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Quality and efficiency within radiology and the added value of a regional PACS

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Preface

Before you lies a report that took me 6 months to fully put together, but I hope it takes you less time to read. I thoroughly enjoyed my time at Ziekenhuisgroep Twente and would like to thank them first for the assignment and the opportunity to do my master thesis with them, MRON, SKB Winterswijk, and MST Enschede. I want to thank them all for providing me with all the data I needed and the radiologists for allowing me to follow them around for half a day. I would like to thank all my supervisors as well for their feedback and time: Anique Bellos-Grob, Tim Boers, Jeroen Geerdink, Erik Leijzer, and Erwin Hans. Finally I'd like to thank my family and friends for standing by me during my master Health Sciences and my master thesis in particular.

Summary

Goal The two main problems in radiology are llimited efficiency and limited quality. These limitations negatively influence the radiology department by worsening the workflow and increasing the number of errors, respectively. The goal of this report is to find out what the current situation is in these two areas within MRON, in order to find out how much a regional PACS could improve upon them.The level of efficiency is defined as the time spent on Non-image Interpretive tasks (NITs) and Image Interpretive Tasks (IITs). This data is compared to the MST's previously collected data from 2013. The level of quality is defined as radiologists working within their subspecialisms.

Methods *Efficiency* The efficiency is measured by an observer using an activity tracker on a radiologist. Data is gathered from the ZGT and SKB hospitals. 17 radiologists from the ZGT and 5 from the SKB are observed. The activities tracked are adapted from previous research by the MST and are divided into the categories IIT, NIT, Management, and Waste. Statistical analyses are performed in SPSS to determine differences between shift characteristics and hospitals. *Quality* The quality is determined using the production data from 2018. The ZGT data consists of 15112 analysed scans which will be cross-referenced to the standard times set by the NVvR, the SKB data consists of 77536 scans. Pivottables are made in Excel to determine the current level of quality.

Results *Efficiency* The ZGT and SKB spent 45.3% of their time on IITs, 27.9% on NITs, 6.3% on Management, and 20.5% on Waste. No statistically significant differences were found between the ZGT and SKB, nor between morning and afternoon shifts. There was a significant difference (p-value <0.05) in four activities when comparing a quiet shift to a busy shift, plus two activities that only occurred during a regular shift. In a quiet shift, significantly more time was spent on ”Logistics”. If a shift was regularly busy significantly more time was spent on ”Internal room/Punctions”, ”Phone”, ”Walking/Moving”, ”Meeting hospital”, and ”Management (other)”. *Quality* On average in the ZGT 21.8% of the total number of scans dictated by a radiologist was not within their subspecialisms. This equalled 15.7% of the time they spent dictating reports. These values are 44.2% and 41.5% respectively within the SKB.

Conclusion The current level of efficiency in the ZGT and SKB is comparable to the MST in 2013. The current level of quality is 77.1% for the ZGT and 55.6% for the SKB. Both levels can be improved upon with a regional PACS.

Hypothetical Solution The gain in efficiency was calculated if all resources are pooled, showing the value of pooling. The current and hypothetical future situations were simulated as well to visualise the pooling solution, showing the advantage of pooling. Finally, the number of scans and time spent on scans outside of the assigned shift was calculated to determine the impact of the necessary change in workscheduling that accompanies the pooling of resources. 35% of the number of scans radiologists dictated were not part of the shifts they were assigned to, equalling 32% of their time.

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List of acronyms

AIOS resident/doctor in training to become a specialist

CARS Computer Assisted Radiology and Surgery

FTE full-time equivalent

IIT image-interpretive tasks

PACS Picture Archiving and Communication System

MDO Multidisciplinary meeting

MRON Maatschap Radiologie Oost-Nederland

MST Medisch Spectrum Twente

NIT non-image-interpretive tasks

NVvR Nederlandse Vereniging voor Radiologie

SPIE The international society for optics and photonics

SKB Streekziekenhuis Koningin Beatrix

SVOB bevolkingsonderzoek op borstkanker

ZGT Ziekenhuisgroep Twente

Chapter 1

Introduction

In 2012 Roland Berger published a report [1] about the future of imaging specialists in the Netherlands. One of the recommendations in this report is to let imaging specialists (radiologists) work in a network that surpasses the boundaries of one hospital. This resulted in the founding of Maatschap Radiologie Oost-Nederland (MRON).
MRON [2] is a partnership that has come into existence by fusing the radiology departments of the Medisch Spectrum Twente (MST) in Enschede, Ziekenhuisgroep Twente (ZGT) in Almelo and Hengelo, and Streekziekenhuis Koningin Beatrix (SKB) in Winterswijk. Currently, there are 40 full-time equivalent (FTE) radiologists and 5 FTE nuclear medicine physicians within MRON. The goal of MRON [2] is to improve patient health and well-being by offering radiological care for a fair price and in a high quality, innovative, safe, and customer-oriented way. In orderto do this,MRON is working on implementing a regional Picture Archiving and Communication System (PACS). PACS is a system that all radiologists use to store images and communicate their findings. All medical images are stored on this PACS and accessed from an individual working system to be interpreted. The history of PACS and some of its possible applications will be explained in Chapter 2.1. Currently, each hospital has their own brand of PACS. These PACS systems will become one when a regional PACS is implemented, but it is unknown how big of an impact this will be.

1.1 Problems within radiology

There are two main problems within the radiology department regarding the work being delivered. These are a lack of quality (errors) and limited efficiency. In ZGT Hengelo alone, 487 scans interpreted by the radiology department in 2018 had a discrepancy registered to them. These errors can be caused by multiple physiological, perceptual, environmental, or system-based factors [3]. More errors are made when work is performed by an assistant instead of a radiologist [4–6], and when a radiologist works outside of their subspecialisations [7–12].
Regarding efficiency, it is standard practice that radiologists do more than just interpret scans. Other time-consuming activities are education-related, breaks, and being called or approached by colleagues. These cause interruptions in a radiologists work flow, leading

to a less efficient workday and more errors [13, 14]. These distractions thus influence both quality and efficiency. All these activities have been divided into categories by Schemmel et al. [15]. They introduced two new terms: non-image-interpretive tasks (NIT)s and image-interpretive tasks (IIT)s. IITs are only the tasks related to actual image interpretation, like dictating reports. NITs are all other radiology-related tasks that are not image-interpretive, like interventions, phonecalls and discussions. Many of these NITs can be regarded as the aforementioned interruptions and will negatively affect the IITs. Schemmel et al. also have the category ”other”, which can be further split up into ”waste” [16] and ”management”. Waste varies from private phone calls to breaks, where management mostly entails meetings.

1.2 Current situation MRON

Currently, all three hospitals within MRON operate independently. MRON has a joint scheduling platform in which all rosters are visible and shifts are allocated. Sometimes a radiologist visits a different hospital and works there for a day if there are shortages or specific skills needed, but they mostly keep to their own locations.

Each radiologist has a number of areas that they are subspecialised in, e.g. Thorax, Mammography, or Cardiography. These subspecialisations coincide with the different shift types, so the scheduling will be based on what a radiologist's areas of expertise are. There are also a couple of shifts that do not match with a certain subspecialisation, like acute care and radiologists on call. MST and ZGT have slightly different names for their shifts, but they are largely the same. SKB divides their work differently. In the SKB, shifts are assigned based on modality, except for the outpatient mammography clinic. Radiologists still have their expertises in specific body parts/organ systems, but they interpret everything within the modality that they are assigned that day. If a difficult scan outside of their area of expertise comes along, it will be swapped with other radiologists. The SKB has expressed their interest in switching to a scheduling system based on subspecialities, but they do not have enough radiologists to be able to do this.

1.3 Motivation for research

A regional PACS (see Chapter 2.1) will be implemented in all of the hospitals connected to MRON. This gives rise to many opportunities. It could solve the problem within the SKB that they cannot make schedules based on subspecialities. It can increase quality, it can decrease workload, and it can make meetings and discussions between hospitals a lot easier. This research will investigate the current situation in the hospitals with regards to radiological quality and efficiency. By analysing this current situation the areas where a regional PACS adds value can be researched and the gain in radiological quality and efficiency can be hypothesised. This current situation within efficiency has already been researched in the MST in 2013 and will be researched in the ZGT and SKB in 2019. The current situation within quality will be researched in the ZGT and SKB only because there is no data available for the MST.

1.4 Research Question

The following research question has been developped based on the previously mentioned current situation, problems within radiology and the motivation for this research:

- What was the state of affairs in ZGT's and SKB's quality in 2018 and efficiency in 2019?

The following sub-questions are defined to further interpret and clarify the research question above:

1. *What was the level of radiological efficiency, defined as time spent on NITs and IITs, in the ZGT and SKB (2019) compared to the MST (2013)?*
2. *What was the level of quality, defined as radiologists working within their areas of expertise, within the ZGT and SKB in 2018?*

1.5 Report Structure

The remainder of this report is organised as follows: in Chapter 2 background is given on the PACS system, current research in this field is described, and hypotheses are formulated based on this theoretical framework. Then, in Chapter 3, the research methods are described for both sub-questions. Afterwards the results are described in Chapter 4. Finally, in Chapter 5 the results are interpreted, conclusions are drawn and recommendations for the hospitals/MRON and future research are given.
After the main matter of this report, a chapter is added discussing the hypothetical future situation where MRON has implemented a regional PACS. Quality and efficiency improvements for this future scenario are analysed.

Chapter 2

Theoretical Framework

In this chapter the necessary background information needed to understand and perform this study will be provided. Based on this information and the current research in this field hypotheses will be formed.

2.1 PACS

The concept of digital image communication and display was first introduced in 1979 by professor Heinz U. Lemke in a technical paper [17]. Further developments were made in conferences organised by The international society for optics and photonics (SPIE), and in 1982 [18] the term ”PACS” was introduced. [19] In the Netherlands, and in Europe as a whole, PACS was popularised by dr. A. Bakker [20]. Since then, multiple developments have been made and PACS is now the standard system used to communicate within hospitals. Surveys among hospital staff [21,22] have shown that the PACS has become an integral part of and an improvement upon their work environment; it increases the quality of reports and it increases efficiency while not being an extra burden. PACS also reduces the number of repeated diagnostics and thus saves costs by reducing the amount machine running hours and staff working hours [23, 24]. New developments and improvements are presented at Computer Assisted Radiology and Surgery (CARS) conferences each year. [20]

A regional PACS is one of these developments. This concept uses an interhospital system that connects multiple healthcare institutions and thus supports the use of telemedicine. This regional PACS is already being tested and sometimes used in e.g. Italy [25], Norway [26], and Spain [27], and MRON hopes to implement this in the Netherlands as well.

2.1.1 Teleradiology

A regional PACS also allows hospitals the use of teleradiology [24]. Teleradiology is a form of telemedicine. Telemedicine is the practice of remotely practicing medicine, or in a different location than the patient. Teleradiology is the practice of interpreting medical scans in a location other than where the scan was made. This could be in a different hospital or a

different building.
A possible disadvantage of teleradiology, and thus a regional PACS, is the possibility of security breaches [28]. These breaches also exist with regular PACS usage and are mostly due to staff ignorance, such as use of patients' data and images for non-medical purposes and sharing downloaded patient data verbally or via email.

2.2 Current Research

There are a few publications within radiology journals about the workflow of radiology, possible interruptions and their potential implications. Research has pointed out that firstly: interruptions will increase the time required to interpret diagnostic images [14], secondly: interruptions are usually not related to the current patient [29], and finally: interruptions are disruptive [29]. Figure 2.1 shows how an interruption can increase the time required to interpret diagnostic images by a time period longer than the interruption itself. It visualises that there are lags around the actual interruption. It will take some time to switch tasks, increasing the interruption time by more than merely the duration of the interrupting task.
The MST [30] has analysed their workflows via self-assesment, and these results show that only 38% of the working hours of a radiologist are spent on interpreting and recording scans. The detailed results from the MST can be found in Table 2.1, to be used as a comparison for the results in this report. Similar research has been performed by Schemmel et al. [15], who first introduced the concept of IITs and NITs. An overview of possible improvements has been given by Kansagra et al. [31], and three of these have been tested in a clinical setting by other researchers. The first of the explored options [32] was a telephone triage system which would reduce the amount of unnecessary calls the radiologists receive. The second [33] was a new work structure where different people were responsible for the NITs and the IITs. NITs were handled by first- or second-year radiology fellows and the IITs were handled by the other physicians. The final option was a workflow management system by Halsted and Froehle [34]. This system would automatically prioritise cases on the basis of medical and operational acuity factors. All three options have shown to increase staff satisfaction and reduce stress, though option three not with a statistical significance. Options one and two also significantly reduced the number of interruptions.

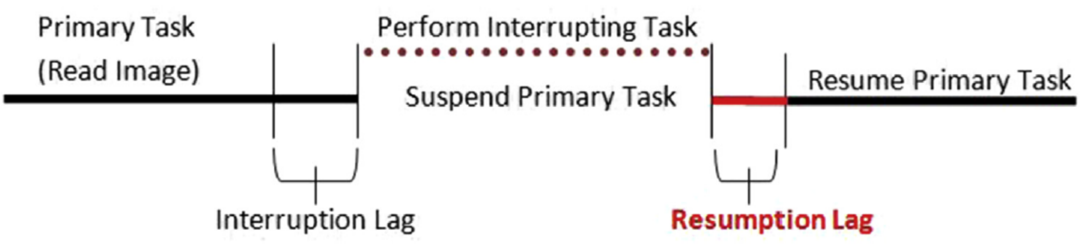

Figure 2.1: Framework for understanding the timeline of interruptions [29]

Limited research is available on how well radiologists stick to their subspecialisms within radiology. One study [35] states that radiologists with one subspecialism plus general capabilities have the most desired hiring preference in the USA, followed by multispecialty radiologists. Another study [36] states that multispecialty radiologists supported by subspecialised radiologists would make the ideal workforce. Rosenkrantz et al. [37] state that over half of the radiologists in the USA are general radiologists. A general radiologists is defined as a radiologists who does not spend over 50% of his/her time on one subspecialty. A radiologist within MRON will usually have completed a fellowship but will not limit themselves to that one subspeciality. Depending on the study, this puts them in the ”subspecialised with general capabilities”, ”multispecialised”, or ”hybrid” group. No research was specifically found on how much time subspecialised radiologists with general capabilities or multispecialty radiologists spend on reports outside of their area(s) of expertise.

2.3 Hypotheses

1 The workflow within ZGT is comparable to that in the MST: 40% on IITs. The SKB spends more time on IITs than the ZGT and MST because it is a smaller, non-teaching hospital and thus has less NITs and managerial tasks.

2 Radiologists of the ZGT spend 5% of their time on scans that do not lie within their subspecialism(s). This equals 10% of the scans that they dictate in total, since most scans outside of their area of expertise are in an emergency setting, and thus a lot of muscoloskeletal, short scans, resulting in a higher number of scans than relative time spent on them. Radiologists of the SKB spend 50% of their time on scans that do not lie within their subspecialisms. These percentages are estimated based on preliminary interviews.

Table 2.1: Workflow measurement data gathered by the MST [30], divided into IIT, NIT, Management, and Waste. Category names translated from Dutch.

Activity	*Total hours measured (%)*
IIT	
Dictating reports/interventions etc	151.8 (38)
Judge scan/MR/CT	5.9 (1)
NIT	
Discussion/consultation	16.4 (4)
Statusupdate (DSV, DOT etc)	1.4 (0)
Signs requests	4.2 (1)
Education	43.8 (11)
Science	1.3 (0)
Being addressed (labtechnician etc)	13.9 (4)
Check colleague/discussion radiologist over phone	24.8 (6)
Logistics (planning an appointment etc)	7.9 (2)
Compose/Respond to Email	8.6 (2)
Supervision ultrasound	17.1 (4)
Discussion doctor with different specialism (on the phone)	17.3 (4)
Management	
Management	17.9 (5)
Meeting for partnership/department	14.0 (4)
Meeting for hospital	1.4 (0)
Waste	
Break (coffee, lunch)	42.1 (11)
Waiting (computer, assistant etc)	3.3 (1)
Malfunction, report lost etc	4.3 (1)
Insufficient reporting stations	0.2 (0)
Total	397.6 (100)

Chapter 3

Methods

Two methods will be discussed here, one for each sub-question.

3.1 Current Efficiency

A radiology-specific activity tracker is created using Javascript (see Appendix A.1). The activites incorporated in this activity tracker are copied from the MST study [30]. Some adaptations are made to this list of activities following the test-period of the activity tracker, as these were absent in the MST study. The final list of activities is divided into IITs, NITs, Management, and Waste [16]. This activity tracker is used to monitor 17 radiologists from ZGT and 5 from SKB during one shift (morning or afternoon). These monitoring sessions are divided over different radiologists with different specialisations between April 2019 and June 2019. Only IIT shifts are used in this study as the goal is to determine their workflow. Other types of shift (managerial shift, educational shift etc) are not taken into account. Data is gathered in .csv files (see Appendix A.2 for an example), to be imported and analysed with Excel and SPSS. For each session the location (ZGT Almelo, ZGT Hengelo, or SKB Winterswijk), time of shift (morning or afternoon), how busy it was as perceived by the radiologist (quiet, regular, or busy), and the type of shift (subspecialism) is recorded as well. Statistical analyses are performed using these four variables to find out whether there are statistically significant differences within these categories. If the variable has two possible options, e.g. morning vs. afternoon, an independent samples T-test is performed. If there are three or more categories, e.g. ZGT Hengelo, ZGT Almelo, and SKB Winterswijk, a one-way ANOVA test is performed.

3.2 Current Quality

An overview of the current staff and their subspecialisations is composed by updating the administrative data with what the radiologists indicate as their subspecialisations. Using this updated overview an analysis is performed on the historical data from the ZGT and SKB from 01-01-2018 to 31-12-2018. This analysis is used to determine how often a radiologist works outside of their subspeciality, to find out whether an increase in quality is possible when using a regional PACS. Initial exclusions before analysing the production data from the ZGT can be seen in Figure 3.1. The full data set received consists of 227141 scans. After removing the scans set in 2019, unfinished reports, scans dictated by radiologists not employed by the ZGT, and scans dictated by fellows 151112 scans remain. These 151112 instances are further analysed. Data from the SKB in 2018 is manually gathered from PACS on location, resulting in a total of 77536 scans.

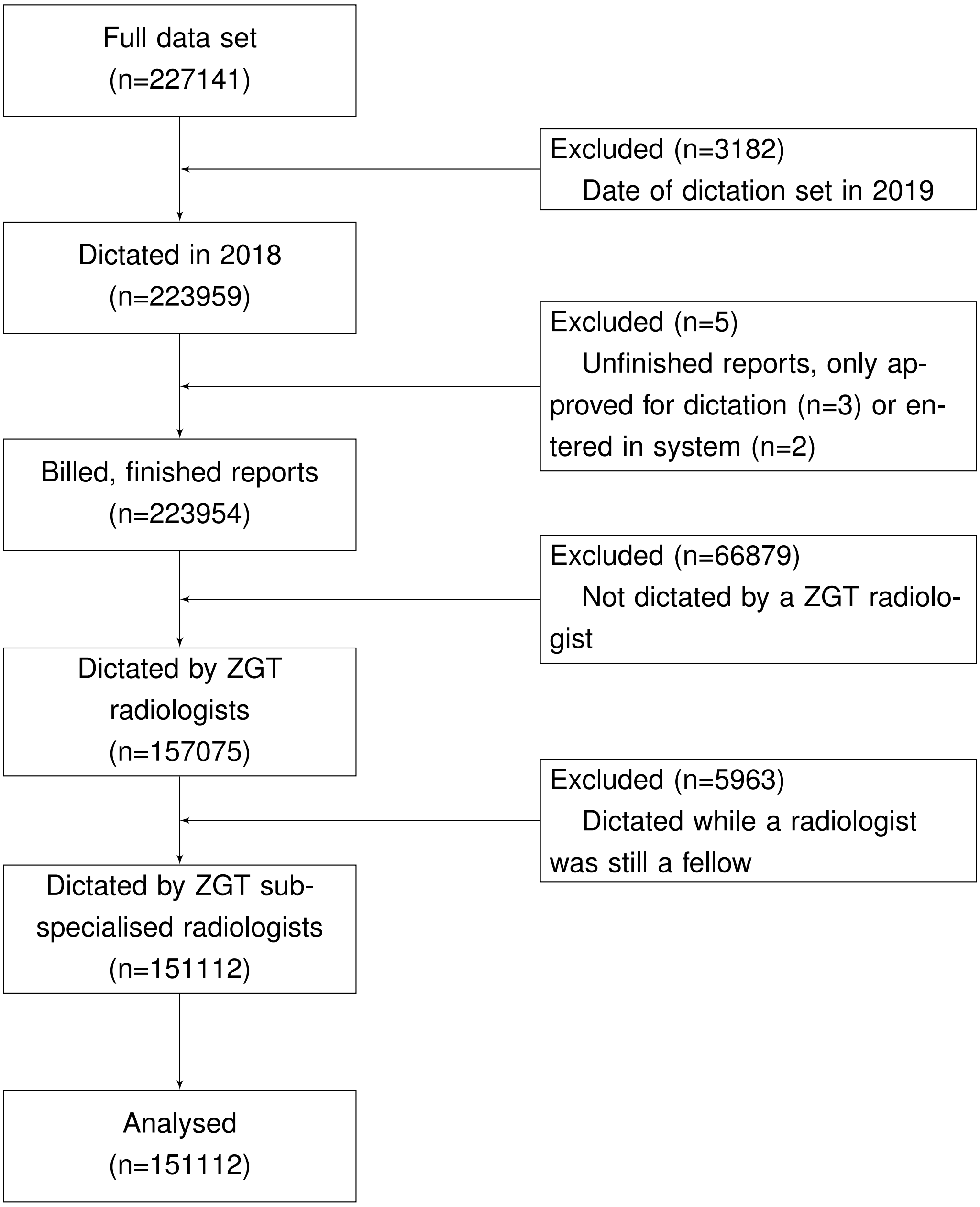

Figure 3.1: Flowdiagram for initial inclusions and exclusions made in production data set received from ZGT

The scans within the ZGT production data will undergo a further two steps to enable a proper analysis:

1. All scans will be cross-referenced to the standard times set by the Nederlandse Vereniging voor Radiologie (NVvR) to determine their duration in minutes
2. Multidisciplinary meeting (MDO)s and Copie bevolkingsonderzoek op borstkanker (SVOB)s will be removed from the data set

The standard times set by the NVvR are used to calculate the average duration of a scan for each subspecialism, based on the historical data from the ZGT. These averages are used when computing the time spent on scans in the SKB, as their data is not detailed enough to compute seperately. MDO radiology and Copie SVOB are removed because they are not usable in this study. The MDOs are not divided into subspecialisms in the dataset, and are thus not usable to determine how much a radiologist operates outside their subspecialisms. Copie SVOBs are non-billable, meaning that no time duration can be allocated to them. Including these provides erronous results for the mammography subspecialism, to which the Copie SVOBs belong.
The Pivottable function in Excel is used to obtain the number of scans dictated and time spent on scans outside of a radiologist's subspecialisms. This number is provided for all radiologists on average, in total, and per subspecialism. The category "Internal" is excluded from the subspecialisms for the ZGT as this is not a subspecialism radiologists can have in the ZGT, but rather a category of scans/interventions multiple subspecialists can perform. The internal scans are counted as "correct" for the overall percentage. In the SKB, the internal scans and punctions are taken into account because the radiologists of the SKB indicated whether they were specialised in these or not.

Chapter 4

Results

4.1 Current Efficiency

All activites in the activity tracker are divided into the four aforementioned categories (IIT, NIT, Management, Waste). Their categorisation is shown in Table 4.1. All results regarding time spent on an activity in this chapter will be given in the hh:mm:ss format.

The activities of 17 radiology shifts from ZGT and 5 shifts from SKB are recorded, see Table 4.2. Total time recorded is 93:07:38 over the 22 shifts, for a mean of 4:13:59 with a standard deviation of $\pm$0:25:47.

A lunchbreak of 30 minutes is manually added for every second shift, and the results of the time spent per activity can be found in Table 4.3. The median and range are provided because the times recorded do not follow a normal distribution. An overview of the daily workflow is shown in Figure 4.1.

IIT 44:25:33 was spent on IITs during the observed shifts, corresponding to 45.3% of a radiologist's total time. The largest contributor to the IITs is the dictating of reports with (time, number of instances, median) 43:49:48, 673, 02:05. The other activity is Judging scans on location (00:35:45, 16, 00:56).

NIT 27:20:40 was spent on NITs during the observational period, corresponding to 27.9% of a radiologist's total time. This included being addressed (5:40:23, 265, 00:38), discussion/consultation (4:34:25, 42, 03:17), education (1:49:11, 54, 00:47), Email (2:00:47, 69, 00:41), internal room/punctions (4:06:46, 35, 03:26), logistics (0:37:37, 23, 00:23), phonecalls (4:33:00, 184, 01:01), science (0:45:47, 12, 01:57), signing requests (0:22:06, 26, 00:39), and other NITs (0:58:52, 29, 01:22).

Management 6:12:48 was spent on management, corresponding to 6.3% of a radiologist's total time. This included meetings with the department/MRON (4:20:16, 14, 13:13), meetings with the hospital (1:30:00, 1, 1:30:00), and other managerial tasks (0:22:32, 6, 0:02:50).

Table 4.1: Activites used in the activity tracker and their source. Most activities adapted from previous data gathered by the MST [30].

Activity	*Source*
IIT	
Dictating reports	MST: Dictating reports/interventions etc
Judge scans on location	MST: Judge scan/MR/CT
NIT	
Being addressed	MST: Being addressed (labtechnician etc)
Discussion/Consultation	MST: Check colleague/discussion radiologist over phone
Education	MST: Education
Email	MST: Compose/Respond to Email
Internal room/Punctions	MST: Dictating reports/interventions etc (2)
Logistics	MST: Logistics (planning an appointment etc)
Phonecalls	Addition after test-phase
Science	MST: Science
Sign requests	MST: Sign requests
Supervision US	MST: Supervision ultrasound
Other NIT	Addition after test-phase
Management	
Meeting dept./MRON	MST: Meeting for partnership/department
Meeting hospital	MST: Meeting for hospital
Management (other)	MST: Management
Waste	
Break	MST: Break (coffee, lunch)
ICT problems	MST: Malfunction, report lost etc
Social contact	Addition after test-phase
Talking to observer	Addition after test-phase
Waiting	MST: Waiting (computer, assistant etc)
Walking/Moving	Addition after test-phase
Other waste	Addition after test-phase

Table 4.2: Characteristics of the radiology shifts that were tracked using the activity tracker made in Javascript.

Characteristic	*Radiology shifts*				*p-value*
	SKB Winterswijk	*ZGT Hengelo*	*ZGT Almelo*	*Total*	
Number of shifts *[n (%)]*	5 (22.7)	13 (59.1)	4 (18.2)	22 (100)	
Busy or quiet? *[n (%)]*					1.000
Quiet	2 (40.0)	6 (46.2)	2 (50.0)	10 (45.5)	
Normal	3 (60.0)	7 (53.8)	2 (50.0)	12 (54.5)	
Busy	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	
Time of day *[n (%)]*					0.455
Morning	3 (60.0)	8 (61.5)	4 (100.0)	15 (68.2)	
Afternoon	2 (40.0)	5 (38.5)		7 (31.8)	
Shift type *[n (%)]*					0.064
Abdomen Acute			1 (25.0)	1 (4.5)	
Cardiology		1 (7.7)		1 (4.5)	
Internal		2 (15.4)		2 (9.1)	
Mammography		2 (15.4)		2 (9.1)	
Muscoloskeletal		2 (15.4)	2 (50.0)	4 (18.2)	
Neurology, head & neck		2 (15.4)		2 (9.1)	
Thorax		1 (7.7)		1 (4.5)	
Thorax Abdomen		3 (23.1)		3 (13.6)	
CT	1 (20.0)			1 (4.5)	
Ultrasound	1 (20.0)		1 (25.0)	2 (9.1)	
Mammo US	1 (20.0)			1 (4.5)	
MRI	2 (40.0)			2 (9.1)	

Waste A final 20:08:37 was spent on wasteful tasks. This included breaks (8:19:09, 73, 03:13), ICT problems (0:34:17, 52, 00:18), social contact (1:48:50, 78, 00:36), talking to observer (3:41:01, 219, 00:32), waiting (1:25:44, 119, 00:20), walking/moving (2:23:10, 259, 00:23), and other waste (1:56:26, 67, 00:35). These "waste" activites corresponded to 20.5% of a radiologist's total time.

No statistically significant differences are found in between the ZGT Almelo, ZGT Hengelo, and SKB (Table B.1 in the appendix) except when one of the hospitals does not have an activity at all. No statistically significant diferences are found between morning and afternoon shifts either. The activites which are absent in one or more hospitals are the following: in the SKB: "Education", "Science", "Meeting hospital", and "Management (other)". In ZGT Almelo only "Meeting hospital" was absent. Similarly "Judge scans on location" and "Meeting hospital" are only performed in the morning. There is a statistically significant difference (p-value $<$0.05) in four activities when comparing a quiet shift to a busy shift, plus two activities that only occur during a regular shift. In a quiet shift, significantly more time is spent on "Logistics". If a shift is regularly busy significantly more time is spent on "Internal room/Punctions", "Phone", "Walking/Moving", "Meeting hospital", and "Management (other)". These six activities and their statistics can be found in Table 4.4. There are also some differences between the different shift types (Table B.2, continued in Table B.3 in the appendix).

Table 4.3: Duration and quantity of all activites recorded with specific statistics.

Activity	*Total time [h:m:s]*	*Number [n]*	*Median [m:s]*	*Minimum [m:s]*	*Maximum [h:m:s]*
IIT					
Dictating reports	43:49:48	673	02:05	00:01	41:22
Judge scans on location	00:35:45	16	00:56	00:02	11:18
NIT					
Being addressed	05:40:23	265	00:38	00:01	14:08
Discussion/Consultation	04:34:25	42	03:17	00:01	35:55
Education	01:49:11	54	00:47	00:04	20:52
Email	02:00:47	69	00:41	00:05	11:29
Internal room/Punctions	04:06:46	35	03:26	00:36	1:05:39
Logistics	00:37:37	23	00:23	00:05	08:44
Phonecalls	04:33:00	184	01:01	00:01	08:57
Science	00:45:47	12	01:57	00:11	22:30
Sign requests	00:22:06	26	00:39	00:03	03:11
Supervision US	01:51:46	20	05:37	00:04	12:35
Other NIT	00:58:52	29	01:22	00:10	07:53
Management					
Meeting dept./MRON	04:20:16	14	13:13	00:48	1:06:18
Meeting hospital	01:30:00	1	1:30:00	1:30:00	1:30:00
Management (other)	00:22:32	6	02:50	00:41	08:25
Waste					
Break	08:19:09	73	03:13	00:06	30:00
ICT problems	00:34:17	53	00:18	00:03	06:44
Social contact	01:48:50	78	00:36	00:03	14:42
Talking to observer	03:41:01	219	00:32	00:02	17:42
Waiting	01:25:44	119	00:20	00:02	07:33
Walking/Moving	02:23:10	259	00:23	00:01	22:46
Other waste	01:56:26	67	00:35	00:02	16:18
Total	98:07:38	2337			

Table 4.4: Time spent per activity, shown for a quiet and regular shift. Only activities with statistically significant differences shown.

Activity	*Quiet shift* *Time spent [h:m:s (%)]*	*Regular shift* *Time spent [h:m:s (%)]*	*p-value*
Internal room/Punctions	0:52:30 (2.14)	3:14:16 (6.19)	.000
Phonecalls	1:52:24 (4.59)	2:40:36 (5.12)	.010
Logistics	0:26:16 (1.07)	0:11:21 (0.36)	.001
Walking/Moving	0:47:51 (1.95)	1:35:19 (3.04)	.013
Meeting hospital	0 (0)	1:30:00 (2.87)	n/a
Management (other)	0 (0)	0:22:32 (0.72)	n/a

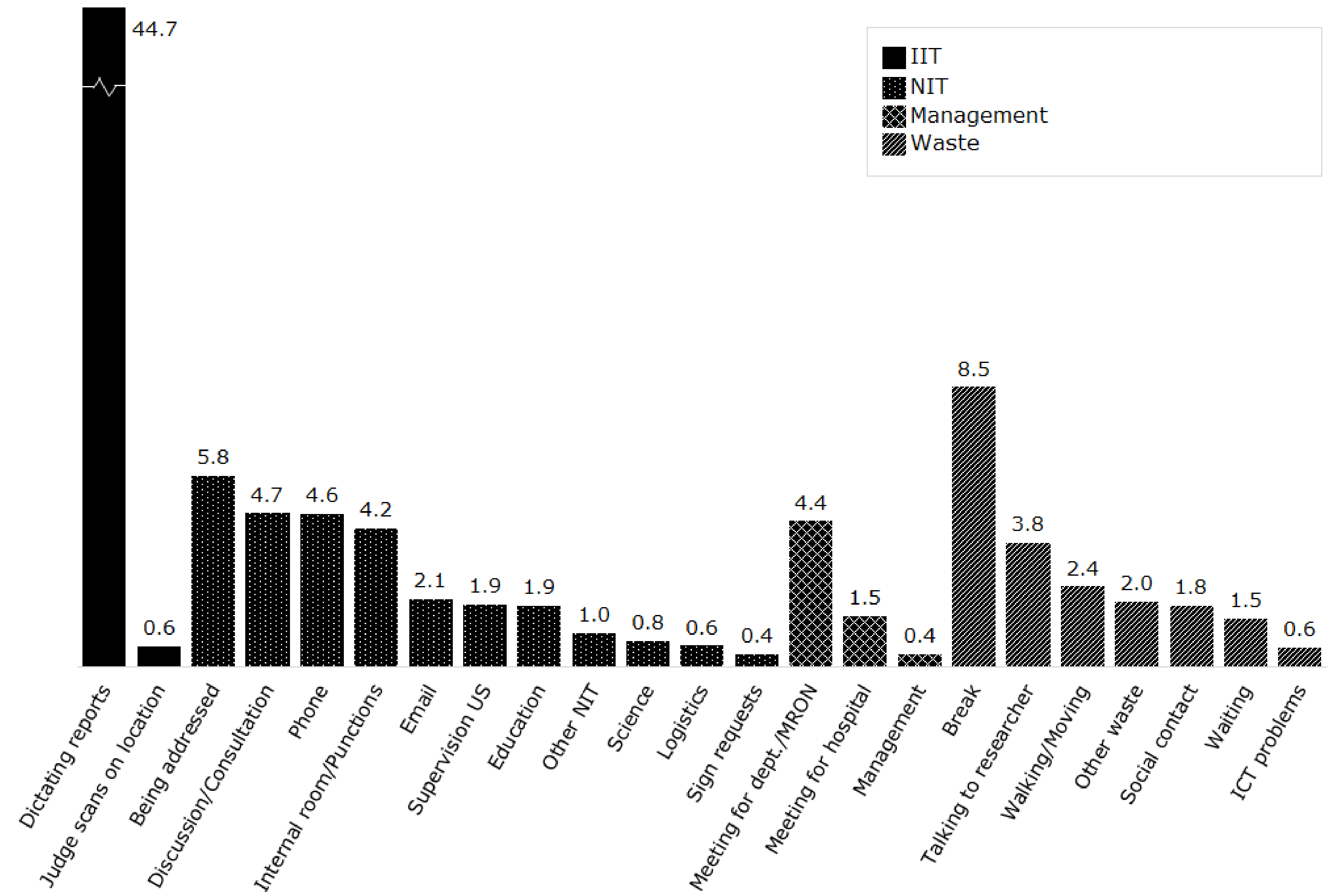

Figure 4.1: Percentage of total time spent per activity, sorted by IIT, NIT, Management, and Waste.

4.2 Current Quality

Production data from the ZGT hospitals is adapted using the two steps from Chapter 3.2. In step two a total of 6133 studies is removed from the data set. This number consists of 5453 MDO's radiology and 680 Copy SVOB's.
The average time allocated per report/intervention for each subspeciality is shown in Table 4.5. On average, an abdominal scan takes the longest to review, followed by a cardiography scan. The quickest studies belong to the muscoloskeletal subspecialism, followed by thorax studies.

Table 4.5: Average duration of a study per subspecialism, according to the combination of historical data from the ZGT and the standard times from the NVvR.

Subspecialism	*Average time*	
Abdomen	38 minutes	11 seconds
Cardiography	33 minutes	0 seconds
Angiography	27 minutes	4 seconds
Internal	22 minutes	32 seconds
Mammography	17 minutes	42 seconds
Ultrasound	15 minutes	1 second
Neurology, head, & neck	13 minutes	8 seconds
Thorax	7 minutes	19 seconds
Musculoskeletal	4 minutes	37 seconds

The number of scans and amount of time spent dictating scans outside of a radiologist's specialities is computed using the dataset. On average, 21.8% of the total number of scans dictated by a radiologist is not within their subspecialisms. This equals 15.7% of the total time they spent dictating reports. In total 33214 scans are dictated by radiologists outside of their subspecialisms in 2018. The percentages per subspecialism can be found in Table 4.6. In this table, the percentages are given as follows: the number equals the percentage of scans dictated within that subspecialism that are dictated by someone who was not subspecialised in that area. Within "Abdomen", 23.5% of scans are dictated by radiologists that does not have a subspecialisation in abdominal scans. This equals 18.7% of the time people spend on abdominal scans in total. The same format goes for Angiography (0.2, 0.4), Cardiography (3.7, 2.5), Mammography (2.1, 1.9), Neurology, head, & neck (18.9, 16.6), Muscoloskeletal (30.1, 21.0), and Thorax (23.1, 21.1).

The same calculations are made for the SKB where on average 44.2% of a radiologist's dictated scans is not among their subspecialisms. This corresponds to an average of 41.5% of their time. In total 34418 scans of the scans are dictated by a radiologist working outside of their subspecialisms in 2018. The numbers per subspecialism can be found in Table 4.7 for the SKB. The format equals that of Table 4.6 and contains the following subspecialisations: Abdomen (40.9), Cardiography (100.0), Children (100.0), Mammography (0.9), Neurology, head, & neck (67.7), Musculoskeletal (53.2), Thorax (11.6), Internal/Punctions (49.9). The percentages for time spent and number of scans are equal because all scans within one subspecialisation had the same duration.

Table 4.6: Number of scans dictated and time spent on dictating scans per subspecialism by radiologists who did not have this as a subspecialism in the ZGT.

Subspecialism	*Number (%)*	*Time [h:m:s (%)]*
Abdomen	5021 (23.5)	1623:20:15 (18.7)
Angiography	2 (0.2)	2:00:00 (0.4)
Cardiography	23 (3.7)	8:45:00 (2.5)
Mammography	139 (2.1)	37:10:30 (1.9)
Neurology, head, & neck	4262 (18.9)	833:18:00 (16.6)
Musculoskeletal	18381 (30.1)	1155:25:30 (21.0)
Thorax	5386 (23.1)	607:24:45 (21.1)
Total	33214 (22.9)	4267:24:0 (15.7)

Table 4.7: Number of scans dictated and time spent on dictating scans per subspecialism by radiologists who did not have this as a subspecialism in the SKB.

Subspecialism	*Number (%)*	*Time [h:m:s (%)]*
Abdomen	3961 (40.9)	2520:28:20 (40.9)
Cardiography	273 (100.0)	150:07:03 (100.0)
Children	3 (100.0)	00:09:50 (100.0)
Mammography	41 (0.9)	12:05:56 (0.9)
Neurology, head, & neck	8832 (67.7)	1933:45:12 (67.7)
Musculoskeletal	19210 (53.2)	1477:16:28 (53.2)
Thorax	1472 (11.6)	179:41:18 (11.6)
Internal/Punctions	626 (49.9)	235:0:40 (49.9)
Total	34418 (44.4)	6508:34:45 (42.6)

Chapter 5

Discussion

In this report the current efficiency and quality within MRON were researched within two specific measures: efficiency and quality. The research on efficiency will be discussed first, followed by the quality. Conclusions and recommendations will be discussed last in a combined subsection.

45.3% of a radiologist's time is spent on IITs within the ZGT and SKB combined. The other 54.7% is comprised of 27.9% NITs, 6.3% Management and 20.5% waste. The workflow results from the ZGT and SKB had statistically insignificant differences and can thus be compared with the MST and literature as one. The MST [30] recorded their time being spent for 40% on IITs, 39% on NITs, 8% on Management, and 13% on waste. Schemmel et al. [15] recorded their time being spent for 53.8% on IITs, 37.1% on NITs, 9.0% on Other tasks (Management and Personal time). This partly confirms the hypothesis in Section 2.3, as the ZGT is comparable to the MST, though it performs slightly better with regards to the IITs and worse in the Waste category, but the SKB does not perform significantly different from the other two hospitals.
A big difference between the research by the MST [30] and the current study is the method of collecting data. The MST had radiologists record their own activities whereas in the ZGT and SKB an independent observer was present in the room. This could explain the smaller percentage of waste in the MST study, as people could be subjective when recording their own workflow. MRON does spend less time on IITs than the results found by Schemmel et al. [15]. This can be caused by the fact that Schemmel et al. only monitored neuroradiology reading-room fellows and they tried to pick the shifts were responsibilities besides image interpretation (education, fMRI duties etc) were minimised. These decisions were made because the goal was to find out how much the NITs interrupted the reading room flow in their academic neuroradiology practice. The current study chose to provide a general image of the workflow within radiology and has thus monitored image-interpretive shifts as well as the outpatient mammography clinic and punctions. Schemmel et al. has also chosen to not record breaks and movement, which could in part explain their low waste-percentage, but these categories were included here to provide a more accurate overview of the situation within the ZGT and SKB. If the category Waste is removed from the dataset to better match

the method by Schemmel et al., the results are quite similar. The current study then records 57.0% on IITs, 35.1% on NITs and 8.0% on Management.
A possible limitation of this study is the amount of shifts that were observed. The MST gathered four times the amount of data in total and should thus, by sheer quantity, provide a more accurate result. However, the current study did incorporate all radiologists of the ZGT and SKB save three, monitor every subspecialism/type of shift at least once, and included all three locations: Almelo, Hengelo, and Winterswijk. These inclusions show that the current study still provides an accurate representation of the current situation. Another limitation related to this is that no busy shifts were observed. How busy a shift would be could not be known in advance and the observer was present at a shift that was ordinarily perceived as a busy shift, just not this time. A final limitation lies within the Hawthorne effect, stating that a bias could be introduced when people are aware that they are being observed. Due to the nature of this study however, an observer was still deemed the best option, as opposed to self-monitoring or a camera. Self-monitoring will introduce a different bias and can result in subjective results, where a camera does not monitor the out-of-room time and will thus be less acurate than an observer. The Hawthorne effect [38] was thus deemed unavoidable but has probably influenced the results because even though every radiologist stated post-observation that they did not behave differently, 3 hours, 41 minutes, and 1 second (3.8% of total time spent) was spent talking to the observer.

33214 scans were dictated by a radiologist not operating in his/her subspecialisations. This equals 22.9% of all scans where an increase in quality should be possible according to Section 1.1. These scans took a relatively short amount of time, since only 15.7% of the time spent dictating scans by the radiology department was spent on these scans. These scans could be dictated within emergency settings, like being on call or during the evening or weekend. This is supported by the fact that over half of the scans belonged to the muscoloskeletal category, which are frequent in emergency settings. These results do not confirm the hypothesis, as the found percentages are higher than the predicted 5% of time and 10% of scans from Section 2.3. As predicted, the SKB's percentages are a lot higher than those of the ZGT with 44.4% of scans and 42.6% of the time spent dictating those scans falling outside of the radiologists' subspecialisms. This is mainly because the radiologists in the SKB do not work according to their subspecialisms but according to modality (as mentioned in Section 1.2). This section also explains why mammography has the lowest percentage of dictation by a radiologists working outside of their subspecialisms in Table 4.7; it is the only subspecialism that is scheduled seperately. Noteworthy in this table are also the values for Cardiography and Children. These are at 100% because none of the radiologists within the SKB have these areas as their subspecialism. These results match the hypothesis quite well, although they are slightly better than the expected 50%.
The greatest limitation in this part of the research is in the SKB results. The average time for a scan in the ZGT does not need to match that of the SKB, but more importantly: it can differ per person. Because there was limited information gathered in the SKB, more detailed information about the time spent could not be calculated. Since the ZGT and SKB dictate similar

scans the averages from the ZGT give a reasonable estimation of the time spent in the SKB. These results are still usable but a small error is introduced here. A second limitation lies in the PACS systems and how they store data. All combined scans (e.g. Thorax+Abdomen, Thorax+Abdomen+Neck etc) were stored under ”Abdomen” in the ZGT. This increases the average duration of an abdominal scan and can give a skewed image on how much time was spent on these scans. This effect has been taken into account by rearranging the combined scans of the SKB to match the ZGT's system and to make the two comparable, plus to be able to use the average scan duration computed from the ZGT in the SKB data.

5.1 Conclusions and Recommendations

The current level of efficiency, defined as time spent on IITs and NITs, in ZGT and SKB in 2019 is comparable to that of the MST in 2013. The level of efficiency can be seen as the combination of IITs and NITs, which is 73.1% for the ZGT and SKB, and 79.1% for the MST. There are a lot of interruptions in both cases though, which can be minimised by a couple of options mentioned in section 2.2: seperating IITs and NITs (similar to a teleradiology setup), setting up a telephone triage system, or sorting all studies by their priorty. For future research it would be interesting to compare the activity tracking data to discrepancies made or time taken to dictate a single report. This way one could find out whether more interruptions cause more errors and how much extra time a radiologist needs to dictate similar reports if he is interrupted a lot or if he is allowed to work continuously.
The current level of quality, defined as radiologists working within their subspecialisms, is 77.1% for the ZGT and 55.6% for the SKB. This level of quality can be greatly increased, especially in the SKB, if more or all radiologists only dictate scans within their subspecialisms. A teleradiology setup and all radiologists working within their own subspecialisms would be made possible by a regional PACS, which will be implemented in MRON in the near future. To quantify how much this could help, the hypothetical scenario where all radiologists only work within their subspecialisations and are pooled throughout the entirety of MRON has been drawn up and expounded in the following chapter.

Chapter 6

Hypothetical Solution: Pooling of Radiologists

Pooling of resources essentially means sharing the workload. If the workload of two radiologists differs greatly, it can be evened out using pooling. If pooling is not applied, the surplus of work from radiologist 1 will remain unfinished, where radiologist 2 would have too little to do and thus create waste [16]. Waste in this case indicates unused resources, or working hours of the radiologist where he is not working (effectively). The efficiency to be gained from pooling can be modelled via a mathematical system of equations. These equations can also be used to simulate scenarios to further visualise the pooling of MRON's resources.

6.1 Mathematical Model

This model is derived from the PhD thesis by Vanberkel [39], and uses the following variables and equations.

λ = Average demand for scans per day
D = Average interpretation length in minutes
V = Variance of the interpretation length
C = Coefficient of variation for the interpretation length ($C = \sqrt{V/D^2}$)
ρ = Utilisation
t = Working minutes per day
W = Expected waiting time in days
L = Average queue length
M = Number of radiologists
$\mathbb{E}[S]$ = Possible number of completed appointments in a day

$$\lambda_{AB} = \lambda_A + \lambda_B \tag{6.1}$$

$$D_{AB} = qD_A + (1-q)D_B \tag{6.2}$$

$$V_{AB} = q(V_A + D_A^2) + (1 - q)(V_B + D_B^2) - D_{AB}^2 \tag{6.3}$$

Where $q = \lambda_A / \lambda_{AB}$.

Using the deductions from Vanberkel [39], the following formulas can be found for $\mathbb{E}[S]$, utilisation, and queue length:

$$\mathbb{E}[S] \approx \frac{Mt}{D} + \frac{M}{2}(C^2 - 1) \tag{6.4}$$

$$\rho \approx \frac{\lambda D}{Mt} \frac{1}{1 + \frac{D}{2t}(C^2 - 1)} \tag{6.5}$$

$$\rho_0 = \frac{\lambda D}{Mt} \tag{6.6}$$

$$L \approx \frac{\rho}{2(1 - \rho)} \left(1 + \frac{C^2}{\rho_0}\right) \tag{6.7}$$

Using Little's Law $(W = L/\lambda)$ and equation 6.7, the formula for W can be determined:

$$W \approx \frac{\rho}{2(1 - \rho)\lambda} \left(1 + \frac{C^2}{\rho_0}\right) \tag{6.8}$$

To find the values for all these input variables, the production data from all hospitals has to be further analysed. The scans per subspecialisation divided by 365 will provide λ. D is given by the average time per subspecialisation, as shown in Table 4.5. V is the variance of D. M will use the time each radiologist spends on each specialisation, which was also used to calculate the average time spent outside of a radiologists subspecialisations in Section 4.2. These durations are transformed into percentages which can be used for variable M. For example: If a radiologist divides his time equally over 4 subspecialisms (25% each) but is only subspecialised in two of these, their M-values would equal 0.5 for both subspecialisations. Working minutes per day (t) has been set to 364.3 ((9 working hours - 30 minutes lunchbreak) * 60 minutes * (5 working days out of 7 weekdays) $= 8.5 * 60 * (5/7)$). These equations can be used to calculate the efficiency of the department, which can in turn be used in combination with a poisson regulated queueing system to simulate the efficiency of the department. Note that the amount of working days here has been set to 5. Most radiologists only work 4 days or less, but for the sake of this model everything has been equalised. All equations were then filled out accordingly for an individual radiologist, for the full ZGT hospital, and for MRON as a whole. The results of the calculations can be seen in Table 6.1.

Table 6.1: Number of radiologists (M), utilisation (rho), expected waiting time in days (W), and average queue length (L) for all three levels. Working minutes per day was set to 8,5 hours a day for 5 days a week.

Variable	*Level*		
	Radiologist	*ZGT*	*MRON*
M	1	19	38*
ρ	.99	.75	.84
W	∞	.01	.01
L	∞	3.87	7.00

**41 radiologists total within MRON, but MST was counted as 0.8 FTE*

There were some difficulties when including the MST in the MRON calculations, because not all data was available. The total number of scans was available and for about 80% of those their subspecialism was noted. Only this 80% was used in the calculations, so the radiologists from the MST (a.k.a. the M-value of the MST) was multiplied by 0.8 to compensate for this.

It may seem like MRON as a whole is less advantageous than only pooling within ZGT, as it has a larger queue length. However, this queue length is divided over more radiologists, making the relative queue similar to that of the ZGT. Secondly, the quality gain has not been incorporated into this table because there are no formulas for this. There would likely be an increase in quality, especially in the SKB, if all radiologists are able to operate based on their areas of expertise. The values in both aforementioned scenarios are better than that of the single radiologist, even though ρ has a higher value there.

Intuitively, a utilisation of 100% seems optimal. However, as patient arrivals are not fully predictable, the workload will vary. If two consecutive days have a high workload this surplus can not be resolved as the future utilisation is already at 100% and does not provide leeway. Thus, a slightly lower utilisation is preferred. A utilisation of 95% for MRON is achieved when working minutes per day are reduced to 322.9, so 7.53 hours a day for 5 days in the week. This would result in a W-value of 0.02 and L-value of 23.1. These working hours may not seem like a significant improvement, but when compared to the values in Table 6.1 of a solo-radiologist the added value of pooling resources becomes apparent. Better quantifying the added value is difficult because different radiologists maintain different working schedules and different dictating tempos.

6.2 Pooling simulations: Evening out the workload

To better grasp the concept of pooling, a simulation has been made for the ZGT. To simulate a typical timeperiod of the radiology department, arrivals are generated using a random number generator, according to a Poisson distribution and using the λ acquired from equation 6.1. This is done for a period of 70 days to limit the computing power needed. For a non-pooled scenario, $\mathbb{E}[S]$ (from equation 6.4) is calculated per specialism and deducted

from the random arrival. The resulting number is the number of scans not completed for that day in that specialism. The sum of these unfinished scans per specialism equals the amount of scans unfinished per day in a non-pooled scenario. For each following day, the uncompleted scans of the previous day are added to the randomly generated new arrivals. In the pooled scenario, all random arrivals are added together and the pooled $\mathbb{E}[S]$ is substracted from that total. This visual representation of the queue is made using Excel and VBa.
This graph, Figure 6.1, shows the scenario where all radiologists only work according to their subspecialisations. The dotted line shows a pooled scenario, where all radiologists share their workload. The regular line shows what happens if each radiologists only dictated their own scans, without giving or receiving help from colleagues.

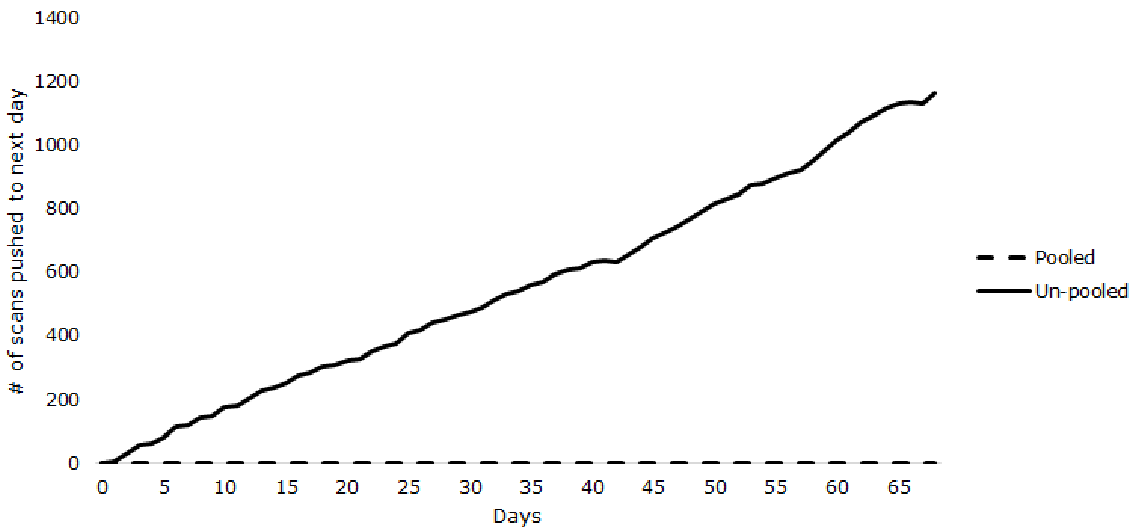

Figure 6.1: Simulation of the current situation in the ZGT if each radiologist stuck to their own specialisations.

What happens in this graph is better explained by simulating the current situation in the ZGT. In this simulation, Figure 6.2, radiologists work like they do currently. The percentage of time they spend on each subspecialisation was used here, not only their areas of expertise. If a radiologist is mainly a thorax/abdomen radiologist but also spends 20% of their time on neuroradiology, it will be incorporated in this simulation. The workload in this scenario will be lower than when everyone sticks to their own subspecialisations, because lmited pooling is automatically introduced when using these values. Abdominal scans are the main reason the work piles up in these simulations, for the same reason mentioned in Chapter 5; The combined scans are stored under ”Abdomen”, increasing the amount of abdominal scans and their duration.

Visible in this graph again are the pooled scenario and the un-pooled scenario, the dotted and regular line respectively. The x-axis is a timeline in days, the y-axis are the number of scans being pushed to the next day, or the unfinished work remaining on that day. To illustrate the trend of this graph, a small portion will be explained with the following example: On day 5, 5 scans were left unfinished at the end of the day. These were added to the

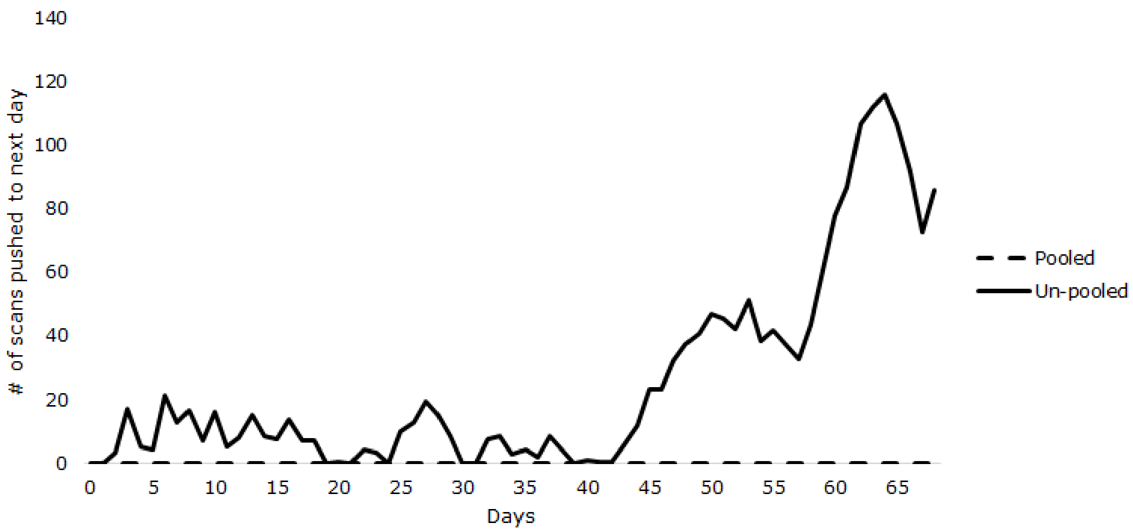

Figure 6.2: Simulation of the current situation in the ZGT.

workload of day 6. However, on day 6 the workload was too large as well: 16 scans surplus. Combining these 16 scans from day 6 with the 5 scans form day 5 meanse 21 scans being pushed to day 7. Day 7 is a bit quieter and a couple of the 21 scans can be dictated on top of the workload from day 7 itself, so the line goes down again.

This rising and falling of the un-pooled line keeps happening for the duration of this simulation. The risk here is that there are a few consecutive busy days and the whole workload spirals out of control. A couple of quiet days may not be enough to compensate, and there will likely be another busy day soon. This is what happened immediately in Figure 6.1. However in both scenarios, the pooled line sticks to the x-axis because of the pooling mechanisms.

Pooling will help with the fluctuating workload the radiology department has to endure, as radiologists mention that the workload currently varies a lot between different days of the week (as shown in Figure 6.2). On top of this the quality would improve because radiologists will be able to work within their subspecialisations more, especially in the SKB where the limited current resources prevent them from working in the same fashion as the ZGT and MST.

6.3 Analysing the current scheduling method

These pooled scenarios are incompatible with the current scheduling method. If all work is fully pooled, radiologists should dictate the highest priority scan within their subspecialisation at that time, not merely those that were assigned to them in their current image-interpretive shift. A possible future schedule would merely note if a radiologist is present or absent, and then they would simply work on what they can do and on where their expertise lies. Shifts like the mammography outpatient clinic and angiography would still be planned the same way, as these cannot be performed on the fly or even from a different location. This new way of planning would be a huge change from the current way of planning, which raises the questions: How much of a change would it actually be? How strict is the current schedule, do people stick to their assigned shift or do they already simply dictate whatever they can? This leads to the following main question:

How many scans do not belong to the assigned shift and how much time is spent on these scans?

To answer these questions, more adaptations and analyses of the ZGT dataset are needed. These analyses are only done for the ZGT because of the large amount of detailed data needed that was not available for the other two hospitals. Three additional steps are initially needed to manipulate the data:

1. Scans are divided into morning, afternoon, evening, and night scans. Morning will range from 07:00-12:45, afternoon from 12:45-18:30, evening from 18:30-00:00, and night from 00:00-07:00. These times were chosen to optimally coincide with the operating times of the radiologists.
2. Each part of the day is compared to historical schedules for each radiologist to determine what their assigned work was that day.
3. Scans performed when radiologists were not supposed to be working will be divided into categories to determine whether to exclude or include them.

These steps resulted in the following changes to the data:

1 The amount of scans per part of the day is as follows:

- Morning: 75850
- Afternoon: 71756
- Evening: 3252
- Night: 254

2 A list of scans performed per radiologist per part of each day was compiled and compared to historical schedules. The assigned shifts were recorded next to their respective productions on that part of the day. 4939 items were produced when radiologists were not supposed to be present and/or working.

3 Each time a report was dictated or an intervention performed when a radiologist was supposed to be absent (or present but not dictating/performing interventions) was manually checked an divided into one of the following 7 categories.

1. Absent without other reason as to why this report has been made. This includes nothing mentioned in the schedule, holidays and/or schedule-free.

2. Started early or stayed late. When a radiologist came in early and already reported on some medical cases before the set time constraints considered the time to be ”morning”, the scan was put into this category. This was apparent when more reports were made shortly after this one and the time of dictation didn’t differ more than one hour from the supposed start of the day. Similar considerations were made for staying late, but the difference was increased from 30 minutes to 2 hours.

3. AW is similar to the first category, meaning ”afwezig” (absent). However, according to the scheduling software AW can also mean ”aanwezig” (present). The hospital says this category is only used to indicate absence, but due to this inaccuracy and the large number of instances with AW, this was made into a seperate category.

4. Dictator does not equal executor. This is not a strange event in itself, but usually only occurs when an resident/doctor in training to become a specialist (AIOS) dictates a scan but does so under the supervision of a radiologist, making the radiologist the executor. However, since all AIOS’s were removed from the data set, the instances in this category all concern 2 different radiologists, which is not supposed to be possible if the dictator is the absentee.

5. Parttime according to the schedule, which means that the radiologist would be absent.

6. Management day according to the schedule, which means that the radiologist is usually present in the hospital but supposed to spend his/her time on management-related tasks.

7. Educational day according to the schedule, which means that the radiologist is usually present in the hospital but supposed to spend his/her time on education-related tasks.

Table 6.2: Number of scans dictated at times that radiologists were supposed to be absent/not working, divided into 7 categories. Numbers given including and excluding MDO radiology and Copy SVOB.

Code	*Description*	*Occurrence*	*Occurrence**
1	Absent	1920	1057
2	Started early/Left late	729	729
3	AW in roster	1335	1269
4	Dictator =/= executor	140	140
5	Parttime in roster	113	18
6	Management day in roster	675	610
7	Education in roster	50	50
	Total	4939	3850

*Occurrences minus MDO radiology & Copy SVOB (Section 3.2, point 2)

All instances with code 2 were manually adjusted to show a different part of the day. If a radiologist came in early, ”night” was changed to ”morning”. Similarly if a radiologist stayed late, ”evening” was changed to ”afternoon”. The rest of these scans were excluded from this calculation because there was no subspecialism assigned to divert from.

This cleaned data was compared to historical schedules to compute how much work was done outside of the assigned shifts. Shifts with ”acute” in the name were automatically set to zero, because acute care encompasses all specialisms so one can’t determine how much was done outside of the assigned scans. On-call shifts were also set to zero for the same reason.
On average, 35% of the number of scans radiologists dictated (32% of time spent dictating) were not part of the shifts they were assigned to. If all shifts with acute care were to be removed from this dataset, the percentages would be higher: 42% of the number of scans and 38% of the time spent is outside of the assigned shift.

6.4 Conclusion

Pooling all radiologists would be beneficial to both the quality and the efficiency of the radiology department. This will require a different scheduling method for all image-interpretive shifts, but the change in roster should not be too great as 42% of the scans dictated in an image-interpretive shift do not match that shift currently.

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Appendix A

Activity tracker

A.1 Javascript

```
import javax.swing.*;
String name;
String shift;
String filename;
String activities = "";
String[] dayspent;
String activity = "";
void setup() {
  size(600, 300);
  try {
    UIManager.setLookAndFeel(UIManager.getSystemLookAndFeelClassName());
  }
  catch (Exception e) {
    e.printStackTrace();
  }
  String preset1="voornaam achternaam";
  String names1 = JOptionPane.showInputDialog(frame, "Naam radioloog", preset1);
  String preset2="specialisme";
  String names2 = JOptionPane.showInputDialog(frame, "Type shift", preset2);
  if (names1 != null) name=names1;
  if (names2 != null) shift=names2;
  filename = (day()+"-"+month()+"-"+year()+"-"+name+" "+shift);
}

void draw() {
  if (keyPressed) {
    background(80);
    fill(255, 255, 255);
    if (key=='1') {
      String activity = (hour()+":"+ minute()+":"+second()+", 1,
          verslaglegging/interventie"+";");
```

```
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='2') {
    String activity = (hour()+":"+ minute()+":"+second()+", 2, (telefonisch)
        overleg andere radioloog"+";");
    println(activity);
    text(activity, 20, 140);
    activities = activities + activity;
  } else if (key=='3') {
    String activity = (hour()+":"+ minute()+":"+second()+", 3, aangesproken
        worden"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='4') {
    String activity = (hour()+":"+ minute()+":"+second()+", 4, pauze
        (wc-koffie-lunch)"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='5') {
    String activity = (hour()+":"+ minute()+":"+second()+", 5,
        bespreking/overleg"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='6') {
    String activity = (hour()+":"+ minute()+":"+second()+", 6, wegkijken
        foto/MR/CT"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='7') {
    String activity = (hour()+":"+ minute()+":"+second()+", 7, (telefonisch)
        overleg arts ander specialisme"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='8') {
    String activity = (hour()+":"+ minute()+":"+second()+", 8, supervisie
        echo"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='9') {
```

```
    String activity = (hour()+":"+ minute()+":"+second()+", 9, email
        beantwoorden/opstellen"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='q') {
    String activity = (hour()+":"+ minute()+":"+second()+", q, opleiding"+";");
    println(activity);
    activities = activities + activity;  ;
    text(activity, 20, 140);
  } else if (key=='w') {
    String activity = (hour()+":"+ minute()+":"+second()+", w, wetenschap"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='c') {
    String activity = (hour()+":"+ minute()+":"+second()+", c, statusvoering
        (DSV/DOT/etc)"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='x') {
    String activity = (hour()+":"+ minute()+":"+second()+", x, aftekenen
        aanvragen"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='r') {
    String activity = (hour()+":"+ minute()+":"+second()+", r, management"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='t') {
    String activity = (hour()+":"+ minute()+":"+second()+", t,
        vergadering/werkgroep tbv maatschap/afdeling"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='g') {
    String activity = (hour()+":"+ minute()+":"+second()+", g,
        vergadering/werkgroep tbv ziekenhuis"+";");
    println(activity);
    activities = activities + activity;
    text(activity, 20, 140);
  } else if (key=='f') {
    String activity = (hour()+":"+ minute()+":"+second()+", f, wachttijd
        (computer/assistent/etc)"+";");
```

```
      println(activity);
      activities = activities + activity;
      text(activity, 20, 140);
    } else if (key=='d') {
      String activity = (hour()+":"+ minute()+":"+second()+", d, storing/verslag
          kwijt/etc"+";");
      println(activity);
      activities = activities + activity;
      text(activity, 20, 140);
    } else if (key=='a') {
      String activity = (hour()+":"+ minute()+":"+second()+", a, onvoldoende
          verslagstations"+";");
      println(activity);
      activities = activities + activity;
      text(activity, 20, 140);
    } else if (key=='z') {
      String activity = (hour()+":"+ minute()+":"+second()+", z, logistiek (maken
          van afspraak etc)"+";");
      println(activity);
      activities = activities + activity;
      text(activity, 20, 140);
    } else if (key=='s') {
      String activity = ("Timestamp,"+"Code,"+"Description"+";"+hour()+":"+
          minute()+":"+second()+", , Start dag"+";");
      println(activity);
      activities = activities + activity;
      textSize(20);
      text(hour()+":"+ minute()+":"+second()+", , Start dag", 20, 140);
    } else if (key=='e') {
      String activity = (hour()+":"+ minute()+":"+second()+", , Einde dag"+";");
      println(activity);
      activities = activities + activity;
      text(activity, 20, 140);
      String[] dayspent = split(activities, ";");
      saveStrings((filename+".csv"), dayspent);
    }
    delay(400);
  }
}
```

A.2 Example output CSV-file

Timestamp,Code,Description
11:34:35, , Start dag
11:34:37, 1, verslaglegging/interventie

11:34:38, 6, wegkijken foto/MR/CT
11:34:39, 7, (telefonisch) overleg arts ander specialisme
11:34:39, 8, supervisie echo
11:34:40, 1, verslaglegging/interventie
11:34:41, 3, aangesproken worden
11:34:41, 1, verslaglegging/interventie
11:34:42, 4, pauze (wc-koffie-lunch)
11:34:43, 2, (telefonisch) overleg andere radioloog
11:34:43, 1, verslaglegging/interventie
11:34:44, d, storing/verslag kwijt/etc
11:34:46, f, wachttijd (computer/assistent/etc)
11:34:48, 1, verslaglegging/interventie
11:34:48, q, opleiding
11:34:49, 1, verslaglegging/interventie
11:34:49, r, management
11:34:51, t, vergadering/werkgroep tbv maatschap/afdeling
11:34:51, 1, verslaglegging/interventie
11:34:52, z, logistiek (maken van afspraak etc)
11:34:53, 9, email beantwoorden/opstellen
11:34:54, 1, verslaglegging/interventie
11:34:55, 8, supervisie echo
11:34:55, 1, verslaglegging/interventie
11:34:56, , Einde dag

Appendix B

Additional results

B.1 Activity tracking

Table B.1: Time spent on each activity, shown per hospital.

	Time spent [h:m:s (%)]		
Activity	*SKB Winterswijk*	*ZGT Almelo*	*ZGT Hengelo*
IIT			
Dictating reports	10:16:22 (46.62)	7:28:42 (41.63)	26:06:44 (44.86)
Internal room/punctions	2:17:43 (10.42)	0:13:56 (1.29)	1:35:07 (2.73)
Judge scans	0:11:18 (0.85)	0:22:07 (2.05)	0:02:20 (0.07)
Supervision US	0:37:38 (2.85)	0:05:43 (0.53)	1:08:25 (1.96)
Other IIT	0:18:59 (1.44)	0:02:54 (0.27)	0:36:59 (1.06)
NIT			
Being addressed	2:01:56 (9.22)	0:51:20 (4.76)	2:47:07 (4.79)
Discussion/consultation	0:06:32 (0.49)	0:52:34 (4.88)	3:35:19 (6.17)
Education	0 (0)	0:54:47 (5.08)	0:54:24 (1.56)
Email	0:06:45 (0.51)	0:38:00 (3.53)	1:16:02 (2.18)
Logistics	0:01:33 (0.12)	0:25:53 (2.40)	0:10:11 (0.29)
Phone	1:17:55 (5.89)	0:51:34 (4.78)	2:23:31 (4.11)
Science	0 (0)	0:37:19 (3.46)	0:08:28 (0.24)
Sign requests	0:03:24 (0.26)	0:00:18 (0.03)	0:18:24 (0.53)
Management			
Meeting for dept./MRON	1:46:17 (8.04)	0:51:32 (4.78)	1:42:27 (2.94)
Meeting for hospital	0 (0)	0 (0)	1:30:00 (2.58)
Management	0 (0)	0:21:51 (2.03)	0:00:41 (0.02)
Waste			
Break	1:43:19 (7.82)	1:31:38 (8.50)	5:04:12 (8.72)
ICT problems	0:07:05 (0.54)	0:02:23 (0.22)	0:24:49 (0.71)
Social contact	0:07:12 (0.54)	0:04:58 (0.46)	1:36:40 (2.77)
Talking to observer	0:29:36 (2.24)	0:31:57 (2.96)	2:39:28 (4.57)
Waiting	0:09:53 (0.75)	0:15:13 (1.41)	1:00:38 (1.74)
Walking/moving	0:10:46 (0.81)	0:22:08 (2.05)	1:50:16 (3.16)
Other waste	0:07:48 (0.59)	0:30:59 (2.87)	1:17:39 (2.23)
Total	**22:02:01 (100.00)**	**17:57:46 (100.00)**	**58:07:51 (100.00)**

Table B.2: Time spent per activity, shown per shift type. Activities with significant differences (p-value <0.05) shown in bold font.

Activity	*Shift-type: Time spent [h:m:s (%)]*					
	Abdomen	*Cardiology*	*CT*	*Echo*	*Internal*	*Mammo*
IIT						
Dictating reports	1:36:43 (40.13)	1:28:58 (32.06)	2:02:34 (52.34)	2:28:11 (26.21)	2:55:38 (37.61)	3:35:42 (41.03)
Internal room/punctions	0:13:56 (5.78)			1:58:49 (21.02)	1:35:07 (20.37)	
Judge scans	**0:15:31 (6.44)**					
Supervision US				0:05:43 (1.01)	0:26:30 (5.67)	0:41:55 (7.97)
Other IIT			0:04:45 (2.03)		0:02:59 (0.64)	
NIT						
Being addressed	0:17:13 (7.14)	0:22:59 (8.28)	0:29:37 (12.65)	0:33:54 (6.00)	0:38:10 (8.17)	0:34:14 (6.51)
Discussion/consultation	**0:16:34 (6.87)**	**1:39:43 (35.93)**	**0:02:39 (1.13)**		**0:10:15 (2.19)**	**0:47:27 (9.02)**
Education				0:33:55 (6.00)	0:06:32 (1.40)	0:40:36 (7.72)
Email	0:02:03 (0.85)	0:10:44 (3.87)	0:03:14 (1.38)	0:31:23 (5.55)	0:12:26 (2.66)	0:00:41 (0.13)
Logistics		**0:01:06 (0.40)**	**0:01:20 (0.57)**	**0:24:51 (4.40)**		
Phone	**0:13:38 (5.66)**	**0:00:50 (0.30)**	**0:11:51 (5.06)**	**0:03:37 (0.64)**	**0:06:24 (1.37)**	**0:12:53 (2.45)**
Science	0:32:31 (13.49)			0:04:48 (0.85)	0:00:59 (0.21)	
Sign requests	0:00:18 (0.12)	0:01:30 (0.54)			0:06:24 (1.37)	0:10:30 (2.00)
Management						
Meeting for dept./MRON			0:39:11 (16.73)	1:34:42 (16.75)		0:22:06 (4.20)
Meeting for hospital						
Management						
Waste						
Break	0:09:54 (4.11)	0:14:12 (5.12)	0:07:51 (3.35)	0:08:55 (1.58)	0:11:11 (2.39)	0:20:58 (3.99)
ICT problems	0:00:35 (0.24)	0:00:56 (0.34)		0:00:24 (0.07)	0:01:10 (0.25)	0:07:05 (1.35)
Social contact		0:12:29 (4.50)	0:00:05 (0.04)	0:05:04 (0.90)	0:04:32 (0.97)	0:04:40 (0.89)
Talking to observer	0:08:18 (3.44)	0:00:26 (0.16)	0:04:52 (2.08)	0:08:10 (1.44)	0:11:30 (2.46)	0:12:38 (2.40)
Waiting	0:03:45 (1.56)	0:07:33 (2.72)	0:04:47 (2.04)	0:10:53 (1.93)	0:20:15 (4.34)	0:09:38 (1.83)
Walking/moving	**0:07:47 (3.23)**	**0:11:02 (3.98)**	**0:00:26 (0.19)**	**0:03:28 (0.61)**	**0:23:22 (5.00)**	**0:24:57 (4.75)**
Other waste	0:02:13 (0.92)	0:05:04 (1.83)	0:00:59 (0.42)	0:28:33 (5.05)	0:13:37 (2.92)	0:19:46 (3.76)
Total	4:00:59 (100.00)	4:37:32 (100.00)	3:54:11 (100.00)	9:25:20 (100.00)	7:47:01 (100.00)	8:45:46 (100.00)

Table B.3: Time spent per activity, shown per shift type. Activities with significant differences (p-value <0.05) shown in bold font. Continued.

Shift type: Time spent [h:m:s (%)]						*p-value*
Mammo Echo	*MRI*	*MSK*	*Neuro HH*	*Thorax*	*Thorax Abdomen*	
1:49:23 (45.65)	5:02:10 (63.19)	10:52:54 (59.04)	4:40:01 (56.64)	1:34:47 (38.23)	5:42:47 (48.22)	.428
0:18:54 (7.89)						.526
	0:11:18 (2.36)	**0:08:56 (0.81)**				**.027**
0:37:38 (15.71)						**
	0:14:14 (2.98)	0:05:07 (0.46)	0:11:39 (2.36)	0:03:49 (1.54)	0:16:19 (2.30)	.802
0:37:36 (15.69)	0:43:19 (9.06)	0:22:59 (2.08)	0:23:57 (4.84)	0:03:59 (1.61)	0:32:26 (4.56)	.520
	0:03:53 (0.81)	**0:50:48 (4.59)**	**0:05:53 (1.19)**		**0:37:13 (5.24)**	**.010**
		0:20:52 (1.89)		0:07:16 (2.93)		**
	0:03:31 (0.74)	0:13:05 (1.18)	0:06:52 (1.39)		0:36:48 (5.18)	.584
	0:00:13 (0.05)	**0:01:42 (0.15)**	**0:00:05 (0.02)**	**0:06:44 (2.72)**	**0:01:36 (0.23)**	**.000**
0:13:52 (5.79)	**0:51:06 (10.69)**	**0:58:54 (5.33)**	**0:30:04 (6.08)**	**0:33:48 (13.63)**	**0:36:03 (5.07)**	**.014**
		0:02:19 (0.21)	0:05:10 (1.05)			.075
0:03:24 (1.42)						**
	0:00:48 (0.17)	1:05:37 (5.93)	0:07:52 (1.59)	0:30:00 (12.10)		.459
					1:30:00 (12.66)	*
		0:21:51 (1.98)				*
0:03:57 (1.65)	0:13:29 (2.82)	1:10:00 (6.33)	0:25:44 (5.21)	0:03:11 (1.28)	0:09:47 (1.38)	.782
	0:07:05 (1:48)	0:05:37 (0.51)	0:09:22 (1.89)	0:00:05 (0.03)	0:01:58 (0.28)	.341
0:01:20 (0.56)	0:02:26 (0.51)	0:05:17 (0.48)	0:38:56 (7.88)	0:02:55 (1.18)	0:31:06 (4.37)	.148
0:06:23 (2.66)	0:13:52 (2.90)	1:00:59 (5.51)	0:33:47 (6.83)	0:09:37 (3.88)	0:50:29 (7.10)	.652
0:00:47 (0.33)	0:03:12 (0.67)	0:12:57 (1.17)	0:01:35 (0.32)	0:09:22 (3.78)	0:01:00 (0.14)	.416
0:06:11 (2.58)	**0:03:56 (0.82)**	**0:16:58 (1.53)**	**0:06:39 (1.35)**	**0:23:51 (9.62)**	**0:14:33 (2.05)**	**.014**
0:00:12 (0.08)	0:03:41 (0.77)	0:08:56 (0.81)	0:06:47 (1.37)	0:17:49 (7.19)	0:08:49 (1.24)	.418
3:59:37 (100.00)	7:58:13 (100.00)	18:25:48 (100.00)	8:14:23 (100.00)	4:07:54 (100.00)	11:50:54 (100.00)	

**fewer than 2 groups for this activity, no statistics were computed.*

***no sum of squares available within groups, no significance could be computed.*