the Monte Carlo simulation are (see **Table 13**).

Capacity [min]	50	150
Refusal rate	24%	9%
Utilization	53%	67%

Table 13 Results of Monte Carlo simulation with different block sizes

Table 13 shows that with decreasing capacity the refusal rate increases and the utilization declines. In the simulation only one examination or two of 30 minutes can be done per block, because there is a maximum overtime of 15 minutes (total of 65 minutes to fill)[1]. The probability to overrun the emergency capacity is higher with smaller capacity blocks. This is why the refusal rate is higher and the utilization lower in a block with three times less capacity and three times less patients. An advantage of three small blocks is that more than one acute patient at a time can be examined. The latter issue will be further discussed below.
The majority of emergency examinations are examinations that need to be done 'today'. This group of examinations can be accumulated in an emergency block. Really acute patients, such as acute stroke patients who need a scan within 15 minutes, can be examined outside the emergency

[1] Two times a 30 minute examination results in 60 minutes. This is less than 65 minutes. Other combinations always result in more than 60 minutes.

block. In the current situation 90 minutes of emergency capacity is allocated to the M1 from 15:00h till 16:30h on working days. The new chosen emergency capacity can also be allocated in one block at the rear of the schedule on one of the MRIs. Emergency capacity at the end of the day is preferable over e.g. an emergency block in the morning, because the majority of the emergency requests that arrive during the day can be accumulated in the emergency block at the end of the day. Although the emergency capacity is not divided over all three MRIs, really acute examinations can be performed outside the emergency block on any MRI. This will result in a shifted schedule for the subsequent elective examinations on that MRI and the probability for overtime. To reduce the risk for overtime an elective examination can be shifted to the emergency block when there is capacity left, with the result that the risk for overtime is reduced and the other elective examinations can start on time (see **Figure 21**).

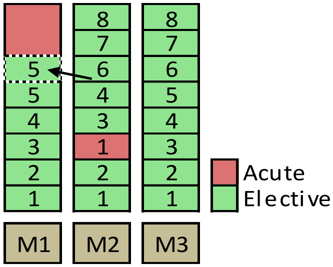


Figure 21 Elective examination shifted to emergency block

The articles of Tancrez et al. (2009) and Wullink et al. (2007) state that with less ORs (seven ORs for Tancrez and twelve for Wullink) there are not enough break-in-moments (BIMs) to give fast access to acute patients (break-in-intervals are too large). This is not the case with three MRIs because of two reasons: (I) the number of really acute patients is less and (II) the elective examinations are much shorter (30, 45 and 60 minutes) compared to surgeries who can take hours. The next paragraph will further discuss fast access for really acute patients (e.g. acute stroke patients).

A specific pattern in the arrivals of emergency patients could influence the way in which emergency capacity is best dealt with. The arrival pattern that is observed is an increase in emergency patients that starts around 7:00h and a decreasing trend that starts around 17:00h. In the night the number of emergency patients is flat and low (see **Figure 22**). During the day the arrival of emergency patients is rather constant. Hence, no structural peaks or drops in arrival of emergency patients in the day are expected.

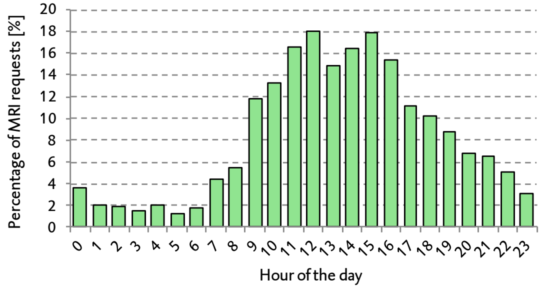


Figure 22 Percentage of requests for an acute MRI per hour of the day (data are acute=today re quests for MRI and acute stroke CTs during 2011)

6.2.1 Sub conclusion

The emergency capacity can best be allocated in one block to one MRI modality at the end of the day. This ensures the best performance in refusal rate and utilization and fast access is not a problem compared to what Wullink et al. (2007) and Tancrez et al. (2009) oppose in their articles, because really acute examinations (e.g. acute stroke) can be conducted outside the emergency block. In the studies of Wullink et al. and Tancrez et al. emergency operations are not possible in elective ORs when dedicated ORs are used. Furthermore, the emergency block can function as a buffer for shifted elective examinations due to an emergency examination outside the emergency block. This buffer function will reduce the risk of overtime. This looks like the situation where emergency capacity is divided over all three MRIs, but the difference is that here emergency capacity is allocated in one block instead of dividing the capacity over all three MRIs.

6.3 IMPROVING FAST ACCESS

Fast access for acute patients such as acute stroke patients is important. It reduces the risk of complications and morbidity for those patients. For acute stroke patients access is needed within 15 minutes. The analysis of the current access times (see paragraph 5.4) reveals that currently the average break-in-interval (BII) is in between 15 to 20 minutes. However, 18% of the intervals take 30 minutes. Van der Lans et al. (2006) introduce a method for improving the access time by better scheduling of examinations which leads to more evenly distributed break-in-moments (BIMs) and a lower average BII. The method that is used is a heuristic that is developed by Van der Lans et al. (2006) and it is called the C1 heuristic. The heuristic schedules examinations forward and backward, trying to avoid large BIIs either at the beginning or at the end of the day. By forward scheduling is meant the scheduling of examinations in an MRI room one after another from the start of the day towards the end of the day, while the reverse holds for backward scheduling. Backward scheduling is possible, since the number and the durations of examinations in an MRI room are known and thus completion times per MRI room. For a more detailed overview of the steps of the heuristic, see Appendix VI.

To see what the effect of the heuristic is for the schedules that are produced currently, without explicitly improving the BIMs, the heuristic is used on the seven schedules that were analysed in paragraph 5.4. (each schedule of a day consists of three sub schedules, one for each individual MRI scanner). After all seven schedules (seven days) are rescheduled with the use of the C1 heuristic, the schedules are further improved with manual changes. No predefined rule is used for the manual improvements. The schedules are just observed and where improvements are possible, they are carried out (e.g. changing two examinations within one MRI room). The results of the heuristic and the manual changes are shown in **Figure 23**, **Figure 24** and **Figure 25**.

The figures show that with forward and backward scheduling (C1 heuristic) the average BII decreases from 18,1 minutes to 15,7 minutes. Furthermore it can be observed that the number of 30 minute intervals are reduced and instead, the 5, 10 and 20 minute intervals increase. When the schedules are further adjusted manually the average BII reduces even further from 15,7 minutes to 14,3 minutes. With a

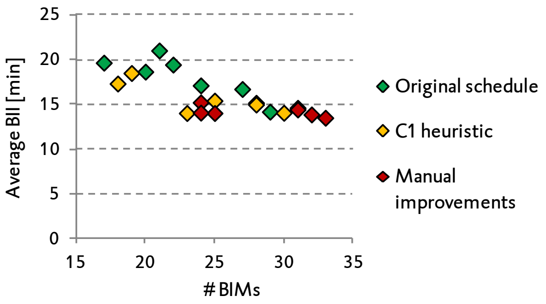


Figure 23 Average BII per schedule type

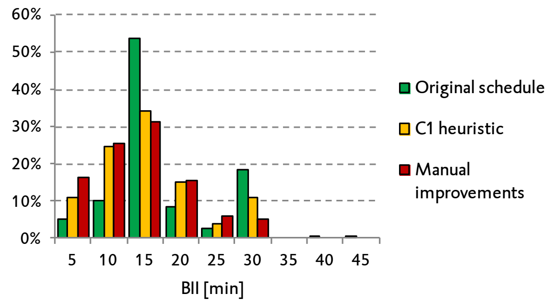


Figure 24 Percentage of different BIIs per schedule type

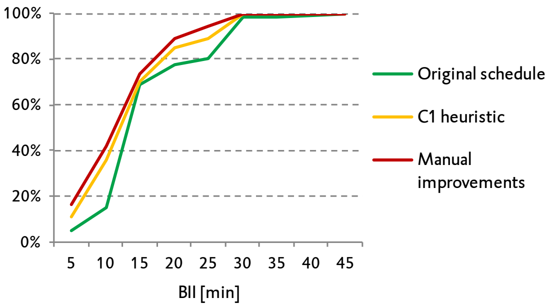


Figure 25 Cumulative function of BIIs per schedule type

paired t-test the averages of the three scheduling types are compared with each other. The difference between the schedules is significant with a confidence interval (CI) of 95% (α=0,05). The difference between the original and C1 heuristic schedule is significant with a P-value of 0,0444. The difference between the original and manual schedule is significant with a P-value of 0,0024 and the difference between the C1heuristic and the manual schedule is significant with a P-value of 0,0411. All the P-values are under 0,05 and hence, all the combinations show a significant difference of the average BII. The deviation of the averages also reduces. The standard deviations are 2,3 minutes, 1,7 minutes and 0,6 minutes for original, C1 and manual improved schedules respectively. **Figure 24** on the previous page shows how the distribution of the different intervals changes from a majority of 15 and 30 minute intervals in the original schedules to more evenly distributed intervals for the C1 and manual schedules. The 5 and 10 minute intervals account for 15% in the original schedules, while this proportion increases to 36% and 42% when the heuristic and manual improvements are conducted respectively. The cumulative graphs in **Figure 25** show that on every point the manual improvement schedule is better than the other two. The fact that the MRI department is informed when an acute stroke patient is on transit to the hospital helps them even more to be ready and realize quick access to one of the MRI modalities.

6.3.1 SUB CONCLUSION

With the use of the heuristic and manual improvements the average BII is reduced and the deviation in average BII is reduced. For all the combinations the difference between the average BIIs is significant. The obtained average BII of 15 minutes corresponds with the objective of radiology to give access to acute stroke patients within 15 minutes after arriving at the hospital. Large improvements in average BII reduction are not obtained, but the deviation in intervals is much better. Therefore, the big advantage of improving the schedules is the reduction of large BIIs instead of drastically reducing the average BII. A point of discussion is the question if the effort to improve the schedules outweighs the improvement in access time. This point will be further discussed in chapter 7.

6.4 IMPROVING LEAD TIME OF RADIOLOGY REPORTING

Making improvement suggestions for reporting of acute examinations is difficult, due to the fact that part of the acute examinations is passed through orally and no data is available about oral reporting. The fact that 52% of the acute examinations are authorized within 24 hours does not necessarily mean that the medical treatment of the patient is interrupted and hence, measuring real performance is not possible. However, 68% of the reports are available within 24 hours after the scan. Hence, 23,5% of the reports that are available within 24 hours are not authorized within 24 hours. A reason for this can be the various activities that a radiologist performs during his workday.

Measuring the performance of acute reports is difficult, but elective examinations are not passed through orally and hence, that performance is better measurable. Reporting of elective examinations falls outside the scope of this study. However, it can be valuable for the UMCG to know how reporting of elective examinations performs. Therefore, an analysis is included in appendix VII.

6.5 CONCLUSION

In this chapter suggestions have been made to improve the MRI process. The last four sub questions of this study can now be answered.

Extra time can be unlocked through better estimation of the protocol times. Inserting the intravenous access lines outside the MRI room reduces the examination time and hence, will also result in extra available time. Improving the supply chain can reduce the time that is spend on waiting for patients, which will increase efficiency and unlock time. Small improvements can be made by using a continuous improvement board. This board can help to solve problems that occur in the process and which can lead to small incremental improvement steps. With a conservative estimation, approximately 60 minutes of extra time can be unlocked per day from 8:00h till 16:30h. This leads to 150 minutes of capacity that can be allocated to emergency patients (the unlocked time of 60 minutes plus the already present emergency capacity of 90 minutes). According to the results of the Monte Carlo simulation, this will result in a refusal rate of 9% and a utilization of 66% for the emergency block.

The emergency capacity can best be allocated in one block to one MRI modality. Dividing emergency capacity in equal parts over the three MRIs will result in decreasing utilization and in an increasing refusal rate.

Improvements in fast access for acute patients and in specific, acute stroke patients, can be obtained by scheduling examinations with the forward-backward heuristic and manual improvements. This will result in an average break-in-interval of around 15 minutes and a better distribution of the BIIs. The improvements should be enough to guarantee fast access for acute stroke patients within 15 minutes after arrival at the hospital.

The performance of radiology reporting of acute MRI examinations is difficult to measure, because part of the reports is passed through orally and oral reports are not recorded. Hence, no conclusion is made about the performance of reporting of acute examinations.

MRI scanner – ca 1994 and present

7 Discussion

Some findings in this study can be discussed. The first one is the examinations that are observed and divided into categories. Each category consists of different protocols from that category (e.g. HH) with the same protocol time. When the individual protocols are analysed the examinations can be even better estimated.

Another point is the access time for acute patients. With the use of the heuristic and manual improvements the access time becomes better. However, when patient A is finished at 10:00h and patient B is scheduled at 10:05h there is a break-in-interval (BII) of 5 minutes. But patient B has arrived 15 minutes before the scheduled appointment (as every patient is asked to do) and the radiographers will start the examination of patient B at 10:00h so they do not waste valuable capacity. In this way the BII is vanished. The effects in practice of the improvements in the schedules should be monitored to see what the real effect is.

A different discussion point about fast access is the effort that is needed to improve the schedules compared to the improvements that are achieved. The effect in practice should be compared to the effort it takes to realise the effect.

The last discussion point for improving access time is that the schedules should only be changed to improve the access time before the appointment letters are send to patients. Rescheduling of the schedules after the appointment letters are send to the patients is not desirable, because then all patients need to get a new appointment letter with the new appointment.

For the acute patient population it is decided to define patients from the acute=today priority that have had an examination within 96 hours after the request was made as acute. There is reasoned that patients that underwent an examination within 96 hours are most likely acute. This is a somewhat arbitrary, because why not including patients that have had an examination within 120 hours after the request was made or 72 hours? This discussion could then continue forever, but it is good to know that other decisions could also be made.

More patients get the priority acute=today than are included in the definition of acute patients in this study. There are patients that have had an MRI examination later than 96 hours after the request was made. This group can result in a higher utilization of the emergency capacity than is stated in this study. This effect is positive, because it will reduce the waste of valuable MRI capacity.

UMCG terrain – ca 1970 and present

8 CONCLUSION AND RECOMMENDATIONS

In this chapter the main research question will be answered. The research question is:

> How can future acute patients who need an MRI scan be diagnosed within 24 hours and how can access within 15 minutes be achieved for acute stroke patients, with a minimal impact on the elective capacity?

The answer will be given in the first paragraph. In the subsequent paragraphs recommendations for implementation of the suggested solutions and suggestions for further research will be made.

8.1 CONCLUSION

With answering the sub questions in this study an answer can be given to the main research question. Depending on the performance (utilization and refusal rate) that management of radiology wants to deliver diagnosis of acute patients within 24 hours is achievable without affecting the elective capacity.
Emergency capacity has to increase to be able to diagnose more acute patients within 24 hours. This can be achieved by unlocking time in the current elective capacity. The first possibility to unlock time is the better estimation of protocol times. The categories HH45, CV60, MSK45 and Ma40 can be reduced with 5 minutes. Secondly, insertion of intravenous access lines should be shifted outside the MRI room. This will reduce variability in examination time and hence, the examination time will decrease. Further, the supply chain should be improved. Patients have to arrive on time and in the right conditions. Patients arriving too late and/or in the wrong condition result in the loss of valuable capacity. When these improvements are implemented a conservative estimation can be made of 60 minutes per day that can be unlocked in the elective capacity. This results in a total emergency capacity of 150 minutes, because there is already an emergency capacity of 90 minutes available in the current process. this capacity results in a utilization level of 66% and a refusal rate of 9%, according to results of the Monte Carlo simulation.
Fast access for acute stroke patients can be achieved by improving the schedules with the C1 heuristic and thereafter further improving it manually.
A continuous improvement board is suggested to be able to solve minor problems. The minor problems together can result in major improvements and the board can help to create a culture of continuous improvement at the MRI department.

8.2 RECOMMENDATIONS FOR IMPLEMENTATION OF THE SOLUTIONS

To realise a lead time reduction for acute MRI examinations the solutions that are opposed in this study have to be implemented. The solutions that can be implemented in a short period of time are the reduction of protocol times and the insertion of IV access lines outside the MRI room. This will result in a reduction in process variability and a schedule that better corresponds to actual examination durations.
Improving the supply chain is more complex, because more departments are involved (e.g. nursing wards and echo center). However, this should also be done, because the waste of valuable time can be reduced with improving the supply chain. A continuous improvement board can help to identify problems in the supply chain and help to take action. In addition to the placing of the board, the whole culture of continuous improvement and problem recognition must take shape.
Improving fast access is in the current organizational structure is difficult, because the whole schedule of the three MRIs for one day is not scheduled by one person. There are three teams who plan examinations. The organizational structure at the MRI department will change in the future and this will i.a. result in one team who schedules all the examinations. This will make it easier to improve a complete schedule. Implementing the new way of scheduling could be included in the project of the new organizational

structure. This will result in less separate improvement projects and maybe more commitment from employees.

8.3 SUGGESTIONS FOR FURTHER RESEARCH

There are several topics where further research could be done. The first topic is the examination times. During the two weeks observation there are 224 examinations conducted. Still, not all categories are equally seen. To make more sound decisions about protocol times and to what extent they differ from the actual examination times, more examinations have to be timed.

In extension to the above, the categories (HH30, CV60, MSK45, etc.) could be further differentiated, because every category consists of all the different protocols in that category with the same protocol time. It could be that some protocols within a category are proper estimated, while other protocols are not. The knowledge of the actual examinations of the different protocols will help to better estimate required examination time and hence, schedules will better represent actual performance with respect to examination times.

The time it takes to insert the IV access lines is not measured separately during this study. To be able to predict the effect on examination time when the insertion of the access lines is done outside the MRI room more precisely it is necessary to measure the time that this activity occupies in the current process.

The use of a continuous improvement board only succeeds when the right culture and structure is present at the MRI department. Just putting such a board at the MRIs does not work. Further research should be done to see which things have to change to make a continuous improvement board a success. PhD student Oskar Roemeling from the University of Groningen is doing his PhD on the topic of Lean in Healthcare and focuses i.a. on the use of continuous improvement boards in hospitals. Involving him in this topic could help to make the implementation a success and it may also improve his PhD study. In this way two birds can be killed with one stone.

To be able to get more insight in the performance of radiology reporting of acute examinations a study should be conducted which includes the measurement of oral reporting. This is the only way to get a more reliable picture of the performance of radiology reporting of acute examinations.

An important last point that should not be forgotten is the experience of the patient that undergoes an MRI examination. It is of value to know how a patient experiences the examination, because changes in the MRI process could also have an effect on them. Patients should not merely be seen as products entering a process, because patients are humans with emotions. Their mental condition is in general more worse compared to healthy people and during a period of illness and medical treatments the least thing a hospital can do is to create a safe, friendly and personal experience for the patient. This trade-off between process efficiency and 'the human factor' should be kept in mind and asking patients about their experiences will help to better understand the process as a whole.

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APPENDIX I - MONTE CARLO SIMULATION

The Monte Carlo simulation used in this study is made by Tjibbe Hoogstins. The simulation is used to analyse the performance of an emergency block.

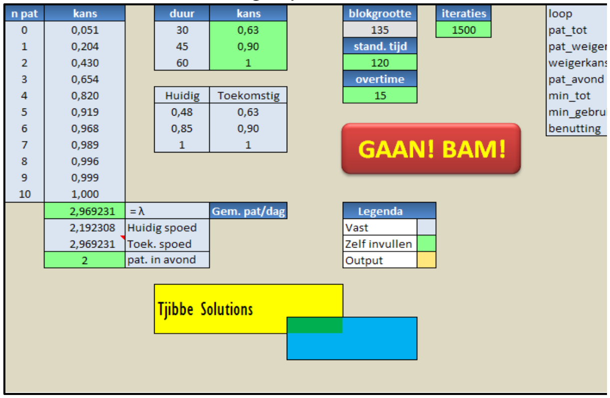


Figure 26 shows a screenshot of the simulation that runs in Microsoft Excel. The green cells have to be filled manually. First, the average number of arrivals per day is filled in (λ). The column 'kans' (probability) is than automatically filled with the cumulative probability distribution of the corresponding Poisson distribution. Then the number of refused patients that are examined in the evening is determined ('pat. in avond'). Thereafter, the three green cells next to 30, 45 and 60 are filled. 30, 45 and 60 represent the scan duration and in the green cells their cumulative probability is filled in. The cell 'stand. tijd' corresponds with the normal size of the emergency block (in minutes). Below the amount of overtime is filled in. 'Blokgrootte' is than automatically filled with the total block size (normal size + overtime). Overtime is used to reduce the effect of patients that would be refused in the simulation while they would be examined in real life because the overtime is small (e.g. 15 minutes). In this way it is tried to better approximate reality. Finally, the number of iterations is chosen. One iteration represents one day. Pressing the 'GAAN! BAM!' button will start the simulation. With every iteration a random number of patients is generated according to the Poisson distribution and every patient

has a random generated examination duration of 30, 45 or 60 minute according to the filled in probability. Next, the emergency block is filled with the patients of the same iteration from shortest till longest duration. The patients who cannot be added to the emergency block, because it is full, are seen as refused patients. A predefined number of refused patients is examined in the evening. Any remaining refused patients are postponed to the next day (the next iteration) where they are scheduled with priority over the generated number of patients of that particular iteration. So, refused patients are examined in the evening or the next day.

The output of the simulation is the total number of patients and the number of refused patients. Dividing the refused patients by the total number of patients will result in a refusal rate. An extra output is the number of patients that is examined in the evening. Further output are the total number of standard minutes (iterations * 'stand. tijd' minutes) and the used minutes (with max. equal to standard time). Dividing the used minutes by the total number of minutes results in a utilization rate. As a last, the number of refusals per iteration are tracked and next to the table that shows these numbers a graph shows the frequency of the number of refusals.

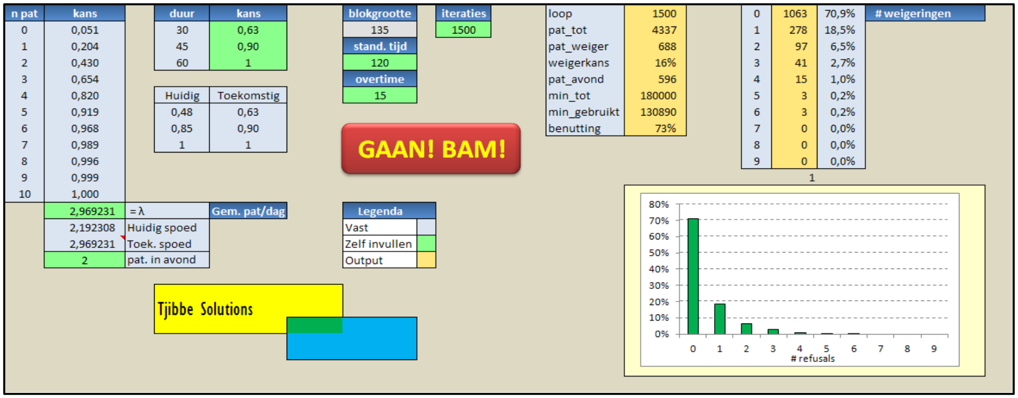


Figure 26 Screenshot of Monte Carlo Simulation in Microsoft Excel

Appendix II – Staffing of radiographers in evening, night and weekend

Evening	
15:30h - 24:00h	3 radiographers
Knowledge	2 CT
	1 MRI
	1 general
13:00h - 21:30h	1 radiographer
Knowledge	1 general
Night (every day)	
23:30h - 08:00h	2 radiographers
Knowledge	1 CT
Weekend	
7:30h - 16:00h	4 radiographers
Knowledge	2 CT
	1 MRI
Weekend evening	
15:30h - 24:00h	3 radiographers
Knowledge	2 CT
	1 MRI

Table 14 shows the staffing of radiographers on the evening, at night and in the weekends. It can be observed that in the evening three radiographers are staffed but that four types of knowledge has to be present. This is possible, because one radiographer can have both knowledge about CT and MRI.

Evening	
15:30h - 24:00h	3 radiographers
Knowledge	2 CT
	1 MRI
	1 general
13:00h - 21:30h	1 radiographer
Knowledge	1 general
Night (every day)	
23:30h - 08:00h	2 radiographers
Knowledge	1 CT
Weekend	
7:30h - 16:00h	4 radiographers
Knowledge	2 CT
	1 MRI
Weekend evening	
15:30h - 24:00h	3 radiographers
Knowledge	2 CT
	1 MRI

Table 14 Staffing of radiographers in evening, night and weekend

All shifts are extra covered with backup radiographers (the so called ‘achterwacht’) in case it becomes extra busy. Where there are gaps in knowledge (e.g. MRI) there is another extra backup. The staffing for the elective program in the evening should be seen separated from the acute cases where the above is about.

APPENDIX III - ANALYSIS OF ACUTE STROKE PATIENT POPULATION

Definition	2010		2011		1-'12 until 8-'12	
	Number	%	Number	%	Number	%
* geen neurologie, werkdiagnose subarachnoidale bloeding	4	0,67	7	1,19	2	0,52
* geen neurologie, werkdiagnose TIA (incl. amaurosis fugax)	6	1,01	7	1,19	3	0,78
** art.temporalis	-	-	-	-	1	0,26
Aneurysma basilaris	2	0,34	-	-	-	-
Aneurysma carotis interna	-	-	1	0,17	1	0,26
Aneurysma cerebri anterior	1	0,17	-	-	1	0,26
Aneurysma cerebri media	-	-	-	-	1	0,26
Aneurysma communicans anterior	1	0,17	1	0,17	-	-
Aneurysma communicans posterior	1	0,17	2	0,34	-	-
Cerebraal infarct	1	0,17	-	-	-	-
Cerebrovasculair accident (CVA)	1	0,17	1	0,17	1	0,26
Cerebrovasculair: carotis dissectie	-	-	2	0,34	1	0,26
Intracerebrale bloeding	60	10,08	71	12,05	-	-
Intra-craniele bloeding	-	-	1	0,17	30	7,79
Intracraniele bloeding (epiduraal)	1	0,17	1	0,17	1	0,26
Intracraniele bloeding (subduraal)	11	1,85	10	1,70	9	2,34
Ischaemisch CVA, atherothrombotisch	42	7,06	78	13,24	56	14,55
Ischaemisch CVA, cardio-embolisch	68	11,43	52	8,83	39	10,13
Ischaemisch CVA, lacunair	70	11,76	45	7,64	39	10,13
Ischaemisch CVA, nno	222	37,31	206	34,97	145	37,66
Rest toestand CVA, incl. hemibeeld	1	0,17	-	-	1	0,26
ROD CVA / TIA / RIND	-	-	1	0,17	-	-
SAB zonder vasculaire afwijkingen	4	0,67	4	0,68	2	0,52
Stroomgebied Carotis Interna	4	0,67	3	0,51	6	1,56
Subarachnoidale bloeding	8	1,34	8	1,36	13	3,38
Subarachnoidale, subdurale, extradurale bloeding na trauma	-	-	1	0,17	-	-
TIA, incl. amaurosis fugax	87	14,62	87	14,77	33	8,57
Total	595	100	589	100	385 578	100 66,6

The total number of 2012 is multiplied by 1,5 to get an approximation of the total number of patients for the whole of 2012.

APPENDIX IV – CTS ON WORKING DAYS

Fout! Verwijzingsbron niet gevonden. shows the number of CTs divided over the day (working days) per hour.

Hours	Number	%	Cumulative
0	11	2,7%	3%
1	4	1,0%	4%
2	8	2,0%	6%
3	6	1,5%	7%
4	7	1,7%	9%
5	1	0,2%	9%
6	2	0,5%	10%
7	16	4,0%	14%
8	15	3,7%	17%
9	15	3,7%	21%
10	19	4,7%	26%
11	25	6,2%	32%
12	30	7,5%	40%
13	29	7,2%	47%
14	26	6,5%	53%
15	34	8,5%	62%
16	21	5,2%	67%
17	28	7,0%	74%
18	28	7,0%	81%
19	25	6,2%	87%
20	17	4,2%	91%
21	18	4,5%	96%
22	9	2,2%	98%
23	8	2,0%	100%
	402	100%	

Table 15 shows the corresponding numbers. 14% of the CTs are conducted between 0:00h and 8:00h, 53% between 8:00h and 17:00h and the remaining 33% between 17:00h and 0:00h.

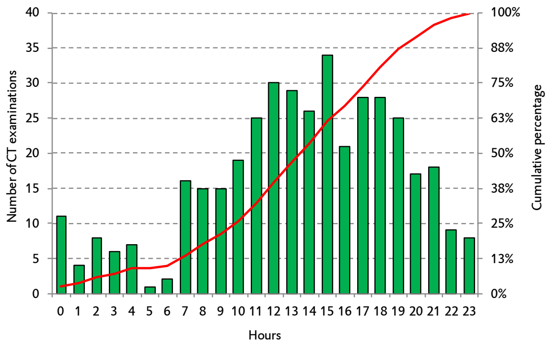


Figure 28 Number of CTs divided per hour (data 2011, working days)

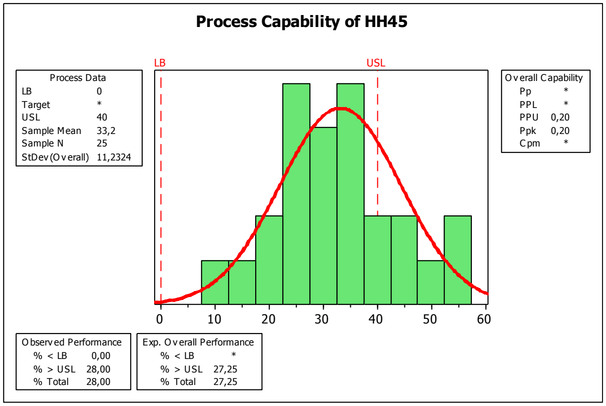
Hours	Number	%	Cumulative
0	11	2,7%	3%
1	4	1,0%	4%
2	8	2,0%	6%
3	6	1,5%	7%
4	7	1,7%	9%
5	1	0,2%	9%

6	2	0,5%	10%
7	16	4,0%	14%
8	15	3,7%	17%
9	15	3,7%	21%
10	19	4,7%	26%
11	25	6,2%	32%
12	30	7,5%	40%
13	29	7,2%	47%
14	26	6,5%	53%
15	34	8,5%	62%
16	21	5,2%	67%
17	28	7,0%	74%
18	28	7,0%	81%
19	25	6,2%	87%
20	17	4,2%	91%
21	18	4,5%	96%
22	9	2,2%	98%
23	8	2,0%	100%
	402	100%	

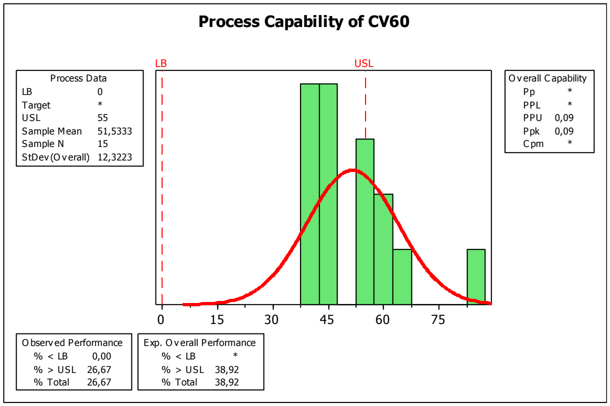
Table 15 Data corresponding to Figure 25

APPENDIX V – PROCESS CAPABILITY ANALYSIS

The process capability plots shown in this appendix show the examination times of the observed examinations per category. The lower bound (LB) is set to zero (a time period is always positive). The upper specification limit (USL) is set to the new protocol time (tp) that is suggested in this study. This makes it more clear which fraction of the observations fall below and above the new protocol time. As can be seen in the plot below, the USL of the HH45 observations is set to 40 minutes and it can be observed that still the majority



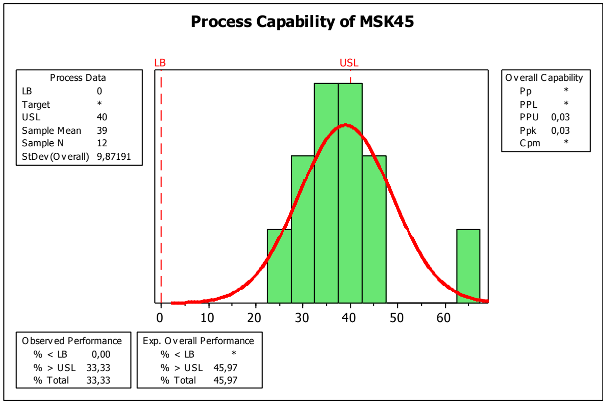
of the observations are conducted in less than 40 minutes (72% < USL). For CV60 examinations it applies that73,3% of the observations are below the suggested protocol time of 55 minutes. **Fout! Verwijzingsbron niet gevonden.** shows the partition of the observations that are below and above the suggested protocol time for HH45 and CV60. The average duration of the two groups (above and below tp) and the deviation from the protocol time are shown. This gives more insight in the deviation from the protocol time.

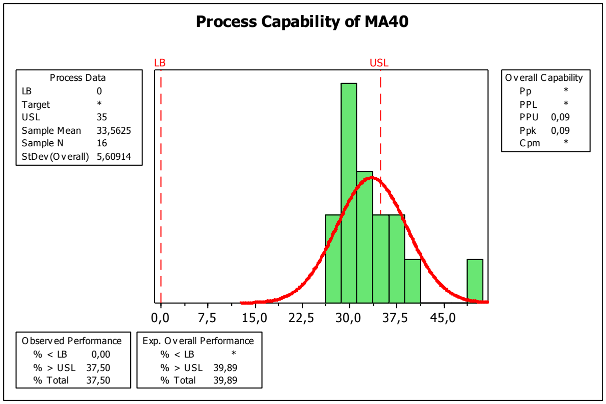


HH45		CV60	
New protocol time tp = 40 minutes		New protocol time tp = 55 minutes	
Time < tp	Time > tp	Time < tp	Time > tp
N = 18	N = 7	N = 11	N = 4
µ = 27,5 min	µ = 47,9 min	µ = 48,8 min	µ = 67,3 min
µ-tp = -12,5 min	µ-tp = 7,9 min	µ-tp = -6,2 min	µ-tp = 12,3 min
tp = 40 min		tp = 55 min	

Figure 29 Observations above and below the suggested protocol times

The process capability plots of the MSK45 and Ma40 examinations can be seen below. With the suggested protocol times of 40 minutes for MSK45 and 35 minutes for Ma40 examinations it can be observed that still 66,7% of the MSK45 examinations are below 40 minutes and 62,5% of the Ma40 examinations take less than 35 minutes. **Figure 27** shows both categories divided in a group of examinations that are below and above the new protocol time and the amount of examinations per group. The deviation of the mean from the protocol time per group gives more insight in the distribution of the examinations.





MSK45	
New protocol time tp = 40 minutes	
Time < tp	Time > tp
N = 8	N = 4
μ = 33,9 min	μ = 49,3 min
μ-tp = -6,1 min	μ-tp = 9,3 min
tp = 40 min	

Ma40	
New protocol time tp = 35 minutes	
Time < tp	Time > tp
N = 10	N = 6
μ = 30,1 min	μ = 39,3 min
μ-tp = -4,9 min	μ-tp = 4,3 min
tp = 35 min	

Figure 27 Observations above and below the suggested protocol times

Appendix VI - Heuristic C1 according to Van der Lans et al. (2006)

- Step 0: Calculate λ
- Step 1: Forward scheduling move. Select the unscheduled examination from one of the MRI rooms *j* for which the completion time will be closest to the latest completion time of all already forward scheduled examinations plus λ and schedule this examination forward in MRI room *j*. If no examinations are scheduled forward so far, select the unscheduled examination from one of the MRI rooms *j* for which the completion time will be closest to the latest starting time of all MRI rooms plus λ = (S + λ) and schedule this examination forward in operating room *j*;
- Step 2: Backward scheduling move. Select the unscheduled examination from one of the MRI rooms *j* for which the starting time will be closest to the earliest starting time of all already backward scheduled examinations minus λ and schedule this examination backward in MRI room *j*. If no examinations are scheduled backward so far, select the unscheduled examination from one of the MRI rooms *j* for which the starting time will be closest to the earliest closing time of all MRI rooms minus λ (=E-λ)
- Step 3: Repeat step 1 and 2 until all examinations are scheduled.

Appendix VII - Radiology reporting of elective examinations

Radiology reporting of elective examinations

In contrast to the reports of acute examinations, reports of elective examinations are not orally transmitted. Hence, the data of the time that reports are authorized are more reliable with respect to the performance of MRI examinations. The data is depicted in **Figure 28** and **Fout! Verwijzingsbron niet gevonden.** on the next page. 38% till 50% is authorized within 24 hours. After fourteen days (336 hours) 90% till 95% of the scans have an authorized report. Reducing the time between scan and authorized report will reduce the total lead time from request for an MRI till the report. Though, in the current situation it is not necessary to finish all reports within e.g. 24 hours. A part of the examinations (especially oncological ones) are discussed in MDOs. MDOs are generally held ones a week. In an MDO physicians from different specialisms discuss patients together in order to come to a treatment plan. When MDOs are on Wednesdays and a patient is scanned on Thursday, the total lead time is not reduced when the report is finished on Thursday.
Cardiovascular (CV) examinations require post processing in 70% to 80% of the cases. This means that images have to be edited after a scan is made. This is done by radiographers. At the UMCG there are four radiographers who can perform post processing. This is uncoupled with performing the scan. For example, on Wednesdays from 12:30h till 16:30h one MRI has CV patients. On Thursdays one radiographer is scheduled to perform the imaging. On Fridays the radiologist renders the reports. To reduce the lead time, post processing could be performed during the CV scan. I.e., post processing of patient A can be done during the examination of patient B. CV examinations are rather long (60 minutes) and post processing takes around 15 to 20 minutes. The MRI is occupied by two radiographers. When one radiographer scans patient B, the other one can perform the post processing of patient A. This reduces the lead time (if the radiologist renders the report on the same day or a day later). According to radiographers there are some drawbacks to this solution. Focus is needed when a radiographer performs imaging to guarantee good quality, but focus is difficult because phone calls

have to be answered and consultation is needed between both radiographers during a scan. If it is actually not possible to perform imaging by one of the two radiographers that occupy the MRI, the question remains why imaging takes place the day after the scans are made. That same radiographer could perform imaging on the day the CV program is scheduled.
Some radiologists indicate that during their shift they prioritize acute patients and patients from a nursing ward over outpatients. As mentioned earlier, performance of acute reporting is difficult to analyse. Analyzing the performance of reporting of patients from a nursing ward is possible. Analysis shows that the statement that those patients have a higher priority is not clearly reflected in the data (see **Figure 28** on the next page). The line is highest of all categories, but a more deviant trend would be expected. Prioritizing inpatients above outpatients can help to reduce the length of stay of those patients and hence, reduce hospital costs.

Conclusion

For fast diagnosis the time between a scan and the availability of a report is relevant. In the case of acute examinations the available data is not sufficient to draw conclusions on the performance, since part of the reports is passed on orally by phone and no data exists for that. A written report is in that case not important with respect to the medical treatment.
Radiology reporting of the elective examinations is more insightful. 38 to 50% of the reports are authorized within 24 hours. 80% within seven days. Availability of reports within 24 hours is not always necessary because of e.g. MDOs that are held ones a week.
Lead time of CV examinations could be reduced when post processing is done on the day the scans are made. Either one of the two radiographers starts imaging of patient A while patient B is scanned or the radiographer who is scheduled to perform imaging will be scheduled on the

same day as the CV program instead of one day later. If it cannot be done simultaneous the examinations can be done in the morning in order to perform post processing in the afternoon.

Increase in lead time is further caused by the various activities radiologists perform besides their core task of producing radiology reports. The statement that patients from a nursing ward are prioritized above outpatients is not clearly reflected in the data.

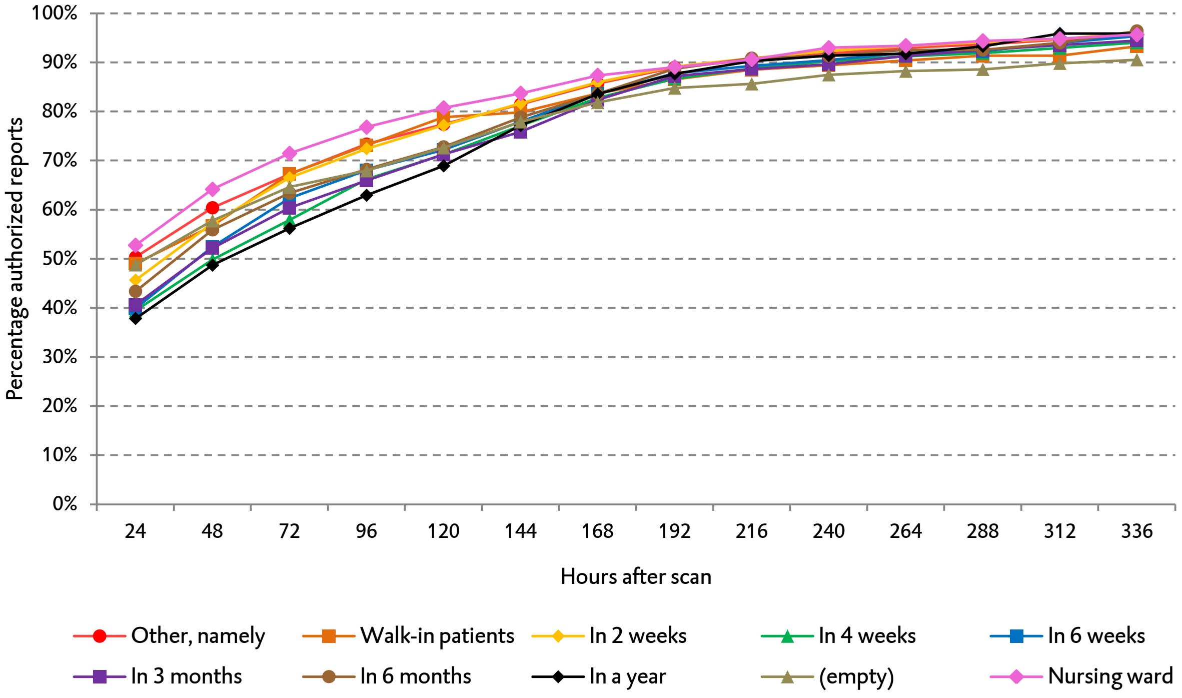


Figure 28 Authorization of report in hours after the scan (per priority)

	Authorized reports hours after scan													
Priority	24	48	72	96	120	144	168	192	216	240	264	288	312	336
Acute=today	56,7%	67,4%	74,9%	80,1%	83,6%	85,6%	88,4%	90,3%	91,4%	91,9%	92,2%	92,4%	93,2%	93,8%
Other, namely	50,3%	60,4%	67,2%	73,3%	77,4%	81,4%	85,7%	89,0%	90,5%	91,8%	93,0%	93,6%	94,6%	95,5%
Walk-in patients	49,0%	56,7%	67,3%	73,1%	78,8%	79,8%	83,7%	86,5%	88,5%	89,4%	90,4%	91,3%	91,3%	93,3%
In 2 weeks	45,7%	57,3%	66,5%	72,4%	77,2%	81,6%	85,9%	89,2%	90,9%	92,3%	93,3%	94,1%	94,8%	96,1%
In 4 weeks	39,4%	49,8%	57,9%	66,2%	71,2%	77,1%	82,8%	86,7%	88,7%	90,2%	91,3%	91,9%	92,9%	94,0%
In 6 weeks	39,9%	52,4%	62,3%	68,0%	72,2%	77,9%	83,6%	87,8%	89,3%	90,5%	92,0%	92,3%	94,0%	95,3%
In 3 months	40,6%	52,2%	60,4%	65,9%	71,3%	75,8%	82,4%	87,2%	88,6%	89,6%	91,3%	92,5%	93,5%	94,4%
In 6 months	43,4%	55,9%	63,4%	68,2%	72,8%	78,8%	83,6%	88,7%	90,8%	91,3%	92,5%	92,5%	94,0%	96,4%
In a year	37,8%	48,7%	56,2%	62,9%	68,9%	77,2%	83,5%	87,6%	90,3%	91,4%	91,8%	93,3%	95,9%	95,9%
(empty)	48,8%	57,7%	64,6%	67,9%	72,6%	77,9%	81,8%	84,8%	85,6%	87,5%	88,2%	88,6%	89,8%	90,5%
Nursing ward	52,7%	64,1%	71,4%	76,8%	80,7%	83,7%	87,3%	89,0%	90,6%	93,0%	93,4%	94,4%	94,8%	95,6%

Table 18 Percentage authorized reports per hours after scan