The effects on examination rate due to nurse staffing variations at a radiology department

Master's thesis in Biomedical Engineering

ARVID BJURKLINT

The effects on examination rate due to nurse staffing variations at a radiology department

ARVID BJURKLINT

The effects on examination rate due to nurse staffing variations at a radiology department
ARVID BJURKLINT

Supervisor: Kristofer Bengtsson, Systems and Control, E2
Examiner: Bengt Lennartsson, Systems and Control, E2

The effects on examination rate due to nurse staffing variations at a radiology department
ARVID BJURKLINT
Department of Electrical Engineering
Chalmers University of Technology

Abstract

In a study from 2016 it was found that the Swedish healthcare system was functioning relatively well compared to other countries, but several inefficiencies were identified. Capacity planning and scheduling were two areas that needed improvement. Capacity planning within healthcare is the process of matching the demand of care to the available resources. The scheduling process did generally not take capacity planning into account and was instead based on the availability of the staff, rather than the demand of care.

This thesis therefore studies the relationship between capacity planning and scheduling at a Magnetic Resonance Imaging (MRI) unit at Sahlgrenska Hospital. The aim is to understand how the scheduling affected the examination rate. The staff schedule and examination data from December 2019 to February 2020 is analyzed and compared, in order to understand how the two were correlated. Each MRI examination room was studied, to see how the staffing of each room affected the overall examination rate.

The number of hours the rooms were staffed and the number of examinations that were done per day were highly positively correlated, the correlation coefficient was 0.95, but with large daily variations. Two other sources that were investigated were the amount of time that was spent on examinations each day and variation within examination durations. These two did not affect the correlation between staff hours and examination rate much. Variation in how much the staff spent on examinations could be due to examinations being cancelled. Variation within examination durations was expected between different types of examinations, and overall the variation was low compared to the average duration of the examinations. Another source of variation was discrepancies between the schedule and the performed examinations, on some days there were examinations done in rooms without any scheduled staff. This could be due to examinations being scheduled on short notice, and the schedule not being updated because of this. Using a time-clock system rather than the schedule could give a more correct understanding of when the staff was working.

To be able to base the scheduling process more on demand of care, it would be interesting in future studies to investigate the flow of incoming referrals and see how this can be used when setting the schedule, something that is not done currently at the unit.

Keywords: Nurse staffing, capacity planning, healthcare, resource management, magnetic resonance imaging.

Acknowledgements

First I would like to thank the staff at the CT and MRI units at Sahlgrenska Hospital for giving me an understanding of the radiology department in just a few days. A big thank you to Sjomen Cheng who answered my many emails about referral codes, schedules and other things. In helping me get the right data for the project and coordinating everything that had to do with Sahlgrenska, I thank Ing-Marie Reuterberg, as well as interpreting the results together with Alexander Johansson and Sjomen Cheng. Finally, a big thank you to my supervisor Kristofer Bengtsson, for helping and guiding me throughout the thesis. Without all these people I would not have been able to accomplish this thesis.

<div align="right">

Arvid Bjurklint, Gothenburg, June 2020

</div>

Contents

1

Introduction

In a study from 2016 [1], done on behalf of the Swedish government to evaluate the efficiency of the Swedish healthcare system, it was concluded that the Swedish healthcare system was functioning relatively well compared to other countries, but several inefficiencies were identified. Capacity planning and scheduling were two areas that needed improvement. Capacity planning within healthcare is the process of matching the demand of care to the available resources [2]. This was usually done at Swedish hospitals but was generally not integrated well in all the hospitals' processes. One example was the scheduling process, which generally did not take capacity planning into account and was instead based on the availability of staff, rather than the demand of care [1]. A similar conclusion came from Swedish Agency for Health and Care Services Analysis in 2013 [3], which recommended that to meet the demand of the patients, the staffing of doctors, nurses and other personnel must come from an analysis of the needs of the patients.

One common scheduling problem was that different professions' schedules were done separately, to plan them together would yield more efficient care [3]. Another problem with scheduling only based on staff availability was that it could lead to not utilizing the improvements within technology. If the improvements are not taken into account when doing the scheduling, the improvements won't increase the efficiency of the hospital.

One of the areas where technological improvement is fast is the field of Magnetic Resonance Imaging (MRI), where scan times have been steadily reduced during the last decades [4]. An MRI scanner uses a magnetic field to generate images of the body [5]. Using new materials to generate the magnetic field is one example that can improve the MRI scan time, this can improve the signal-to-noise ratio and in turn shorten the image acquisition time [6, 7].

Another inefficiency that was identified in the governmental study from 2016 [1], was that the availability of competences varying over time can be a risk for patient safety. It is important to have a certain baseline of competences available at all times, and this is something that also must be taken into account when scheduling.

Effective use of different types of imaging scanners, such as MRI and CT scanners, is important to hospitals since these scanners are very expensive. Keeping these machines up to date using the latest technologies also increases the cost as healthcare becomes more and more dependent on advanced technologies [8, 9, 10].

A scanner being unused will generate a loss for the hospital and there have been much research done on how to schedule examinations to ensure that the scanners are used as much as possible [11, 12, 13]. Examination scheduling is highly coupled with the availability of the staff, and therefore the scheduling of the staff. A thorough understanding of the available resources, i.e. the machines and employees, is required for a well-functioning examination scheduling process. A study from 2013 [11] at a radiology department showed that a heuristic algorithm for finding the optimal lengths of examination slots and when to schedule examinations increased the scanner utilization significantly, compared to scheduling examinations manually. What was found was that it was very important to fit the scheduling algorithm to the current scheduling process, e.g. keeping the same resolution as the manual scheduling, in this case 15 minutes, and to utilize the radiologists' knowledge to classify the examinations with regards to examination type and the mobility of the patient before the examination was fed to the scheduling algorithm [11].

Lean methodology [12] has been implemented in radiology departments, with the aim to standardize processes and remove unnecessary steps. This methodology was first used in the car manufacturing industry, and was detailed in 1988 [14] to describe the Toyota Production System. When applying this to a radiology department, the standardization of processes can make it easier to schedule examinations, since the aim of standardization is to reduce the variation between examinations. One case study showed that setting the examination time to always be 45 minutes, rather than to be dependent on the examination type, improved the time it took to schedule an examination and also increased MRI scanner utilization [13]. This study was using lean methods and it showed that the variation in examination duration between different examination types can make scheduling complicated if this is taken too much into consideration [13].

The ability to compare scanner utilization between hospitals, in order to learn from each other, has been researched [15]. In one study [15], a method was developed that used the DICOM [16], Digital Imaging Communication in Medicine, protocol, which is a widely used standard for storing imaging data, that could be used to specify certain efficiency metrics that could be compared between hospitals. Some of the efficiency metrics suggested were examination duration, time between examinations, time between image series and scanner utilization [15].

Attempts to model the patient flow through a hospital unit have been done, and models using queueing theory are the most common [17]. The variation due to individual patient profiles and treatment decisions taken by physicians can make it difficult to model the patient flow well [17]. Therefore, standardization of care, for example with the help of lean methodologies, can reduce this variation and make it easier to model the patient flow. Standardization of care can also ensure that all patients get equal treatment, which patients are stated by Swedish law to get [18]. Standardization of care can also simplify the training of new physicians as well as make it easier to move patients between hospitals. For example if a physician is ill and the examination needs to be rescheduled, the examination can be performed at a different hospital by a different physician without affecting the examination outcome or the examination duration, which will make it easier to schedule the

examination as well.

In this thesis, the MRI Unit at Sahlgrenska Hospital will be studied. Sahlgrenska Hospital, together with Mölndal Hospital and Östra Hospital, form Sahlgrenska University Hospital, which is situated in Västra Götaland, Sweden. These hospitals are all part of Västra Götaland Regional Council (VGR). Sahlgrenska Hospital is the largest hospital in VGR, and there are three other hospital groups in VGR [19]. The population of VGR is 1.75 million and is expected to increase steadily over the coming years [20]. In VGR, the waiting times for patients that need specialized care were longer compared to the national average during 2019 [21], and the number of patients waiting for 90 days or more for their first visit for specialized care increased during 2019 [21].

1.1 Aim

The aim of this exploratory study is to investigate how the nurse staffing at a hospital unit affects the examination rate. A case study will be done at the MRI unit at Sahlgrenska Hospital to answer the aim. The research questions are

1. What is the examination rate of the MRI unit?

2. How much are the examination rooms open?

3. How does the number of hours the examination rooms are open explain the examination rate?

4. How is the examination rate affected by demand of care not being considered when scheduling?

Since the demand of care is not taken into consideration when scheduling at the MRI unit, the time the employees' spend on examinations will likely vary. A hypothesis for the third question is then that the correlation between the examination rooms being staffed and the examination rate is low.

1.1.1 Delimitations

The examination rooms were staffed by one or two employees. The room smr1 was always staffed with one employee, the other rooms generally had two employees, only in a few cases did one employee work alone. Because of this, the time the room was open was investigated, and the number of employees that were staffed to the room was ignored.

1.1.2 Societal, ethical, and ecological concerns

There are no societal, ethical and ecological concerns that needs to be considered for this thesis. No employee data will be used in this thesis and no data from the examinations will be used that could link any examination to a patient.

2

The MRI Unit

The hospital unit that was chosen to study was the MRI unit at Sahlgrenska University Hospital in Gothenburg, Sweden. Being a small unit made it a good fit for the scope of this thesis. The scheduling process was representative of the general Swedish model in that it was mainly based on the availability of staff rather than the demand of care.

This chapter describes the MRI unit and is divided into three sections. The first section gives an overview of the processes involved when an MRI examination is undertaken. The next section describes the examination rooms at the unit and how they differ from each other. The third section describes the scheduling process at the unit.

2.1   Overview of the MRI examination process

There are three main processes that take place when a patient undergoes an MRI examination at Sahlgrenska hospital. These are the booking process, the examination process and the analysis process. These processes will be described below and are illustrated in Figures 2.1 to 2.3.

The booking process starts with a referral, which can come from several different places. For out-patients, the referrals usually come from the primary care system, and for in-patients the referrals come from the units at Sahlgrenska that is responsible for the patient. The booking staff at the MRI unit schedules an examination time, which is dependent on the priority of the referral. The different referral types that determines this priority are described in Section 2.1.1. There are one or two employees that work as MRI coordinators that work together with the booking staff. They have an overview of the examination rooms and the waiting examinations and apart from helping to schedule the examinations, they can redirect staff to other examination rooms if needed. They also handle contact with other units at the hospital, for example to ensure that the needed patient data for the examination exists in the data system that is used when performing the examination. After the examination is scheduled, out-patients are contacted through mail or Vårdguiden 1177, which is a national online portal that provides services related to Swedish healthcare. Information about the examination procedure is given as well as the examination time. The patient then confirms the examination time through phone, e-mail or 1177. In-patients do not confirm their examination times, this is handled

by the unit that cares for the patient. In-patients are usually transported to the examination room in a hospital bed by janitors working at the hospital. Scarcity of janitors makes it difficult to anticipate how long it will take to transport the patient to the examination, making it harder to schedule examinations for in-patients that need to be done quickly.

Before the examination starts, certain information about the patient is needed, such as if they have any metal in their bodies, e.g. a pacemaker, or if they are allergic to any contrast mediums. Out-patients are supposed to fill this in themselves, and bring to the examination. The patient first comes to the reception and is then prepared for the examination, which includes changing into examination clothes and removing any external metal objects. If contrast medium is going to be used in the examination, which is used to enhance certain parts inside the body in the resulting MRI images, an intravenous needle is placed and connected to the contrast medium. Then the patient is placed in the MRI scanner and the examination starts. Usually, one radiation nurse inserts the needle and places the patient in the scanner while another radiation nurse prepares the examination protocol for the scanner. Depending on the examination type, different scan protocols are used. The referral specifies what information is sought from the scan, and the radiology nurse operating the MRI scanner selects the scanning protocol, or multiple scanning protocols, that will give these results. The scan is then started, and the radiology nurses monitor the scan, ensuring that the images are of good enough quality. An example of something that can lower image quality is patient movement during the scan. After the scan is finished, the patient is helped out of the machine and exits the scan room. If the patient is an in-patient, they are taken back to their hospital unit. The MRI images are signed by the radiology nurse(s) and uploaded for analysis.

The MRI images are analyzed by a radiologist. Images from an examination with referral type *a* (emergency examination) or *1* (examination to be done within 1 week), are always analyzed by radiologists at Sahlgrenska hospital. Images with other referral types are analyzed at Sahlgrenska hospital if there are available radiologists, otherwise they are sent abroad, usually to Spain or Australia, for analysis. This is mainly done due to a shortage of radiologists at Sahlgrenska hospital. Another reason to send the analysis to Australia can be if the analysis needs to be done during the night, daytime radiologists can then be available in Australia. The analysis of the MRI images are dictated by the radiologist and are then either written down by a secretary or automatically transcribed. Finally, the analysis is sent to the physician/unit that sent the original referral and the patient is notified if needed by this physician/unit.

Part of the referrals to the radiology department at Sahlgrenska hospital are sent to external private companies for examinations. This is due to the department not being able to handle the volume of examinations that are needed. In these cases, usually both the MRI scan and analysis is performed by the external part, and the analysis is then sent back to the person/unit that sent the referral.
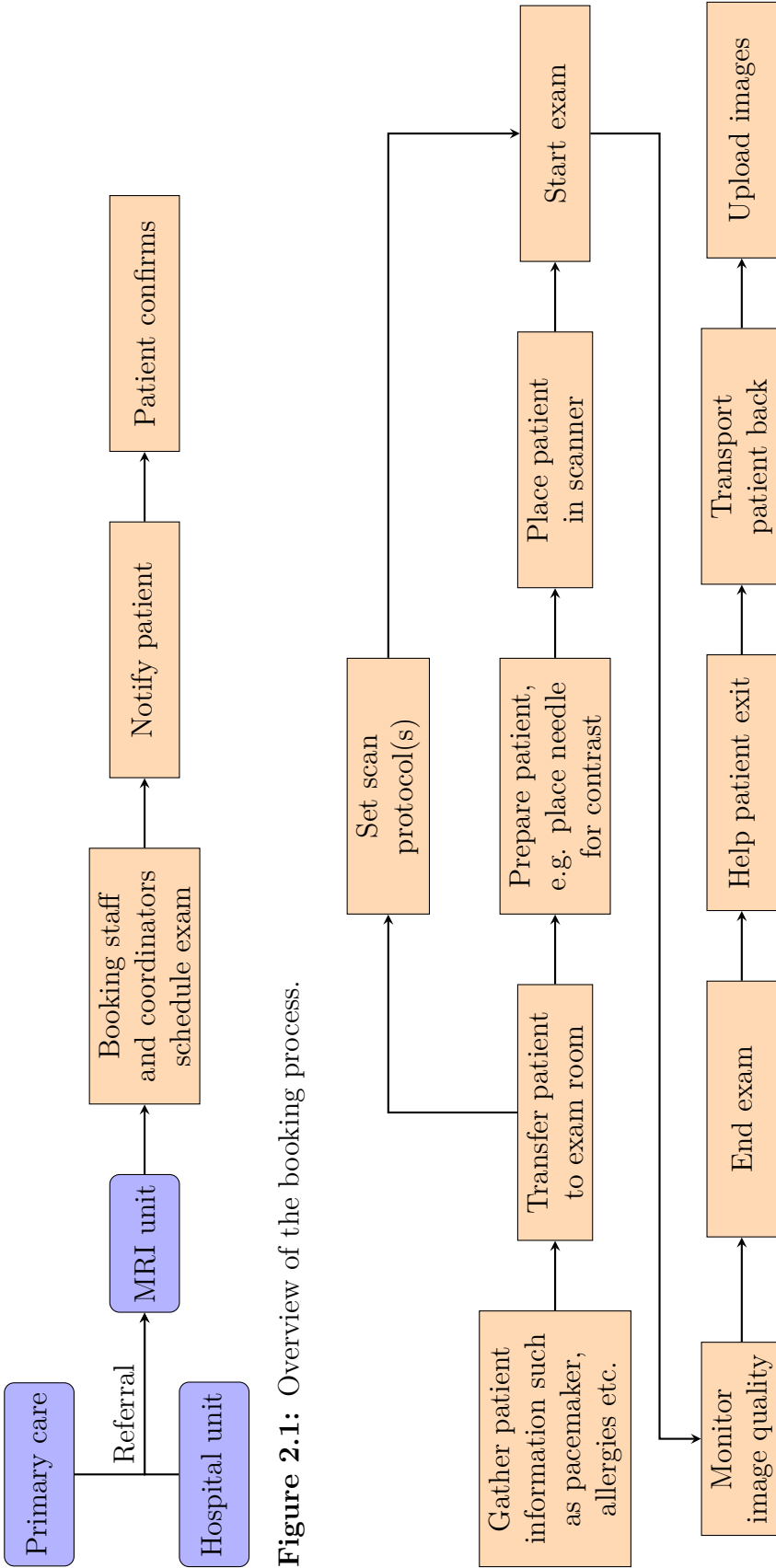
Figure 2.1: Overview of the booking process.

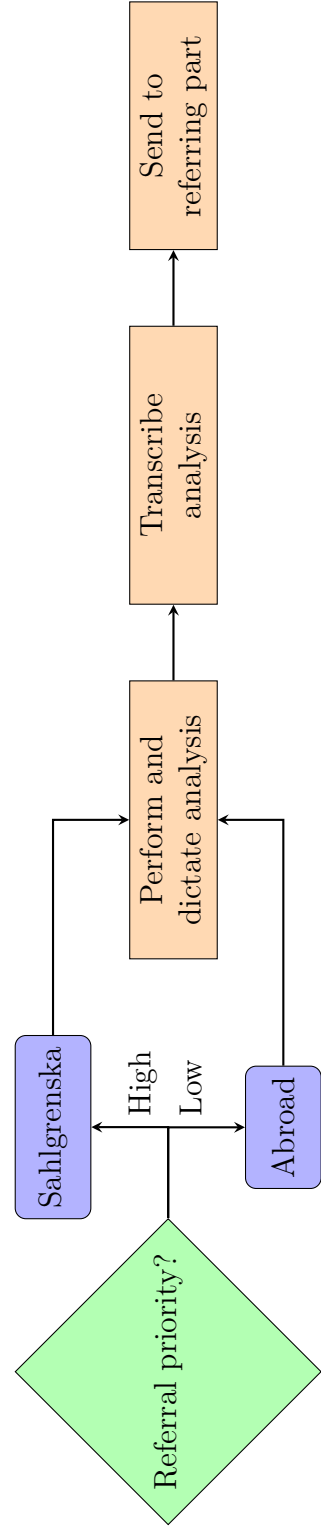**Figure 2.2:** Overview of the examination process.

Figure 2.3: Overview of the analysis process.

2.1.1 Referral types

There are 14 different referral types used at the MRI unit, and these determine the priority of the examinations. Table 2.1 list these codes and their descriptions. Some of the codes have similar descriptions, such as *0* and *9v* as well as *3* and *9*, which lead to ambiguities when to use which. The referral types used could also deviate a bit from their description, for example, sometimes referral type *1* was used for examinations that could wait longer than one week, even though this code should be used for examinations that should be done within one week. This means that the referral type gave an approximate understanding of the priority of the examination, but they could deviate a bit from their original meaning. Each referral type will now be explained in detail.

Table 2.1: The referral types used at the MRI unit and their descriptions.

Referral type	Description
0	Stand by
1	Within 1 week
2	Within 2-3 weeks
3	Within a certain month
9	Less than a month
9k	The remittent re-schedules the examination
9v	Wait
9p	The patient cancelled the appointment
fo	Research
svf	Standardized course of care
a	Emergency
e	Elective
d	Definitely booked
x	External supplier

The referral type *0*, meaning stand by, is used when an examination is not urgent and can be done when no other higher prioritized examinations are waiting. This is usually used for in-patients. The codes *1*, *2*, *3* and *9* mean that the examination should be done within 1 week, 2-3 weeks, within a certain month and less than a month. Examinations with referral type *9k* are put on hold and await the instance that sent the referral to the MRI unit to re-schedule the examination. Referral code *9v* is used for the same examinations as *0*. *9p* means that the patient cancelled the appointment, and the MRI unit waits for the referral to be sent again. Examinations that are part of research have the referral type *fo*. Standardized course of care, referral type *svf*, is used for certain cancer examinations and these examinations are prioritized by being given a set number of hours each week, independent on how many of these examinations that are waiting. Emergency examinations, i.e. examinations that need to be performed immediately, have the referral type *a*. Examinations that are scheduled in advance by the hospital are called elective and have the referral type *e*. The referral type *d* was almost never used and it was not clear when it was supposed to be used. Referral code *x* means that an external

supplier was used to perform the examination, i.e. the MRI scanner and/or the staff that performed this examination was not part of Sahlgrenska hospital.

2.2 The examination rooms

In this section, the nine examination rooms at the MRI unit will be described. The differences between the rooms that will be described are the number of examinations that are performed, the types of examinations and the referral types of the examinations. The rooms will be described individually, starting with the rooms that had the most examinations performed during December 2 2019 to February 28 2020. The examination types and referral types for all the rooms combined will also be described. The top four examination and referral types will be described for each room and for the rooms combined. The examination types will be written in both Swedish and English, in the data the Swedish names are used.

There were different types of MRI scanners in the examination rooms and the employees needed to be trained on each scanner before they were allowed to operate it. Not all employees were trained on all MRI scanners and thus some employees could not work in all examination rooms.

s18

580 examinations were performed in examination room s18 during the studied time period and was the room that had most examinations performed. Table 2.2 show the total number of examinations performed in this room as well as the four most common examination types in s18. The most common examination type was the *brain* examination, 306 examinations of this type were performed. The second most common type was *back full*, 66 were done of this type. The third and fourth most common were *lumbar region* and *back neck* examinations with 22 and 20 examinations done respectively.

Looking at the referral types for s18, which are listed in Table 2.3, the most common was *a*, 227 examinations of this type were done. The second most common was *0*, with 180 examinations performed of this type. The third and fourth most common were *1* and *9v*, with 85 and 29 examinations performed respectively.

Table 2.2: The top examination types in room s18.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	580
MRI Brain	MR Hjärna	306
MRI Back full	MR Rygg helrygg	66
MRI Lumbar region	MR Rygg ländrygg	22
MRI Back neck	MR Rygg halsrygg	20

Table 2.3: The top referral types in room s18.

Referral type	Total
All referral types	580
a (emergency)	227
0 (standby)	180
1 (within a week)	85
9v (standby)	29

s17

Room s17 was the examination room with the second most examinations performed, 505 in total. The most common examination types can be seen in Table 2.4, the most common type was the *heart examination*, 190 examinations were done of this type. The second most common examination type was the *brain* examination with a total of 84 examinations. The third and fourth most common examinations were *pelvis leg angiogram* and *back full*, with 56 and 35 examinations performed respectively.

Referral type *1* was the most common type in room s17, 151 examinations of this type were performed, which can be seen in Table 2.5. The second most common was type *2*, with 107 examinations performed. The third and fourth most common examination types were *0* and *9v*, with 84 and 63 examinations respectively.

Table 2.4: The top examination types in room s17.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	505
MRI Heart	MR Hjärta	190
MRI Brain	MR Hjärna	84
MRI Pelvis leg angiogram	MR Bäcken-benangiografi	56
MRI Back full	MR Rygg helrygg	35

Table 2.5: The top referral types in room s17.

Referral type	Total
All referral types	505
1 (within a week)	151
2 (within 2-3 weeks)	107
0 (standby)	84
9v (standby)	63

r51

Tables 2.6 and 2.7 show the most common examination types and referral types for room r51. In total, 490 examinations were performed in r51, and the most common examination type was the *prostate and vesicles* examination. 194 examinations

of this type were performed. *Brain* examinations were the second most common examination type, 146 examinations of this type were performed. The third and fourth most common examination types were *liver* and *lower abdomen* examinations, 74 and 14 examinations were done of each respectively.

The most common referral type in r51 was *fo*, examinations done as part of research. 312 such examinations were done. The second most common referral type was *1*, 53 examinations of this type were performed. The third and fourth most common referral types in r51 were *9v* and *2,* with 53 and 28 examinations performed respectively.

Table 2.6: The top examination types in room r51.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	490
MRI Prostate and vesicles	MR Prostata och vesiklar	194
MRI Brain	MR Hjärna	146
MRI Liver	MR Lever	74
MRI Lower abdomen	MR Nedre delen av buken	14

Table 2.7: The top referral types in room r51.

Referral type	Total
All referral types	490
fo (research)	312
1 (within a week)	53
9v (standby)	53
2 (within 2-3 weeks)	28

s19

A total of 458 examinations were performed in room s19, the most common examination types and referral types can be seen in Tables 2.8 and 2.9. The *brain* examination was the most common examination type in s19, 262 examinations of this type were performed. The second most common was *back full*, 32 examinations were done of this type. The third and fourth most common examination types were *head face throat* and *liver*, 28 and 20 examinations were done of each type respectively.

Examinations of referral type *1* were the most common in s19, 121 examinations of this type were performed. *9v* was the second most common referral type with 107 examinations performed of this type. The third and fourth most common referral types were *2* and *3*, 72 and 38 examinations were done respectively.

Table 2.8: The top examination types in room s19.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	458
MRI Brain	MR Hjärna	262
MRI Back full	MR Rygg helrygg	32
MRI Head face throat	MR Huvud ansikte hals	28
MRI Liver	MR Lever	20

Table 2.9: The top referral types in room s19.

Referral type	Total
All referral types	458
1 (within a week)	121
9v (standby)	107
2 (within 2-3 weeks)	72
3 (within a month)	38

s14

The most common examination types and referral types in room s14 are shown in Tables 2.10 and 2.11. 425 examinations were performed in total in s14 and the most common examination type was the *brain* examination, 194 examinations of this type were done. The *prostate and vesicles* examination was the second most common examination type with 51 examinations performed. The third and fourth most common examination types were *head face throat* and *liver*, 38 and 25 examinations were performed of each.

Referral type *1* was the most common referral type for examinations performed in s14, 116 examinations of this type were performed. The second most common type was *e*, with 84 examinations. The third and fourth most common referral types were *9v* and *2*, with 77 and 63 examinations performed of each.

Table 2.10: The top examination types in room s14.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	425
MRI Brain	MR Hjärna	194
MRI Prostate and vesicles	MR Prostata och vesiklar	51
MRI Head face throat	MR Huvud ansikte hals	38
MRI Liver	MR Lever	25

Table 2.11: The top referral types in room s14.

Referral type	Total
All referral types	425
1 (within a week)	116
e (elective)	84
9v (standby)	77
2 (within 2-3 weeks)	63

s13

Tables 2.12 and 2.13 show the most common examination types and referral types for room s13. In total, 394 examinations were performed in s13, and the most common was the *brain* examination, 120 examinations of this type were performed. The second most common examination type was the *prostate and vesicles* examination, 79 of this type were done. The third and fourth most common examination types were *mammary glands* and *abdomen (unspecified)*, 54 and 40 examinations were performed of these two respectively.

The most common referral type in s13 was *9v*, 122 examinations of this type were performed. Referral type *1* was the second most common with 84 examinations. The third and fourth most common referral types were *fo* and *2*, 60 and 44 examinations of these types were performed respectively.

Table 2.12: The top examination types in room s13.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	394
MRI Brain	MR Hjärna	120
MRI Prostate and vesicles	MR Prostata och vesiklar	79
MRI Mammary glands	MR Bröstkörtlar	54
MRI Abdomen (unspecified)	MR Buk (ospecificerat)	40

Table 2.13: The top referral types in room s13.

Referral type	Total
All referral types	394
9v (standby)	122
1 (within a week)	84
fo (research)	60
2 (within 2-3 weeks)	44

smr1

299 examinations were done in total in examination room smr1, Tables 2.14 and 2.15 show the most common examination types and referral types for this room.

The most common examination type was *radiation therapy prostate and vesicles*, 157 examinations of this type were performed. The second most common type was *radiation therapy head face throat* with 69 examinations. The third and fourth most common examination types were *radiation therapy brain* and *radiation therapy brachy gyn cervix*, with 54 and 14 examinations of each type.

All but one of the examinations in smr1 were of referral type *e*, 298 examinations of this type were performed. One examination of referral type *0* was done. No examinations of other referral types were performed in smr1.

Table 2.14: The top examination types in room smr1. Radiation therapy is abbreviated as Rad.ther.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	299
MRI Rad.ther. prostate and vesicles	MR Strålbeh Prostata och vesik	157
MRI Rad.ther. head face throat	MR Strålbeh Huvud ansikte hals	69
MRI Rad.ther. brain	MR Strålbeh Hjärna	54
MRI Rad.ther. Brachy gyn cervix	MR Strål Brachy Gyn cervix	14

Table 2.15: The top referral types in room smr1.

Referral type	Total
All referral types	299
e (elective)	298
0 (standby)	1
a (emergency)	0
1 (within a week)	0

r52

The most common examination types and referral types for room r52 can be seen in Tables 2.16 and 2.17. 275 examinations in total were done in r52, and the most common examination type was the *brain* examination. 105 *brain* examinations were done in this room. The second most common examination type was the *colon* examination, 23 examinations of this type were performed. The third and fourth most common examination types were *prostate and vesicles* and *brain angio*, 22 and 18 examinations of each type were done.

The most common referral type in r52 was *1*, 89 examinations of this type were performed. The second most common type was *9v* with 77 examinations. The third and fourth most common examination types were *2* and *fo*, 37 and 27 examinations were done respectively.

Table 2.16: The top examination types in room r52.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	275
MRI Brain	MR Hjärna	105
MRI Colon	MR Colon	23
MRI Prostate and vesicles	MR Prostata och vesiklar	22
MRI Brain Angio	MR Hjärna Angio	18

Table 2.17: The top referral types in room r52.

Referral type	Total
All referral types	275
1 (within a week)	89
9v (standby)	77
2 (within 2-3 weeks)	37
fo (research)	27

s23

s23 was the room with the fewest examinations performed, 11 examinations were performed in total during the studied time period. The most common examination types and referral types for s23 are shown in Tables 2.18 and 2.19. Five *brain* examinations were performed in s23, this was the most common examination type. The remaining examinations were *lower leg* and *pelvis leg angiogram* with three examinations of each type.

The most common referral type in s23 was *fo*, five examinations of this type were performed. The second most common referral type were *9k* with 3 examinations of this type. The third and fourth most common examination types were *1* and *0*, with one examination of each type.

Room s23 differed from the other rooms in that it was used for intraoperative surgery. This means that the MRI scanner in s23 was used to monitor the patient during surgery, rather than capturing images that would later be used to analyze the patient.

Table 2.18: The top examination types in room s23.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	11
MRI Brain	MR Hjärna	5
MRI Lower leg	MR Underben	3
MRI Pelvis leg angiogram	MR Bäcken-benangiografi	3
MRI Heart	MR Hjärta	0

Table 2.19: The top referral types in room s23.

Referral type	Total
All referral types	11
fo (research)	5
9k (wait for remittent to schedule)	3
1 (within a week)	1
0 (standby)	1

All rooms combined

Tables 2.20 and 2.21 show the most common examination types and referral types when the examinations from all the rooms are combined. A total of 3437 examinations were performed during the studied time period. The most common examination type was the *brain* examination, 1222 examinations were done. The second most common examination type was the *prostate and vesicles* examination with 363 examinations. The third and fourth most common examination types were *heart* and *liver*, 197 and 181 examinations were done of each respectively.

The most common referral type for all rooms combined was *1*, 700 examinations of this referral type were done. Referral type *9v* was the second most common type with 528 examinations. The third and fourth most common referral types were *fo* and *e*, 450 and 437 examinations were done of each.

Table 2.20: The top examination types in all rooms.

Examination type	Examination type Swedish	Total
All examination types	Alla undersökningstyper	3437
MRI Brain	MR Hjärna	1222
MRI Prostate and vesicles	MR Prostata och vesiklar	363
MRI Heart	MR Hjärta	197
MRI Liver	MR Lever	181

Table 2.21: The top referral types in all rooms.

Referral type	Total
All referral types	3437
1 (within a week)	700
9v (standby)	528
fo (research)	450
e (elective)	437

2.3   The scheduling process

The focus of the scheduling process at the MRI unit at Sahlgrenska is ensuring that everyone in the staff get the correct amount of hours and that the staff is placed in

a room with an MRI scanner they have the competence to operate, since different rooms can have different MRI scanners. The schedule is done weekly, at the end of the week the schedule for the next week is presented. There is always one room designated for emergency examinations and this room is always staffed with two employees for the whole day. As many examination rooms as possible should be open and in general two people work in the same room, smr1 being the exception with only one person. Due to e.g. illness, sometimes only one person work in a room. The number of waiting referrals or how much the rooms were used the previous week for example is not used to determine in which rooms to place staff.

Sometimes rooms that were not scheduled to be staffed could be opened when an examination was needed to be performed in that room and staff was available. Doing so could make it harder to use the time the room was open to its full extent since it would be difficult to schedule several examinations tightly after each other compared to a room that was scheduled in advance to be open.

The working hours for the employees were between 7:30 and 16:15 Mondays to Fridays, with a lunch break between 12:00 and 13:00. Once per week, usually on Wednesdays or Thursdays, there was a 30 minute staff meeting in the morning and on this day the staff started their regular work at 8:00 instead of 7:30. Usually an employee worked in the same examination room throughout the day, but in some cases they switched rooms during the day. When this happened, usually an employee was in one room in the morning until lunch and in another room after lunch. It also happened that individual employees had meetings or training sessions during their regular working hours, and this was registered in the schedule as well.

3

Data Gathering

The following sections describe how the data researched in this thesis was selected, the way it was structured and the methods that were used to understand the data.

3.1 Data selection

The time period that was studied was December 2 2019 to February 28 2020. This gave a total of 65 working days, since the MRI unit was not open during Saturdays and Sundays. This date range was chosen since it reflected how the unit worked at the time of writing, it included one holiday period and a limited data set was good for an exploratory study. The schedule data and the examination data will be explained separately in the following two sections.

3.1.1 Schedule data

The schedule was done weekly and for each examination room it showed which employees worked there and during what times, and meetings and training sessions for individual employees were also registered. The schedule was usually updated throughout the week to reflect any changes such as employees being home from work. The latest updates of the schedules were used in this thesis. To understand the information that was found in the schedule, a made-up example of one work day will be shown and analyzed.

A made-up example of the schedule for one day is shown in Table 3.1. If no times were specified for a room, the employees worked from 7:30-16:15 in this room, with a lunch break at 12:00-13:00. The smallest time unit that was used to indicate the employee's work times in the schedule was five minutes. In Table 3.1, each of the capital letters A to M corresponds to one employee. In the example, the rooms s14 and s18 are staffed with two employees throughout the whole day. Rooms s13 and s23 are marked as closed, meaning that no employees worked in these two rooms anytime during the day. In room s17, employee C was scheduled to work in this room during the afternoon, i.e. 13:00-16:15, and employee D during the whole day. In room s19, employees G and H worked in this room during the entire day except between 10:00 and 11:00, when only employee H was in the room and employee G was in a meeting. Room r51 was only open during the morning, 7:30-12:00, and were staffed by employees I and J during this time. Similarly to s19, room r52 was

staffed by two employees throughout the day apart from 15:00-16:15 when it was only staffed by employee K, employee L was in training during this time. Finally, room smr1 was staffed throughout the whole day by employee M.

Table 3.1: Example of how the schedule could look on one day. Each capital letter A to M corresponds to one employee.

Room	Employee information
s13	Closed
s14	A, B
s17	C (Afternoon only), D
s18	E, F
s19	G (Meeting 10:00-11:00), H
r51	I (Morning only), J (Morning only)
r52	K, L (Training 15:00-16:15)
s23	Closed
smr1	M

3.1.2 Examination data

The examination data was taken from the ADAPT database, which was used at the radiology department at Sahlgrenska at the time of writing. The data was stored in Excel files, one file per month, and for each examination that was performed, multiple fields of information were stored. The data held all radiology examinations, not just the MRI examinations, for Sahlgrenska hospital as well as two other hospitals, Mölndal hospital and Östra hospital. The fields and their descriptions are shown in Table 3.2. Each field will now be explained in detail.

The field *Vp* is a unique digit ID that can be used to search for the examination in other databases. *Lev* describes both the hospital and which part of the hospital that performed the examination. The field *Kund* shows who ordered the examination, i.e. the customer. The field *Motpart* also shows who ordered the examination, but with another code that is used for accounting and statistics. *Enhet* is connected to *Lev*, it gives a more detailed description of which part of the hospital unit that performed the examination. *Sektion* describes which section of the hospital that performed the examination. The field *Rum* shows which examination room the examination was performed in. *U.S. Kod* is a code describing the examination type, exactly what this code meant was not found. *Klartext* is the examination type described in Swedish, which was used to describe the examination rooms in Section 2.2. *Remisstyp* is the referral type, also used to describe the examination rooms in Section 2.2. The field *Aktivitet* was very rarely used, when it was used it was mainly to indicate that the examination needed to be re-scheduled or that the patient did not show up. The difference between fields *Tid Remix* and *Tid Remiss* was not clear, both fields held a date and time and the time for *Tid Remiss* was usually a few minutes after *Tid Remix*. The data system that held the referrals was called Remix, so both these fields described when the referral was entered into this system. *Start tid* held the date and time of the examination start. *Slut tid* held

the date and time of the examination end. The field *Utl tid* held the date and time of when the radiologist's analysis was registered. The field *Ank.tid-Rem.tid* showed the time difference between the fields *Start tid* and *Remiss tid*, i.e. the duration from when the referral was registered to the start of the examination. Similarly, *Slut.tid-Ank.tid* held the duration between *Start tid* and *Slut tid*, i.e. the duration of the examination. *Svar.tid-Ank.tid* showed the time difference between *Utl tid* and *Start tid*, i.e. the time from the start of the examination to the radiologist's analysis was registered. Finally, *Svar.tid-Rem.tid* held the duration from *Remiss tid* to *Utl tid*, i.e. the time from the registration of the referral to the registration of the radiologist's analysis. The resolution of all fields with time values was in minutes, both the date and time values and the time durations.

Table 3.2: The field names that were stored for each performed examination and their descriptions.

Field name	Description
Vp	A unique ID for each examination
Lev	The hospital unit that performed the examination
Kund	The customer that ordered the examination
Motpart	A second code for the customer, used for accounting
Enhet	Which part of the unit that performed the examination
Sektion	The section of the hospital that performed the examination
Rum	The examination room
U.S. Kod	Code that describes the examination
Klartext	Examination type
Remisstyp	Referral type
Aktivitet	Comment if something needed to be done with the referral
Tid Remix	Date and time of when the referral was registered
Remiss tid	Date and time of when the referral was registered
Start tid	Date and time of the examination start
Slut tid	Date and time of the examination end
Utl tid	Date and time of when the radiologist's analysis was registered
Ank.tid-Rem.tid	Time difference between *Start tid* and *Remiss tid*
Slut.tid-Ank.tid	Time difference between *Slut tid* and *Start tid*
Svar.tid-Ank.tid	Time difference between *Utl tid* and *Start tid*
Svar.tid-Rem.tid	Time difference between *Utl tid* and *Remiss tid*

The examinations that were extracted from the data were MRI examinations that were done at Sahlgrenska hospital, during the studied time period. To be able to compare these examinations to the schedule, only examinations that were done during the employees' regular working hours were extracted. To fulfil the date and time requirements, the following conditions had to be satisfied:

- The date of *Start tid* must be between December 2 2019 and February 28 2020, inclusively;

- The day corresponding to the date of *Start tid* must be a weekday, i.e. not a

Saturday or a Sunday;

- The time of *Start tid* must be after or on 7:30;

- The time of *Slut tid* must be before or on 16:15;

- The date of *Start tid* and the date of *Slut tid* must be the same.

The last condition ensured that the examination did not span multiple days, this should never happen in reality but sometimes happened due to erroneous data registration, usually when the staff forgot to end the examination in ADAPT and realized this the day after and registered it in ADAPT then.

To extract the examinations that were done at the radiology department at Sahlgrenska hospital, the field *Lev* had to be one of *I11100*, *I11101*, *I11102*, *I11103*, *I11104* and *I11105*. These values corresponded to all the different units that were part of the radiology department at Sahlgrenska hospital. Their meanings are shown below, first as their original definition in Swedish and then their explanation in English. Note that not all MRI examinations were performed by *I11102*.

- *I11100* - Neuro, Neurology;

- *I11101* - MSK (orto), Musculoskeletal (Orthopaedics);

- *I11102* - MR, MRI;

- *I11103* - Embo, Embolic;

- *I11104* - UGK, Urogynecology surgery;

- *I11105* - Thorax, Thorax;

Next, only MRI examinations should be extracted. To satisfy this, the field *Klartext*, had to contain the text string *MR*. The last condition to be satisfied was ensuring that the examination was performed in one of the nine MRI examination rooms that were part of the MRI unit, described in Section 2.2. I.e., the value of the field *Rum* had to be one of *s13*, *s14*, *s17*, *s18*, *s19*, *s23*, *r51*, *r52* and *smr1*.

3.2 Key Performance Indicators

To compare the schedule with the examinations, certain Key Performance Indicators (KPIs) were defined for each room and day. These KPIs described how many hours a room was open per day, how many examinations were done per day, how much of the staff's time was spent on performing examinations and how long the average examination duration was per day. This was also computed as a total for all the rooms. Below follows a description of each KPI and how they were computed using the schedule and examination data.

3.2.1 Number of examinations

The number of examinations were computed for each individual room and day. This was the sum of the number of examinations where the date of the field *Start*

tid matched the given day.

3.2.2   Number of hours a room was open

An examination room was defined as open if it had at least one employee scheduled to be in this room at a given time. The number of employees did not matter as long as there were more than one. Using the schedule example in Table 3.1, rooms s13 and s23 were both closed and thus would be open 0 hours on that day. Rooms s14 and s18 were both staffed by two employees during the entire work day, meaning that these rooms were open for 7 hours and 45 minutes on that day. Rooms s17, s19 and r52 were also open 7 hours and 45 minutes, since during the entire day there was at least one employee in these rooms. Room r51 was open in the morning only, i.e. between 7:30 and 12:00, and was therefore open for 4 hours and 30 minutes. Room smr1 had one employee staffed to it during the entire day, and was therefore open for 7 hours and 45 minutes.

A similar KPI that could have been used instead of the number of hours a room was open is the total number of employee hours per room. For example, in Table 3.1, rooms s14 and smr1 would have been open the same number of hours but s14 would have had two employees working 7 hours and 45 minutes, i.e. 15 hours and 30 minutes in total, and smr1 would have had 7 hours and 45 minutes of total employee hours. The reason for using the number of hours a room was open rather than the total number of employee hours per room was that very seldom did the number of employees in a room change from day to day. All rooms except smr1 almost always had two employees working when they were open, and smr1 was always staffed with one employee when it was open.

3.2.3   Number of hours used for examinations

The number of hours used for examinations was the total duration of all examinations that were performed in a given room on a given day. The examination duration for one examination was given by the value of the field *Slut.tid-Ank.tid*, see Table 3.2, and was converted to hours.

3.2.4   Ratio of the staff's time used for examinations

To compute the ratio of the staff's time used for examinations for a given room and day, the KPI for the number of hours used for examinations was divided by the KPI for the number of hours the room was open. If all of the employees' time was used for examinations, this KPI would be 1. If none of the employee's time was used for examinations, i.e. the employees were scheduled to a room where no examinations were done during the day, this KPI would be 0. When computing this KPI for each room, only days when the room was open was used. On days when the room was closed this KPI was not defined.

3.2.5 Average examination duration

For each room and day the average examination duration was computed. To do this, the value for the field *Slut.tid-Ank.tid* was used, see Table 3.2, after it was converted to minutes. This KPI would thus be the average of all the examination durations for a given room and day. If no examinations were done in a room on a given day, this KPI was not defined for this room and day.

3.3 Pearson's correlation coefficient

When computing the correlation between the number of hours the rooms were open and the number of examinations that were performed, Pearson's correlation coefficient, $\rho_{X,Y}$, was used. For two variables X and Y, the Pearson correlation coefficient is defined as

$$\rho_{X,Y} = \frac{\mathrm{cov}(X,Y)}{\sigma_X \sigma_Y},$$

where $\mathrm{cov}(X,Y)$ is the covariance between the variables X and Y, and σ_X and σ_Y are the standard deviations of X and Y. When applying this to a sample, the Pearson correlation coefficient is approximated using the sample covariance and sample standard deviations, yielding

$$\rho_{X,Y} \approx \frac{s_{xy}}{s_x s_y},$$

$$s_{xy} = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}),$$

$$s_z = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (z_i - \bar{z})^2},$$

where n is the number of data points in the sample. Common intervals for interpreting the correlation coefficient [22] are shown in Table 3.3, which were used in this thesis.

Table 3.3: Intervals for interpreting the size of the correlation coefficient.

Size of correlation	Interpretation
0.90 to 1.00 (-0.90 to -1.00)	Very high positive (negative) correlation
0.70 to 0.90 (-0.70 to -0.90)	High positive (negative) correlation
0.50 to 0.70 (-0.50 to -0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (-0.30 to -0.50)	Low positive (negative) correlation
0.00 to 0.30 (-0.00 to -0.30)	Negligible correlation

4

Results

This chapter details the results that were found to answer the research questions. Section 4.1 shows the examination rate of the MRI unit. Section 4.2 details how many hours the examination rooms were open per day and Section 4.3 uses the results from the previous two sections to show how well the examination rate was explained by the number of hours the rooms were open. Finally, Section 4.4 details three sources other than the number of hours the rooms were open that could potentially affect the examination rate.

The data included one holiday period, between December 24 2019 and January 6 2020, and here the examination rate as well as the number of hours the rooms were open went down. Therefore, the data was divided into two parts, which will be referred to as the *regular work days* and the *holiday period.* The regular work days consisted of the days between December 2 2019 and December 23 2019 and between January 7 2020 and February 28 2020, inclusively. The holiday period consisted of the days between December 24 2019 and January 6 2020, inclusively. The regular work days consisted of 55 days and the holiday period of 10 days. In sections 4.1 and 4.2, which describes the examination rate and the daily number of hours the rooms were open, the regular work days and the holiday period will be analyzed separately. In the remaining sections of this chapter, the regular work days and the holiday period will mostly be analyzed together.

Since no employees were scheduled to work during the weekends, the figures in this chapter will not include Saturdays and Sundays. The only data points that will be plotted are days corresponding to Mondays through Fridays, and no gap will be shown in the figures for the weekends.
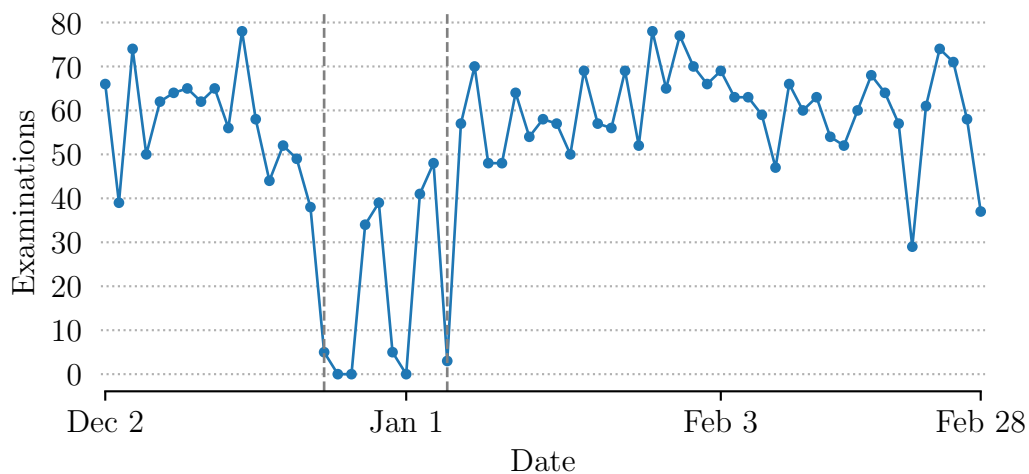
4.1   Examination rate

This section will detail the examination rate at the MRI unit for the studied time period. First, the total number of examinations performed per day at the MRI unit will be shown, and then the examination rate for the individual examination rooms. After this, statistics will be computed for the regular work days and for the holiday period.

4.1.1 Daily examination rate

The total daily examination rate, as well as the examination rate for the individual rooms, will be described here. The order of the examination rooms follows that of Section 2.2, starting with the rooms that had the most performed examinations. In the figures that show the examination rate, the start and end of the holiday period will be marked with gray dashed lines.

Total examination rate

Figure 4.1 shows the daily total examination rate for the MRI unit, i.e. the sum of all examinations from the nine examination rooms per day. On the regular work days, the MRI unit performed roughly between 30 and 80 examinations per day, and most days between 50 and 70 examinations were done. Three days during the regular work days, the examination rate dropped below 40 examinations per day. During the holiday period, the examination rate was below 10 on 6 days, on the remaining days between 35 and 50 examinations were performed.

Figure 4.1: The total number of examinations performed per day at the MRI unit.

s18

The daily examination rate for room s18 is shown in Figure 4.2. During the regular work days the number of examinations varied between 6 and 14, except for one day towards the end of February when only 1 examination was performed. During the holiday period, the examination rate went down to 0 on 3 days, on the other days there were between 3 and 11 examinations done.
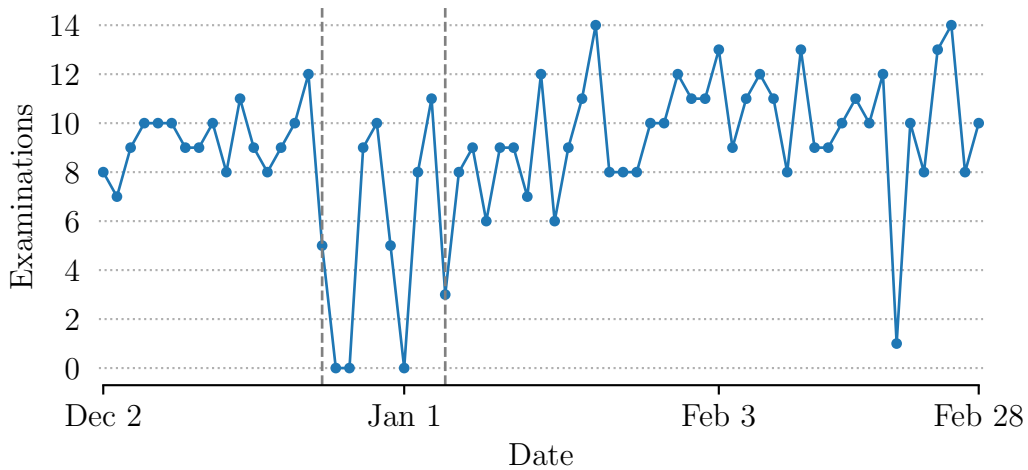
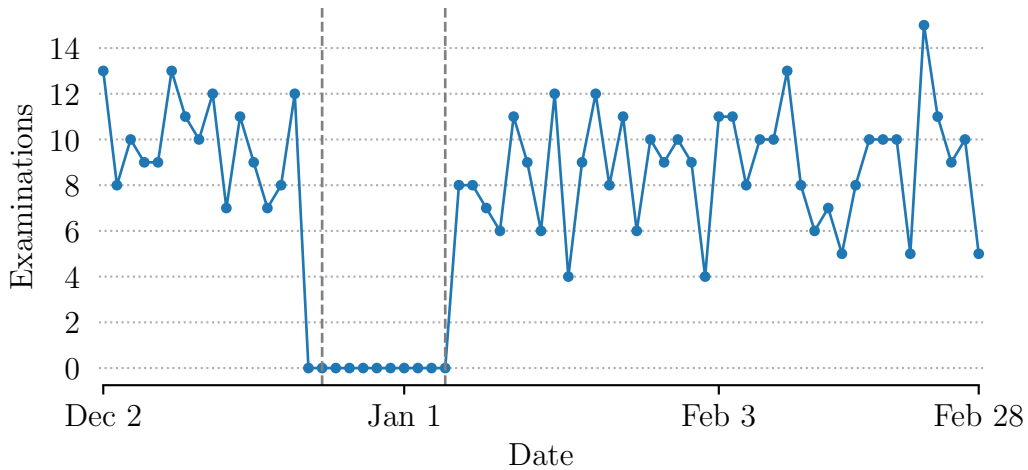**Figure 4.2:** The number of examinations performed per day in s18.

s17

The number of examinations per day for room s17 is shown in Figure 4.3. During the regular work days, the number of examinations was between 5 and 13, except on two days when it went down to 1 and 2. During the holiday period, no examinations were done on six of the days, on the remaining four days between 9 and 12 examinations were done.
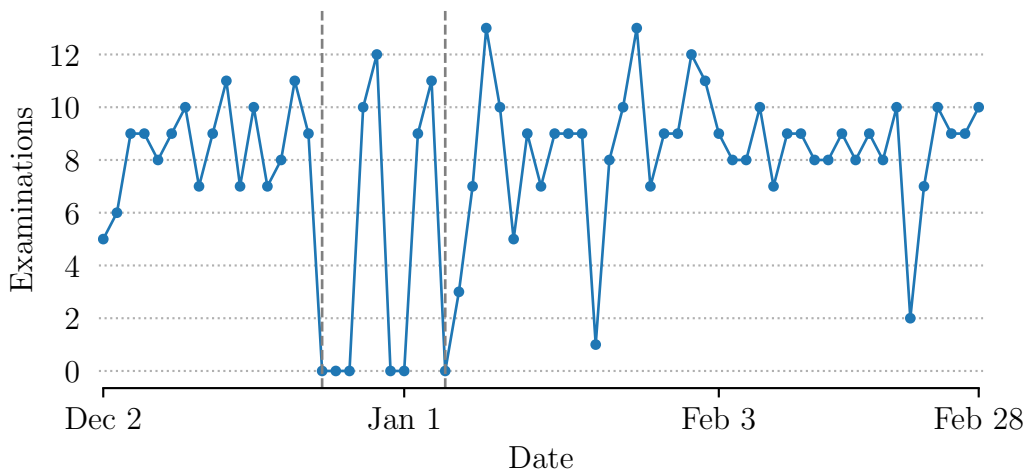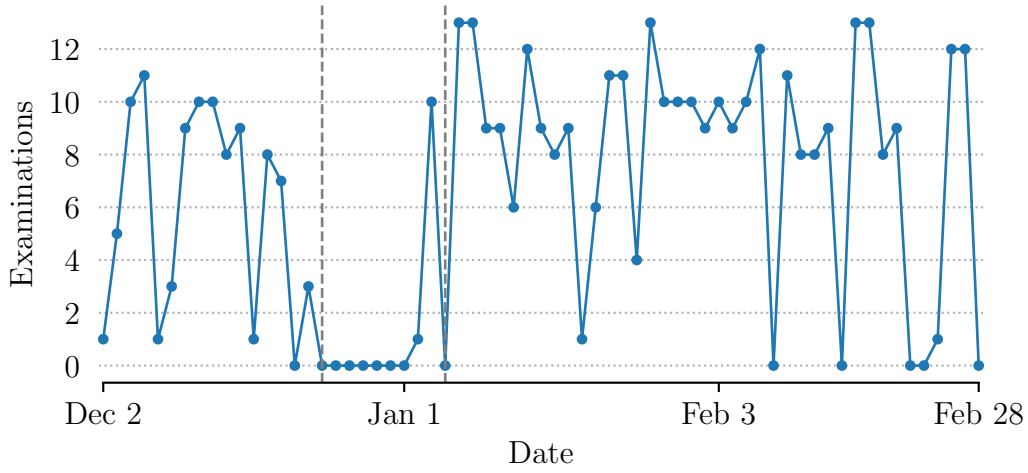

Figure 4.3: The number of examinations performed per day in s17.

r51

Figure 4.4 shows the daily examination rate for room r51. During the regular work days, examinations were performed every day apart from December 23 2019, the day before the holiday period started. The number of examinations varied between 4 and 15 during the regular work days. No examinations were done during the holiday period.

Figure 4.4: The number of examinations performed per day in r51.

s19

Figure 4.5 shows the daily examination rate in room s19. The number of examinations varied a lot, both during the regular work days and the holiday period. During the regular work days, the examination rate went down to 0 on 5 days, and it was below 5 on 13 days. The highest examination rate was 14. During the holiday period, no examinations were done on 6 of the days, the remaining days between 9 and 11 examinations were performed.
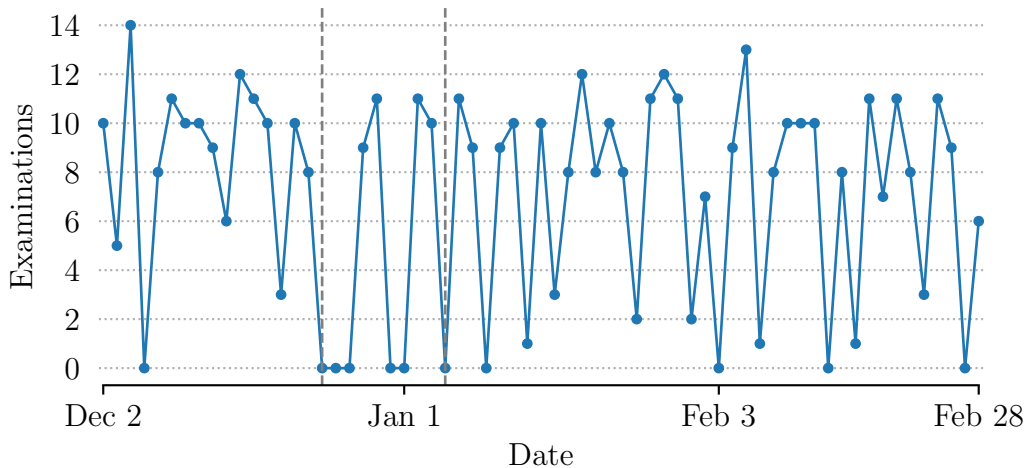
Figure 4.5: The number of examinations performed per day in s19.

s14

Figure 4.6 shows the daily examination rate in room s14. During the regular work days, the examination rate varied much from day to day. No examinations were done on 7 of the regular work days, and the examination rate was below 5 on 14 regular work days. On the regular work days with higher examination rates, the rate
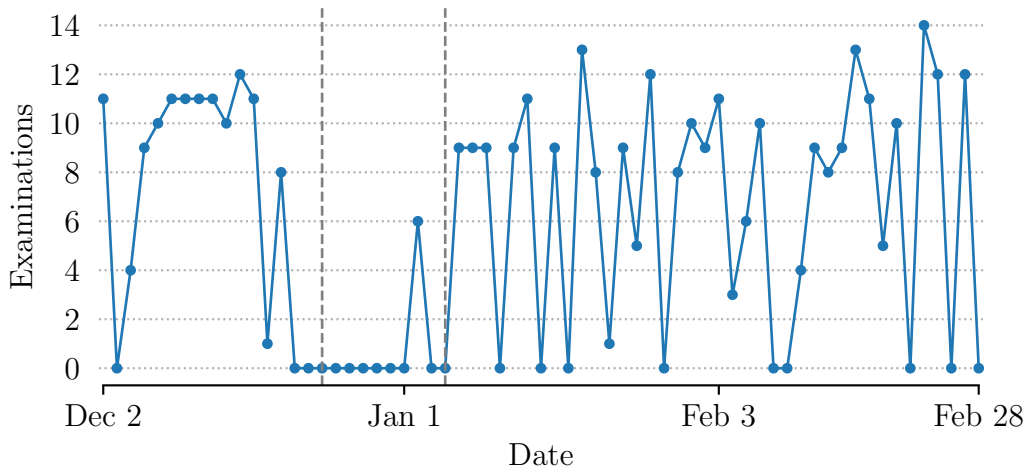
varied between 4 and 13. During the holiday period, examinations were performed on two days only. 1 and 10 examinations were performed respectively on these days.

Figure 4.6: The number of examinations performed per day in s14.
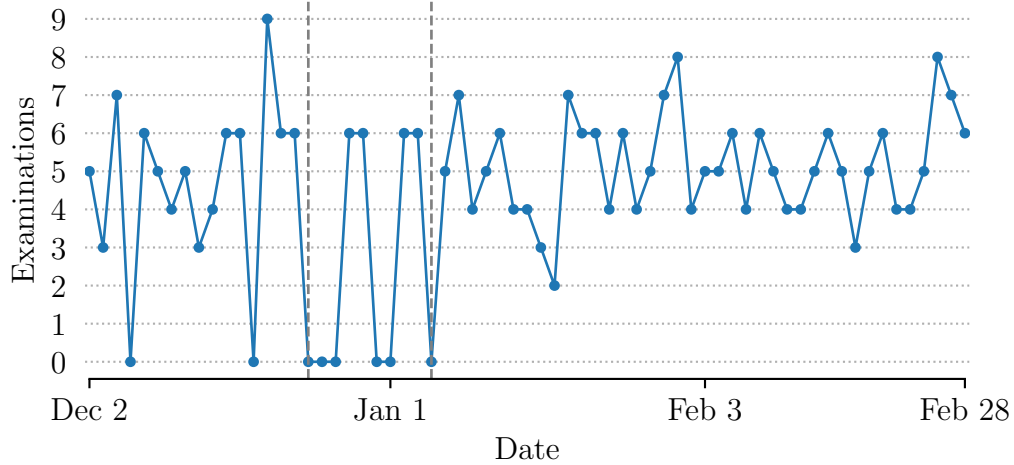
s13

The examination rate in room s13 is show in Figure 4.7. During the regular work days, the examination rate varied much from day to day. On 12 regular work days there were no examinations done, on 17 days the examination rate was below 5 and on the remaining regular work days the examination rate varied between 5 and 14 examinations per day. s13 was only used on one of the days during the holiday period, 6 examinations were performed on this day.

Figure 4.7: The number of examinations performed per day in s13.

smr1

The examination rate in smr1 is shown in Figure 4.8. During the regular work days, the room was used on all days apart from two days. The examination rate varied between 3 and 9 examinations per day. smr1 was used on 4 days during the holiday period, and 6 examinations were performed on all of these days.

Figure 4.8: The number of examinations performed per day in smr1.

r52

Figure 4.9 shows the examination rate in room r52. The examination rate varied much from day to day during the regular work days. The room was not in use on 16 of the regular work days and the examination rate was below 5 on 24 of the regular work days. During the remaining regular work days the examination rate was between 5 and 12 examinations per day. r52 was not used on any of the days during the holiday period.
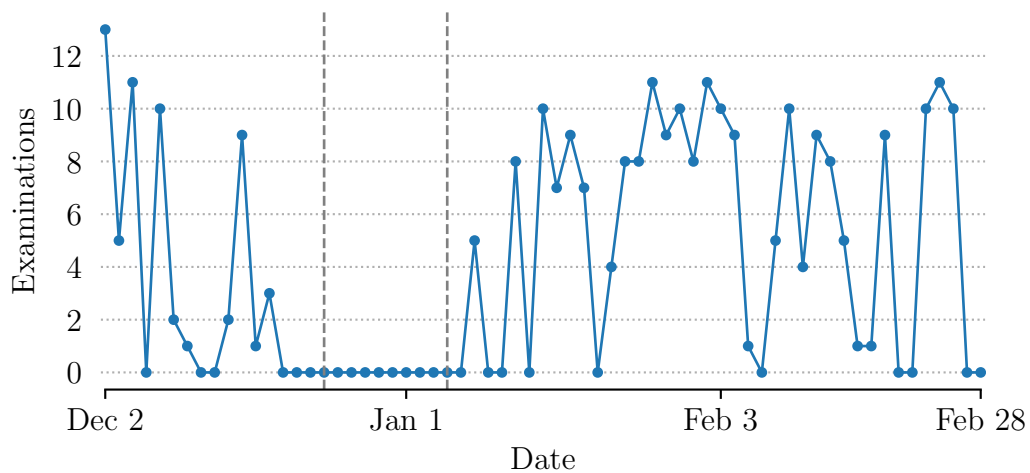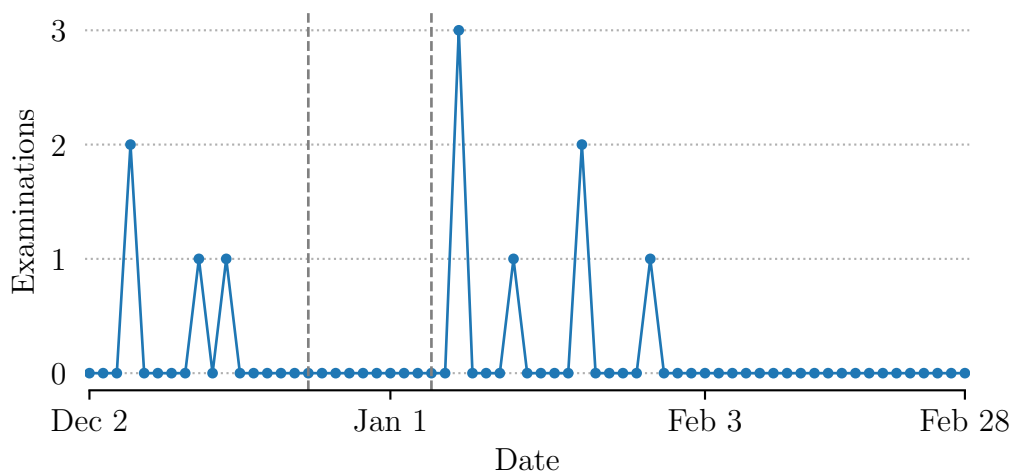

Figure 4.9: The number of examinations performed per day in r52.

s23

Room s23 was only used on 7 of the regular work days, which can be seen in Figure 4.10. When the room was used, the examination rate varied between 1 and 3 examinations per day. The room was not used on any of the days during the holiday period.

Figure 4.10: The number of examinations performed per day in s23.

4.1.2 Statistics for the regular work days

Table 4.1 shows the mean and standard deviation of the daily examination rate for all rooms combined and for the individual rooms during the regular work days. The total number of examinations for this period is also shown. The average examination rate for the MRI unit during this period was 59.31 examinations per day, and the standard deviation 10.44. A total of 3262 examinations were done during the regular work days.

The room with the highest average examination rate was s18, with a mean of 9.62 examinations per day. Rooms r51 and s17 had the second and third highest average examination rate, 8.91 and 8.42 respectively. Three rooms had an average examination rate between 7 and 8, rooms s19, s14 and s13. r52 and smr1 both had an average examination rate of 5.00 examinations per day. s23 had the lowest average examination rate, 0.20 examinations per day.

The room with the lowest standard deviation was s23 with 0.58 examinations per day. smr1 had the second lowest standard deviation, 1.68 examinations per day. s18, r51 and s17 all had a standard deviation between 2 and 3. s19 had a standard deviation of 3.94 and the remaining rooms, s14, s13 and r52 had a standard deviation between 4 and 5.

s18 was the room with the highest number of examinations during the regular work days, 529 were done during this period. The second highest was r51, 490 examinations were performed here. In s17, s19 and s14, between 400 and 500 examinations were performed in each room. 388 examinations were performed in s13

31

and 275 examinations were performed in both r52 and smr1. 11 examinations were performed in s23.

Table 4.1: Statistics for the number of examinations per room and day during the regular work days. The rooms are sorted by the mean.

Room	Mean	Std	Total examinations
All rooms	59.31	10.44	3262
s18	9.62	2.18	529
r51	8.91	2.69	490
s17	8.42	2.23	463
s19	7.58	3.94	417
s14	7.53	4.19	414
s13	7.05	4.59	388
r52	5.00	4.34	275
smr1	5.00	1.68	275
s23	0.20	0.58	11

4.1.3 Statistics for the holiday period

Table 4.2 shows the mean and standard deviation of the daily examination rate during the holiday period, both for all rooms combined and for the individual rooms. The total number of examinations during this period is also shown. The average daily examination rate for the MRI unit during the holiday period was 17.50 examinations per day, and the standard deviation was 19.13. A total of 175 examinations were performed.

s18 had the highest average examination rate during the holiday period, 5.10 examinations per day. s17 and s19 had the second and third highest average daily examination rate, 4.20 and 4.10 respectively. smr1 had an average of 2.40 examinations per day and s14 and s13 had 1.10 and 0.60 respectively. In the remaining rooms, r51, r52 and s23, no examinations were done during the holiday period.

Excluding the rooms where no examinations were done, s13 had the lowest standard deviation during the holiday period, 1.80. Then came s14 and smr1 with 2.98 and 2.94 respectively. s18 had a standard deviation of 4.06, and s19 and s17 had 5.05 and 5.19 respectively.

s18 was the room where most examinations were done during the holiday period, a total of 51 examinations. s17 and s19 had 42 and 41 respectively. 24 examinations were done in smr1 and 11 and 6 in s14 and s13 respectively. No examinations were done in the remaining three rooms, r51, r52 and s23.

Table 4.2: Statistics for the number of examinations per room and day during the holiday period. The rooms are sorted by the mean.

Room	Mean	Std	Total examinations
All rooms	17.50	19.13	175
s18	5.10	4.06	51
s17	4.20	5.19	42
s19	4.10	5.05	41
smr1	2.40	2.94	24
s14	1.10	2.98	11
s13	0.60	1.80	6
r51	0.00	0.00	0
r52	0.00	0.00	0
s23	0.00	0.00	0

4.2 The number of hours the rooms were open

In this section, the number of hours the examination rooms were open per day will be detailed. Just like in Section 4.1, the data will be divided into the regular work days and the holiday period. First, the total number of hours the rooms were open per day will be shown, and then broken down by the individual rooms. Then, the statistics for the regular work days and for the holiday period will be shown.

4.2.1 Daily number of hours

In this section, the number of hours the rooms were open per day will be detailed. The rooms will be shown in the same order as in Section 4.1, and the start and end of the holiday period will be shown with gray dashed lines in the figures.

Total daily hours

Figure 4.11 shows the total number of hours the rooms at the MRI unit were open per day. During all of the regular work days, at least some of the rooms were open. The number of hours ranged roughly between 23 and 64 per day. During the holiday period, all of the rooms were closed on 6 of the days. The remaining 4 days the rooms were open around 32 or 40 hours per day.
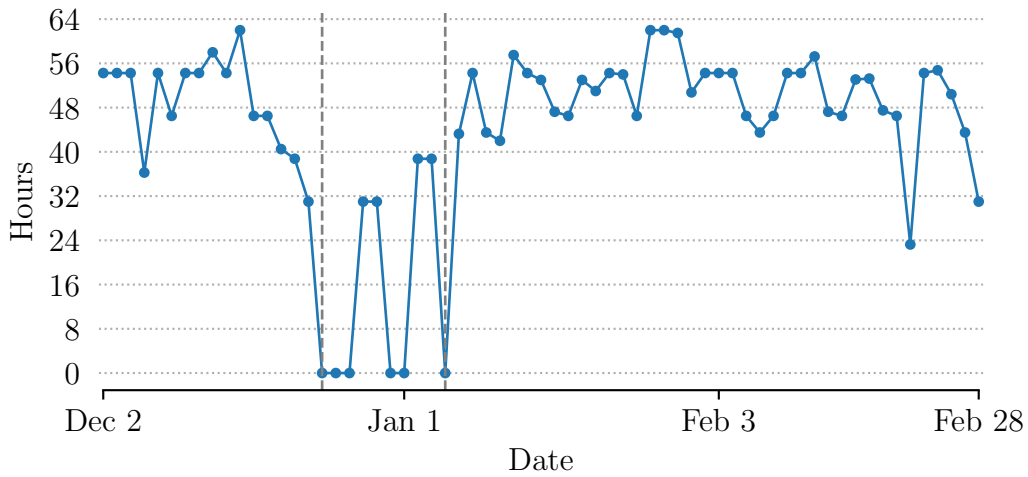
Figure 4.11: The total number of hours the rooms were open per day at the MRI unit.

s18

Figure 4.12 shows the number of hours that s18 was open per day. During the regular work days, s18 was open on all days except 1. The majority of the days it was open for the full day, 7 hours and 45 minutes or 7 hours and 15 minutes on the days with a morning staff meeting. On a few days it was open 6 hours and 45 minutes and one day 8 hours and 15 minutes. During the holiday period s18 was closed on 6 days, the remaining 4 days it was open 7 hours and 45 minutes.
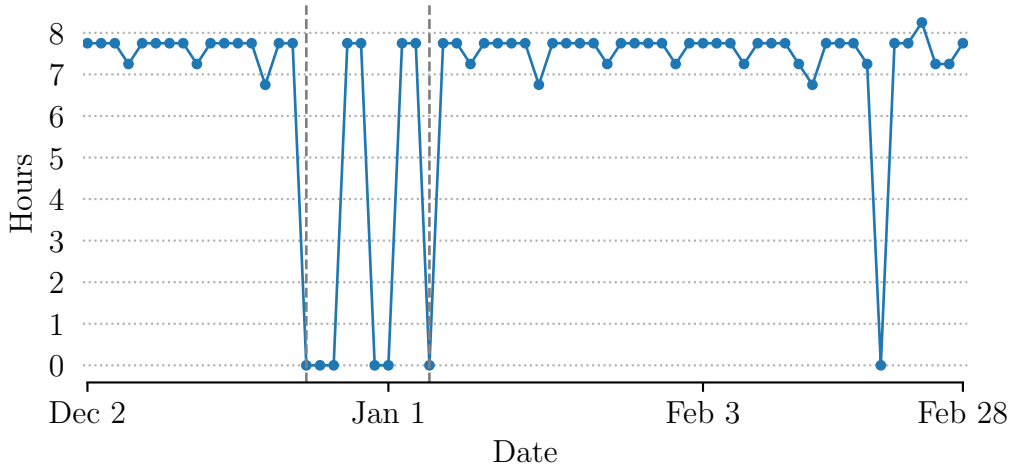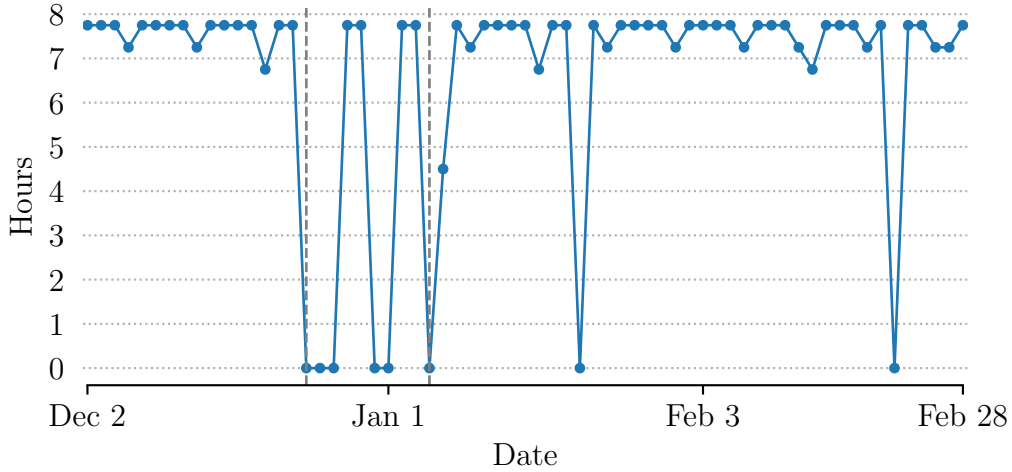

Figure 4.12: The number of hours room s18 was open per day.

s17

Figure 4.13 shows the number of hours that s17 was open each day. During the regular work days s17 was closed on 2 days. The majority of the remaining regular work days it was open the whole day, 7 hours and 45 minutes or 7 hours and 15
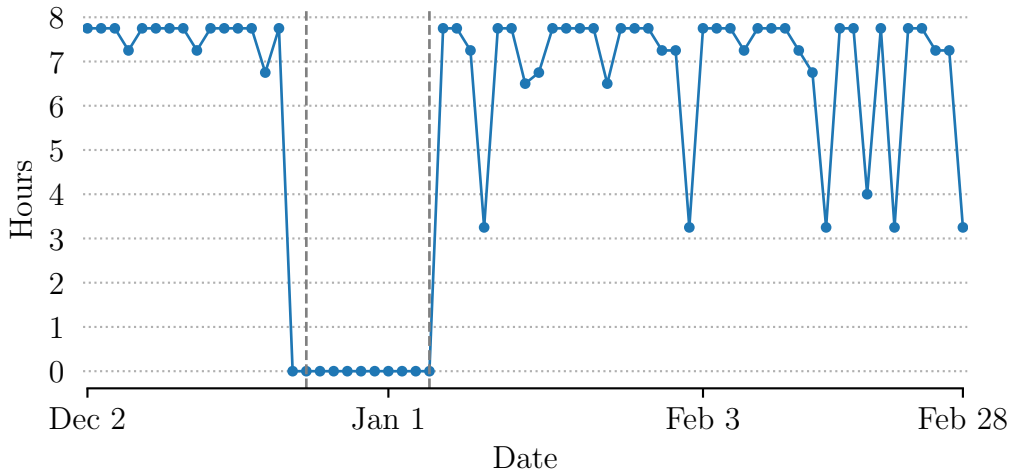
minutes. On a few days it was open for 6 hours and 45 minutes and one day it was open 4 hours and 30 minutes. During the holiday period s17 was closed on 6 days and open for 7 hours and 45 minutes on the remaining 4 days.

Figure 4.13: The number of hours room s17 was open per day.

r51

The number of hours room r51 was open per day is shown in Figure 4.14. During the regular work days, r51 was closed on one day. On 6 of the regular work days, the room was open either 3 hours and 15 minutes or 4 hours. The remaining regular work days, r51 was open between 6 hours and 30 minutes and 7 hours and 45 minutes. r51 was closed during all of the holiday period.

Figure 4.14: The number of hours room r51 was open per day.

s19

Figure 4.15 shows the number of hours that s19 was open per day. During the regular work days, s19 was closed on 13 days. On three of the regular work days it was open either for 4 hours or 4 hours and 30 minutes. The remaining regular work days s19 was open for the whole day, 7 hours and 45 minutes or 7 hours and 15 minutes. During the holiday period, s19 was open for 7 hours and 45 minutes on 4 days, and closed on the remaining 6 days.
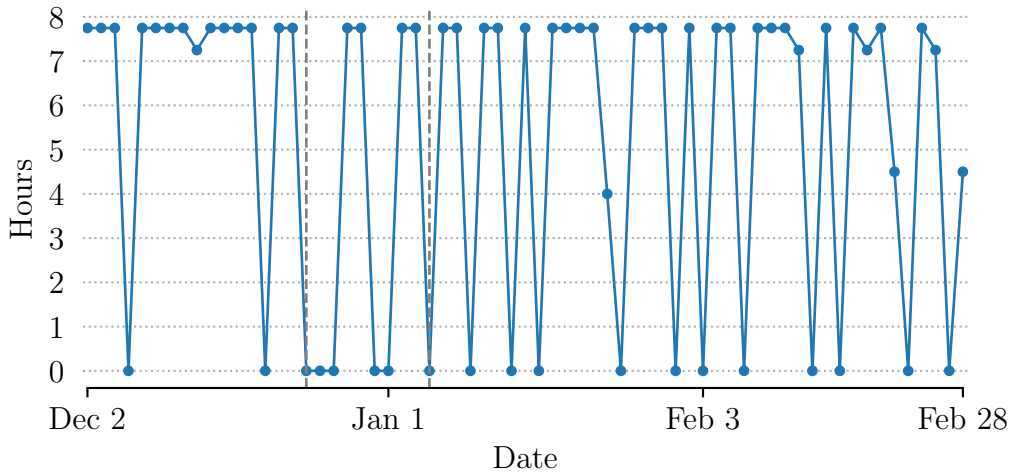
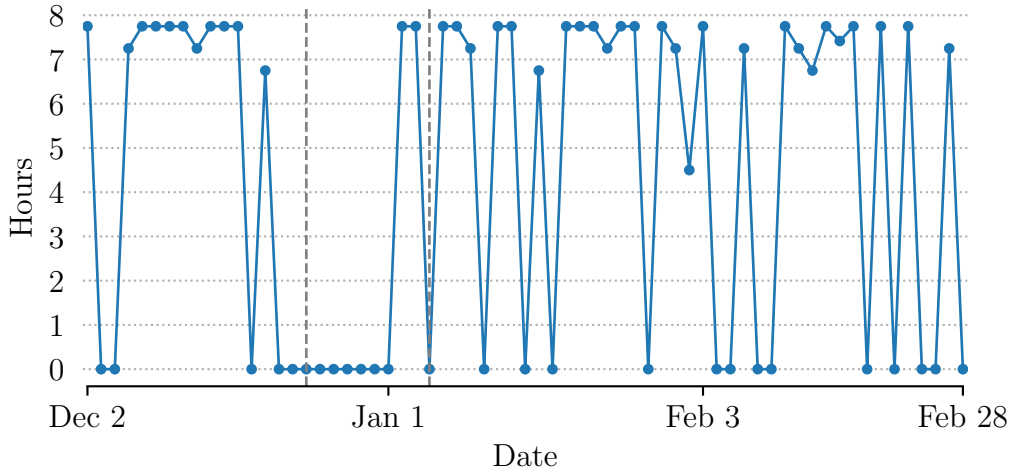**Figure 4.15:** The number of hours room s19 was open per day.

s14

Figure 4.16 shows the number of hours that s14 was open per day. During 13 of the regular work days s14 was closed, and 3 of the days it was open either 3 hours and 15 minutes or 4 hours and 30 minutes. The remaining regular work days, s14 was open between 6 hours and 45 minutes and 7 hours and 45 minutes. s14 was closed during the entire holiday period.
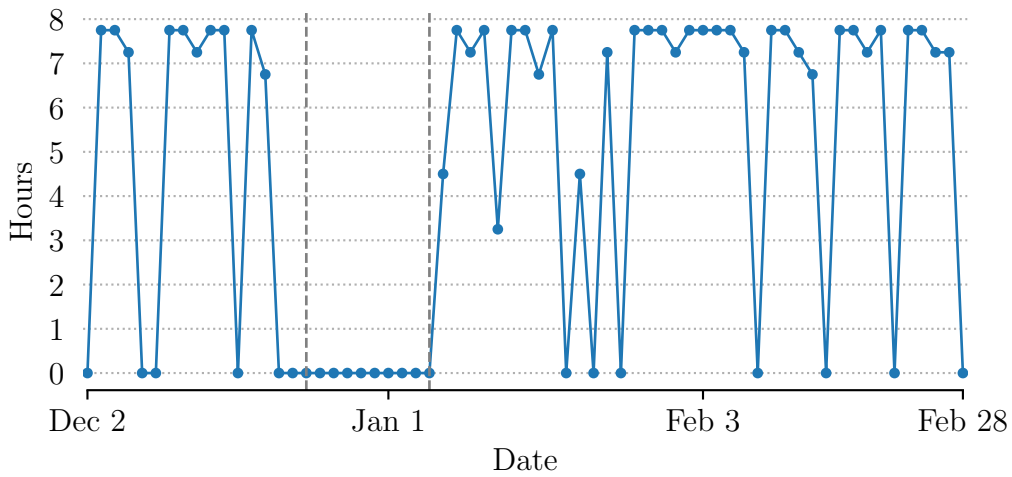
Figure 4.16: The number of hours room s14 was open per day.

s13

Figure 4.17 shows the number of hours s13 was open per day. s13 was closed on 18 of the regular work days and was open for 4 hours and 30 minutes on 1 regular work day. On the remaining regular work days, s13 was open between 6 hours and 45 minutes and 7 hours and 45 minutes. s13 was open 7 hours and 45 minutes on 2 days during the holiday period, during the rest of the holiday period it was closed.
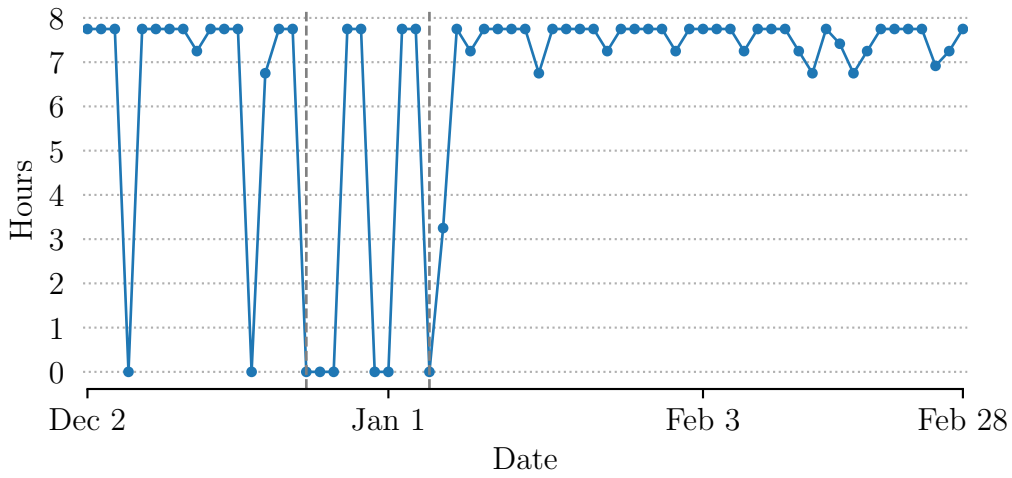

Figure 4.17: The number of hours room s13 was open per day.

smr1

The number of hours that smr1 was open each day is shown in Figure 4.18. During the regular work days, smr1 was closed on 2 days. On one regular work day it was open 3 hours and 15 minutes and during the remaining regular work days it was open between 6 hours and 45 minutes and 7 hours and 45 minutes. During the

37

holiday period, smr1 was open on 4 days for 7 hours and 45 minutes, and closed the remaining 6 days.

Figure 4.18: The number of hours room smr1 was open per day.

r52

Figure 4.19 shows the number of hours that r52 was open each day. During the regular work days, it was closed on roughly half of the days. On the remaining work days r52 was open between 6 hours and 30 minutes and 7 hours and 45 minutes except for 1 day, when it was open 4 hours and 30 minutes. r52 was closed during the entire holiday period.
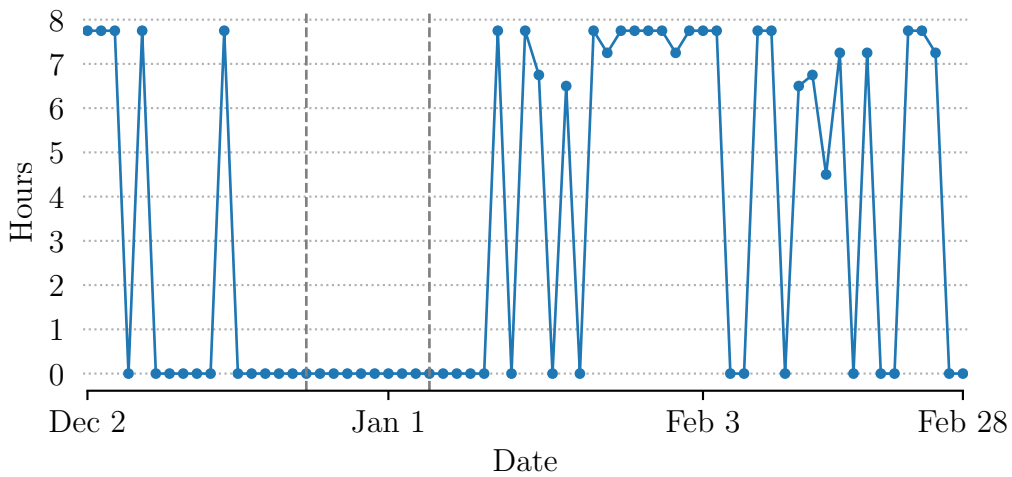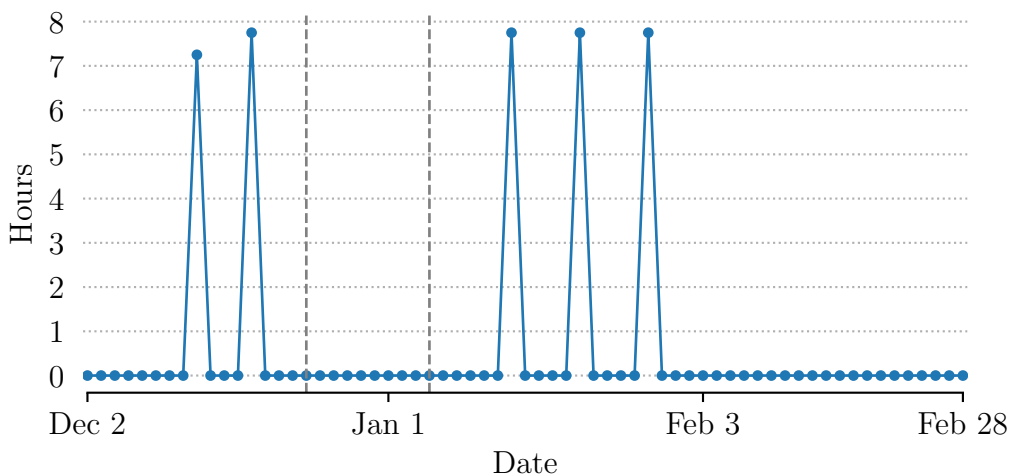

Figure 4.19: The number of hours room r52 was open per day.

s23

Figure 4.20 shows the number of hours that s23 was open per day. s23 was open on 5 of the regular work days, either for 7 hours and 45 minutes or 7 hours and 15

minutes. On the remaining regular work days s23 was closed, and it was also closed during the entire holiday period.

Figure 4.20: The number of hours room s23 was open per day.

4.2.2 Statistics for the regular work days

Table 4.3 shows the mean and standard deviation for the daily number of hours the rooms were open during the regular work days. The total average at the MRI unit was 49.79 hours per day and the standard deviation was 7.76 hours.

Room s18 was open the most on average, its daily average was 7.47 hours. s17 and smr1 both had averages above 7 hours per day, they were open 7.26 hours and 7.22 hours per day on average respectively. r51 had a daily average of 6.95 hours and then three rooms had a daily average between 5 and 6 hours. s19, s14 and s13 were open for 5.70, 5.57 and 5.02 hours per day on average respectively. Finally, r52 was open 3.90 hours per day on average and s23 had the lowest average, 0.70 hours per day.

Starting with the lowest standard deviation, s18 had a standard deviation of 1.06 hours. The second and third lowest had rooms s17 and smr1, 1.50 and 1.55 hours respectively. r51 had a standard deviation of 1.64 hours and s23 had 2.20 hours. The remaining rooms all had a standard deviation above 3 hours, the standard deviation of s14 was 3.21, s19 had 3.26, s13 had 3.53 and r52 had a standard deviation of 3.73 hours.

Table 4.3: Statistics for the daily number of hours each room was open during the regular work days. The rooms are sorted by the mean.

Room	Mean	Std
All rooms	49.79	7.76
s18	7.47	1.06
s17	7.26	1.50
smr1	7.22	1.55
r51	6.95	1.64
s19	5.70	3.26
s14	5.57	3.21
s13	5.02	3.53
r52	3.90	3.73
s23	0.70	2.20

4.2.3 Statistics for the holiday period

Table 4.4 shows the mean and standard deviation for the daily number of hours the rooms were open during the holiday period. The total number of hours the rooms were open on average per day was 13.95 hours, with a standard deviation of 17.26.

Rooms s17, s18, s19 and smr1 were all open 3.10 hours per day on average during the holiday period, and these rooms were the ones that were open the most. The average of smr1 was 1.55 hours per day. The remaining four rooms, r51, r52, s14 and s23, were closed during the holiday period.

s13 had the lowest standard deviation of the rooms that were open during the holiday period, 3.10 hours. The remaining rooms that were open all had a standard deviation of 3.80 hours.

**Table 4.4:** Statistics for the daily number of hours each room was open during the holiday period. The rooms are sorted by the mean.

Room	Mean	Std
All rooms	13.95	17.26
s17	3.10	3.80
s18	3.10	3.80
s19	3.10	3.80
smr1	3.10	3.80
s13	1.55	3.10
r51	0.00	0.00
r52	0.00	0.00
s14	0.00	0.00
s23	0.00	0.00

4.3 Correlation between the number of hours the rooms were open and the examination rate

This section will detail how the total daily number of hours the rooms were open explained the total examination rate at the MRI unit. To do this, the correlation between these two variables will be shown, using the results from Section 4.1 and Section 4.2. All 65 days of data will be used, i.e. both the days from the regular work days and the days from the holiday period. The correlation between the number of hours the individual rooms were open and the total examination rate will be shown as well.

Each point in Figure 4.21 corresponds to one of the days during the studied time period, with the total number of hours the rooms were open that day on the x axis, and the total number of examinations done on this day on the y axis. The x axis correspond to the data in Figure 4.11 and the y axis to that of Figure 4.1. Figure 4.21 shows that there is a positive correlation between the two variables. The majority of the days has an examination rate above 40 examinations per day and above 40 daily open hours. Around 55 hours, there is a large variation in examination rate, the fewest examinations for this amount of hours was around 39, and the most around 74. Some amount of hours are more common than others, such as around 31, 46 and 54 hours. The points in the lower left corner correspond to days where none of the rooms were open. The points with a y value value above 0 show that there are days when none of the rooms were open but examinations were still performed.
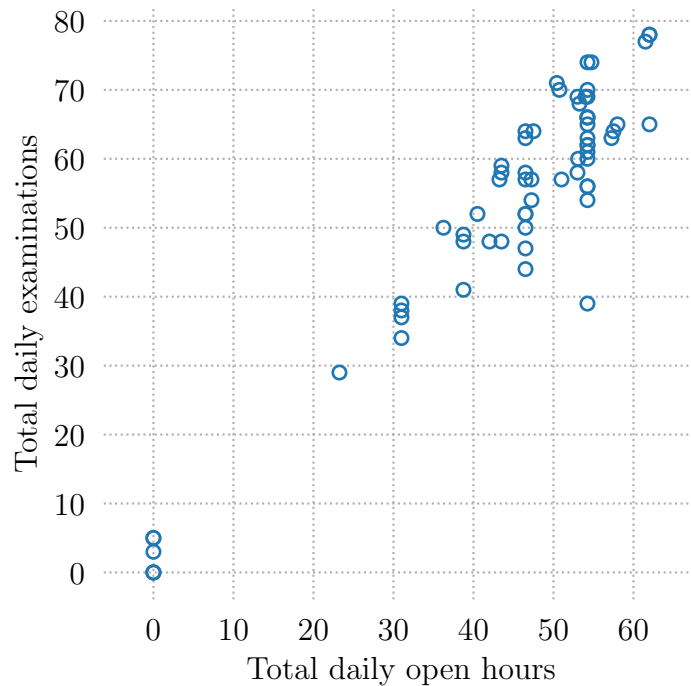
Figure 4.21: Correlation between the total daily number of hours the rooms were open and the total daily examination rate.

Table 4.5 shows the value of Pearson's correlation coefficient between the total daily number of hours the rooms were open and the total examination rate, and between the daily number of hours the individual rooms were open and the total examination rate. The first row corresponds to the data in Figure 4.21, and shows that the correlation between the total daily number of hours the rooms were open and the total examination rate was 0.95, a very high positive correlation.

The room with the highest correlation between the daily number of hours it was open and the total examination rate was room r51, the correlation was 0.78, a high positive correlation. The next three rooms also had a high positive correlation, s17, s18 and smr1 had 0.77, 0.76 and 0.74 respectively. Room s14 had a moderate positive correlation, 0.60. Rooms r52, s13 and s19 all had low to moderate positive correlation, r52 and s13 had 0.50, and s19 had 0.45. The correlation of room s23 was negligible, 0.06.

Table 4.5: Pearson's correlation coefficient for the correlation between the total daily number of hours the rooms were open and the total daily examination rate, and between the daily number of hours the individual rooms were open and the total daily examination rate.

| Room	Correlation coefficient
All rooms	0.95
r51	0.78
s17	0.77
s18	0.76
smr1	0.74
s14	0.60
r52	0.50
s13	0.50
s19	0.45
s23	0.06

4.4 Other sources that could affect the examination rate

In this section, three sources other than the daily number of hours the rooms were open will be investigated, to see if these affected the examination rate. First, the ratio of the staff's time that was used for examinations will be looked at. Then, the daily average examination duration will be investigated and lastly the discrepancies between the schedule and the examination data. The aim here is to identify sources that could explain the part of the examination rate that was not explained by how much the rooms were open. The holiday period will be marked in the figures, but other than that the regular work days and the holiday period will be analyzed together.

4.4.1 Ratio of the staff's time used for examinations

In this section, the ratio of the staff's time that was used for examinations will be detailed. Figure 4.22 shows this ratio averaged over all examination rooms for each day. The holiday period is marked with gray dashed lines and the days that are missing data points correspond to days when none of the rooms were open.

The lowest ratio happened on the second day of the studied timed period, here around 50% of the staff's time was used for examinations. During the rest of the days, the ratio varied between around 0.7 and 1.0, and on one day the ratio exceeded 1.0. A ratio above 1 meant that the total duration of all the examinations exceeded the total number of hours that the rooms were open, this discrepancy will be investigated more in Section 4.4.3. During the holiday period there were 4 days when at least some of the rooms were open, and the ratio did not seem to differ during these days compared to the regular work days.
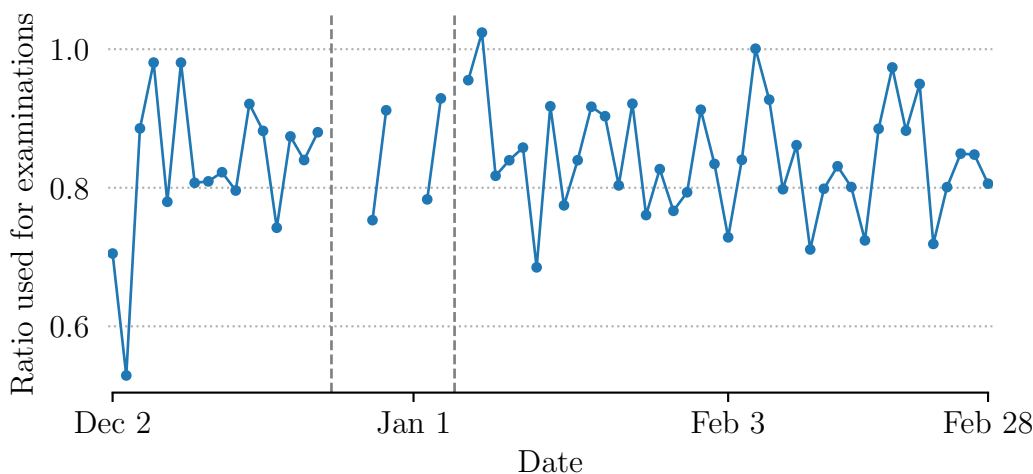
Figure 4.22: The ratio of the staff's time that was used for examinations, averaged over all rooms.

Table 4.6 shows the mean and standard deviation of the ratio of the staff's time that was used for examinations, both for the individual rooms and when averaged over all rooms. The total number of days each room was open is also shown since the ratio was only computed for these days. Both the regular work days and the days from the holiday period was used.

When averaging over all rooms, the mean was 0.84, meaning that on average 84% of the staff's time across the MRI unit was used for examinations each day. The standard deviation was 9 percentage points. The individual room with the highest average ratio was s17, with 0.89. Three other rooms had averages above 0.8, s19, s18 and r51 had an average ratio of 0.86, 0.85 and 0.81 respectively. smr1 and r52 both had an average ratio of 0.79 and s14 and s13 had average ratios of 0.76 and 0.75 respectively. s23 was the room where the least amount of the staff's time was used for examinations, the average ratio here was 0.24.

The range of the standard deviations for the individual rooms was between 0.18 and 0.24. s17 and s18 had the lowest standard deviations, 0.18. s23 had a standard deviation of 0.19 and s19 had 0.20. r51, smr1 and r52 all had a standard deviation of 0.22 and s13 and s14 had standard deviations of 0.23 and 0.24 respectively.

At least one of the rooms were open on 59 of the 65 days that was studied. The room that was open the most was s18, which was open on 58 days. s17 and smr1 were both open on 57 days, and r51 was open on 54 days. s19 was open on 46 days and s14 on 42 days. s13, r52 and s23 were open 39, 29 and 5 days respectively.

Table 4.6: Statistics for the ratio of the staff's time that was used for examinations. The rooms are sorted by the mean.

Room	Mean	Std	Days open
s17	0.89	0.18	57
s19	0.86	0.20	46
s18	0.85	0.18	58
All rooms	0.84	0.09	59
r51	0.81	0.22	54
smr1	0.79	0.22	57
r52	0.79	0.22	29
s14	0.76	0.24	42
s13	0.75	0.23	39
s23	0.24	0.19	5

4.4.2 Daily average examination duration

This section will show the daily average examination duration, both for the individual rooms and averaged over all rooms. Figure 4.23 shows the daily average examination duration, averaged over all rooms for each day of the studied time period. The days that are missing data points correspond to days when no examinations were performed. The start and end of the holiday period are marked with gray dashed lines.

Figure 4.23 shows that the daily average examination duration when averaged over all rooms ranged between around 30 and 65 minutes. The two lowest daily average examination durations happened during the holiday period, and the remaining 4 days of the holiday period had daily average examination durations of around 45 minutes.
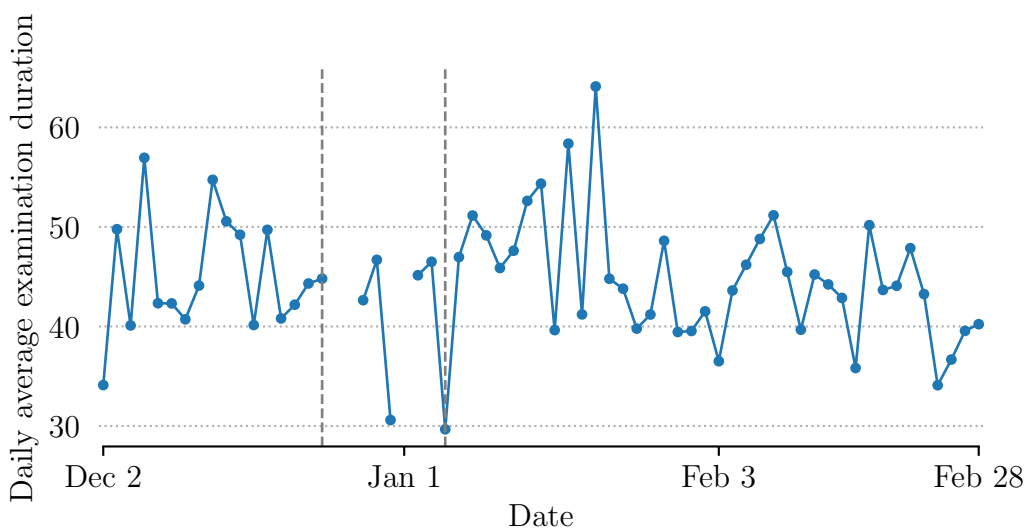
Figure 4.23: The daily average examination duration in minutes, averaged over all rooms.

Table 4.7 shows the mean and standard deviation for the daily average examination duration, both for the individual rooms and averaged over all rooms. The number of days when examinations were performed is also shown. The mean when averaged over all rooms, corresponding to the data points in Figure 4.23, was 44.47 minutes, and the standard deviation was 6.28 minutes. The room with the lowest mean was s14, with 35.24 minutes. Three other rooms had means below 40 minutes, s13, r51 and s19 had 36.21, 37.89 and 39.37 minutes as their respective means. s18, r52 and s17 had 40.05, 40.45 and 47.47 minutes as means respectively. The rooms that had the highest means were smr1 and s23, they had 70.59 and 98.60 minutes as their respective means.

The standard deviation of the daily average examination duration for the individual rooms varied between 8.29 and 35.10 minutes. s13 had the lowest standard deviation, 8.29 minutes. s18 was the only other room that had a standard deviation below 9 minutes, the standard deviation of s18 was 8.53 minutes. r51 and s19 had 9.21 and 9.32 minutes respectively as their standard deviations. s17 and s14 had the standard deviations 11.16 and 11.20 minutes and r52 had the standard deviation 12.11 minutes. The highest standard deviations were in rooms smr1 and s23, which had 21.63 and 35.10 as their respective standard deviations.

On 62 of the 65 days, examinations were performed in at least one of the rooms. The room that had the most days when examinations were performed was s18, with 62 days. 5 rooms had between 50 and 60 days when examinations were performed, these were s17, smr1, r51, s19 and s14, with 59, 57, 54, 54 and 51 days respectively. In s13, examinations were performed on 44 days, and in r52 examinations were performed on 39 days. Finally, examinations were performed in s23 on 7 days.

Table 4.7: Statistics for the daily average examination duration per room in minutes. The rooms are sorted by the means.

| Room	Mean	Std	Days with examinations
s14	35.24	11.20	51
s13	36.21	8.29	44
r51	37.89	9.21	54
s19	39.37	9.32	54
s18	40.05	8.53	62
r52	40.45	12.11	39
All rooms	44.47	6.28	62
s17	47.47	11.16	59
smr1	70.59	21.63	57
s23	98.60	35.10	7

4.4.3 Discrepancy between schedule and examination data

As was seen in Figure 4.21, on some of the days there were examinations done but no staff scheduled to be in any of the rooms. This showed that there were discrepancies between the schedule and the examination data. This section will detail the extent of these discrepancies. Each examination room will be looked at individually, in the same order as in sections 4.1 and 4.2, starting with the days when none of the rooms were open and examinations were still performed. In rooms r51 and smr1, there were no days when examinations were performed without scheduled staff, and therefore these rooms will not be detailed in this section. The start and end of the holiday period will be marked with gray dashed lines in the figures.

All rooms closed

Figure 4.24 shows the total daily number of examinations that were done at the MRI unit when none of the rooms were scheduled to be open. This happened on 3 days, all during the holiday period. On 2 days, there were 5 examinations done without scheduled staff to any of the rooms and on the third day there were 3 examinations performed.
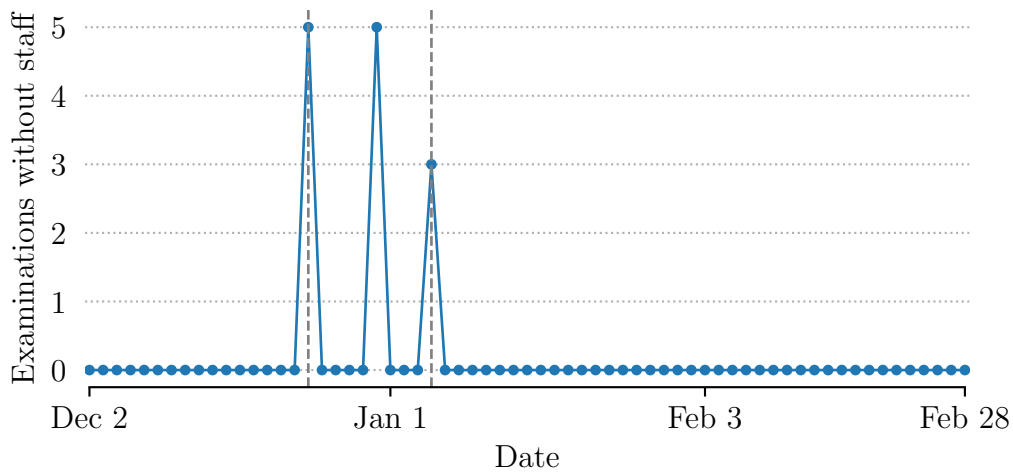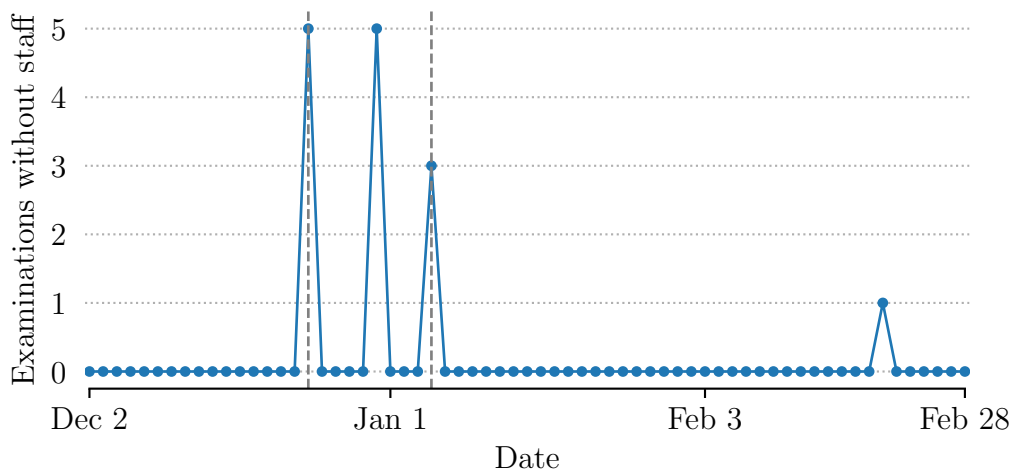
Figure 4.24: The total daily number of examinations that were performed at the MRI unit when none of the rooms were scheduled to be open.

s18

Figure 4.25 shows the daily number of examinations in s18 when examinations were done and no employees were scheduled to work in s18. During the regular work days, this happened on 1 day, and 1 examination was performed on this day. During the holiday period, this happened on 3 days, with 5 examinations on 2 of the days and 3 examinations on the third.
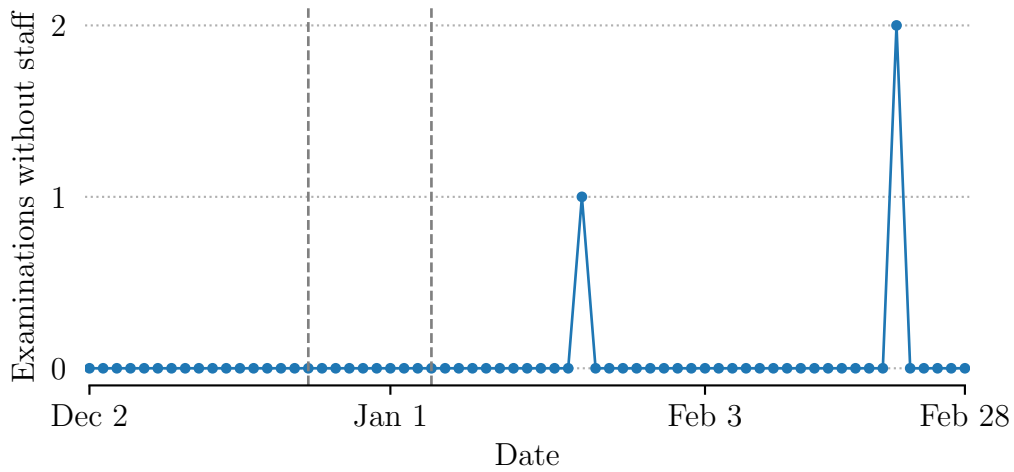

Figure 4.25: The daily number of examinations in s18 that were performed without scheduled staff.

s17

The daily number of examinations in s17 that were performed without any staff scheduled to it are shown in Figure 4.26. Examinations were performed without
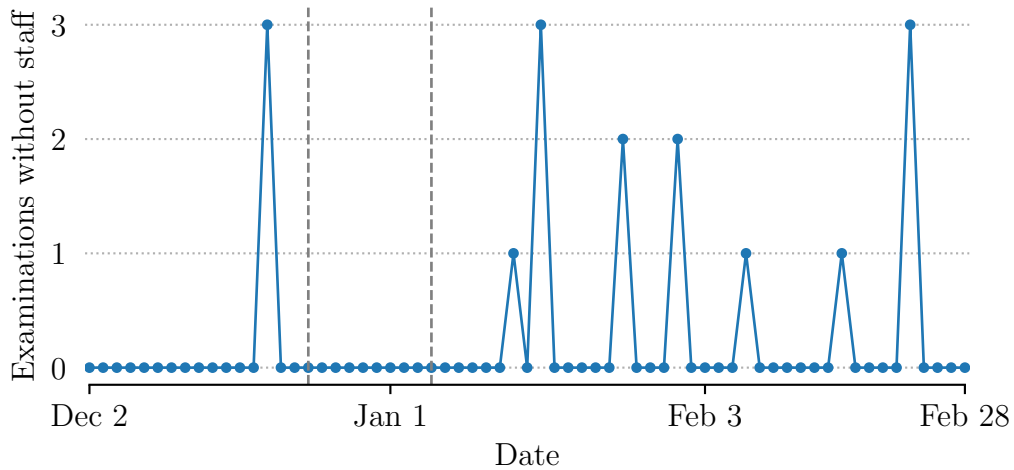
47

scheduled staff on 2 days, both during the regular work days. 1 and 2 examinations were performed on these days respectively.

Figure 4.26: The daily number of examinations in s17 that were performed without scheduled staff.

s19

Figure 4.27 shows the daily number of examinations that were performed in s19 without scheduled staff. Examinations without scheduled staff were done on 8 days, all during the regular work days. The number of examinations on these days varied between 1 and 3.

Figure 4.27: The daily number of examinations in s19 that were performed without scheduled staff.

s14

Figure 4.28 shows the daily number of examinations in s14 that were done without any scheduled staff. During the regular work days, there were 8 days when examina-

tions were performed without scheduled staff and 2 days during the holiday period. On 8 of the days, the number of examinations were between 1 and 4 and on the remaining 2 days there were 10 and 11 examinations done respectively without any scheduled staff.
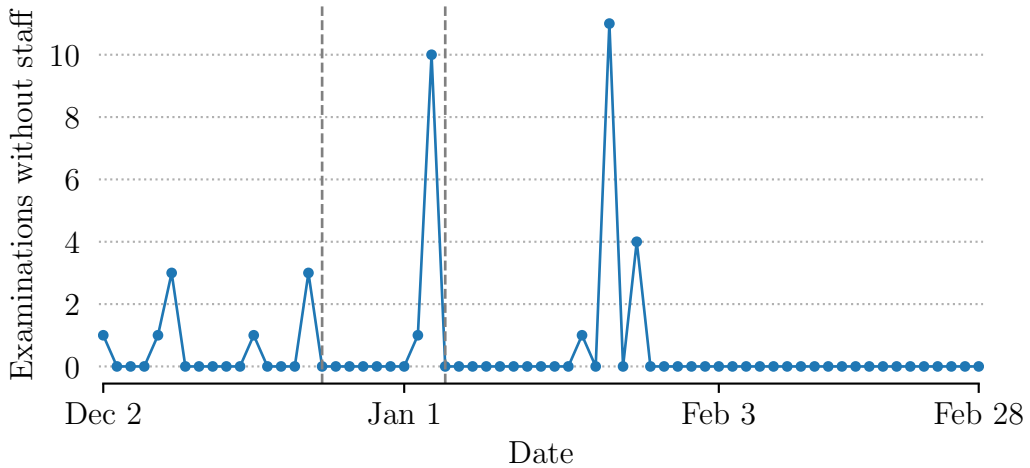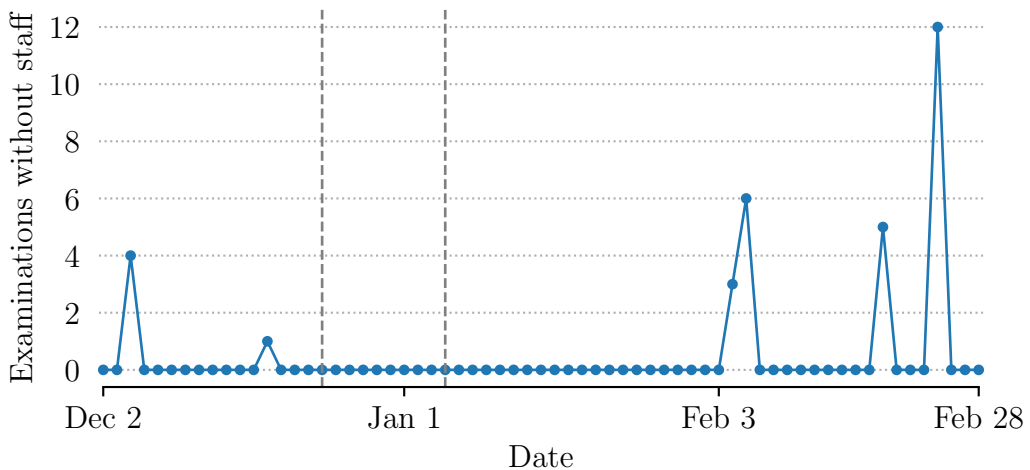

Figure 4.28: The daily number of examinations in s14 that were performed without scheduled staff.

s13

Figure 4.29 shows the daily number of examinations that were performed without any scheduled staff in room s13. Examinations were performed without scheduled staff on 6 days, all during the regular work days. On 1 of these days, there were 12 examinations performed, on the remaining 5 days the number of examinations varied between 1 and 6.

Figure 4.29: The daily number of examinations in s13 that were performed without scheduled staff.

r52

The daily number of examinations that were performed in r52 without scheduled staff is shown in Figure 4.30. Examinations without scheduled staff were performed on 10 days, all during the regular work days. On one of these days, 9 examinations were performed, and on the remaining 9 days the number of examinations varied between 1 and 5.
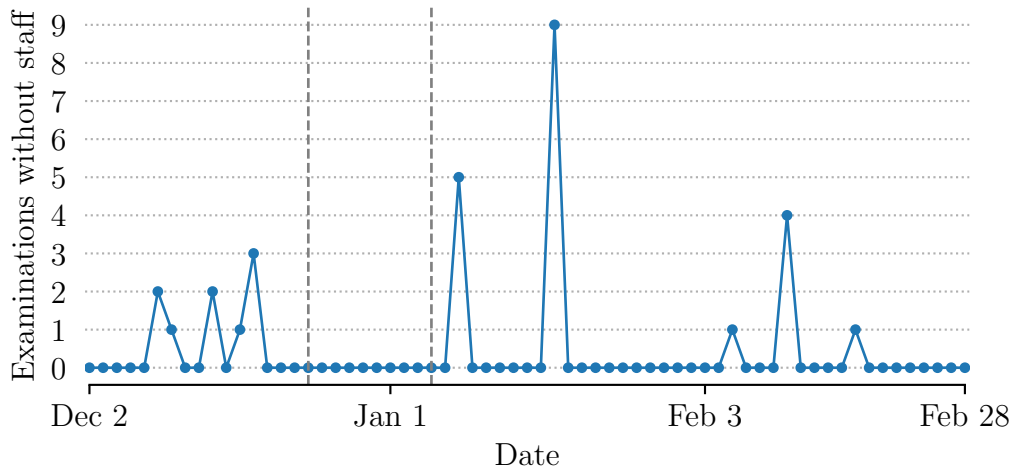
Figure 4.30: The daily number of examinations in r52 that were performed without scheduled staff.

s23

Figure 4.31 shows the daily number of examinations performed in s23 without staff scheduled to this room. Examinations without scheduled staff were performed on 3 days, all during the regular work days. The number of examinations during these days varied between 1 and 3.

Figure 4.31: The daily number of examinations in s23 that were performed without scheduled staff.

5

Discussion
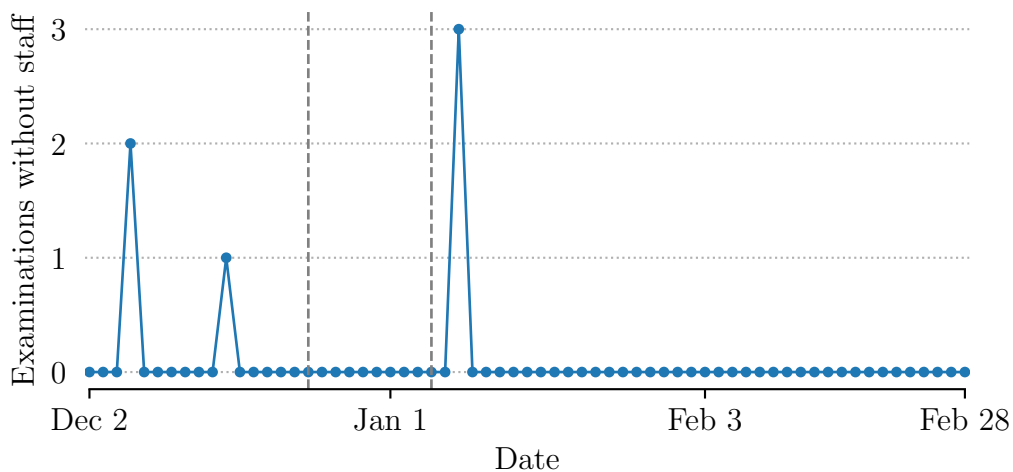
In this chapter, the results from the previous chapter will be discussed and related to the description of the MRI unit in Chapter 2. First, the examination rate will be discussed and then the daily number of hours the rooms were open. The correlation between these two variables will then be discussed and finally the three other sources that were looked at that could influence the examination rate will be discussed.

Examination rate   The total examination rate at the MRI unit varied much from day to day, both during the regular work days and during the holiday period. Some of the rooms had a high variation in daily examination rate, and this led to the variation in the total examination rate. s19, s14, s13 and r52 had many days when no examinations were done, and on the remaining days the examination rate was relatively high. The rooms where the examination rate varied less from day to day were s18, r51, s17 and smr1, there were few days when no examinations were done in these rooms, at least during the regular work days. The examination rate in s23 was very low, only 11 examinations were done in this room and did therefore not affect the total examination rate much.

The profiles of the examination rooms, described in Section 2.2, can partly describe the similarities and differences in examination rate between the rooms. The type of examinations that were done in the rooms affected the examination durations, and therefore the examination rate. This is clearest in smr1, here only radiation therapy examinations were done, which was not done in any of the other rooms, and the average examination duration was higher than all other rooms apart from s23. The daily average examination duration in smr1 was 70.59 minutes, the average over all rooms was 44.47 minutes. It is therefore not surprising that smr1 had a low examination rate during the regular work days, even though it rarely was closed. The examination durations for the other rooms, excluding s23, did not differ much, and this could be because the examination types were more similar in these rooms. For example, most of these rooms did many brain examinations. Out of these rooms, s14 had the shortest daily average examination duration, and s17 the longest. In s14, brain examinations were the most common and in s17 heart examinations were the most common, indicating that brain examinations were faster to perform than heart examinations. The average examination duration in room s23 was the highest, indicating that intraoperative surgery took a longer time compared to the more common MRI examination types.

The ratio of the staff's time that was used for examinations can also explain the difference in examination rate between the rooms. The four rooms with the highest ratio were s17, s19, s18 and r51, and these were also the rooms that had the highest examination rates during the regular work days.

The number of hours the rooms were open   s18 was the room that had the highest daily average of hours that it was open. This was expected since s18 was the room that was designated for emergency examinations during most days, and therefore prioritized for staffing. The variation in how much the individual rooms were open is similar to the variation in examination rate for the individual rooms. s18, s17, smr1 and r51 all have relatively low standard deviations compared to their means, both for the daily number of hours they were open and the daily examination rate, during the regular work days. This indicates that the daily number of hours the rooms were open and the examination rate could be correlating well, even for the individual rooms.

There are a few discrete values that the number of daily open hours take for the individual rooms. These usually corresponds to the room being open the entire day, or during the morning or the afternoon. On the days when there was no morning meeting, a room that was open the entire day would be open for 7 hours and 45 minutes. On the days with a morning meeting, usually once a week, the room would be open for 7 hours and 15 minutes. A room that was open in the morning would be open for 4 hours and 30 minutes, or 4 hours on the days with a morning meeting. A room that was open in the afternoon would be open for 3 hours and 15 minutes. These values are very common and it is rare that the number of hours take other values. When this happened, this was usually due to training or meetings.

Correlation between the number of hours the rooms were open and the examination rate   The discrete values that the daily number of hours took for the individual rooms can be seen when looking at the correlation between the number of total daily open hours and the total daily examination rate in Figure 4.21. There were some values that were more common than others for the total daily open hours, such as around 31, 46 and 54 hours. The first value can correspond to 4 rooms being open the entire day, $4 \times (7$ hours 45 minutes$) = 31$ hours. 6 rooms being open the entire day corresponds to 46 hours and 30 minutes, and 7 rooms being open the entire day corresponds to 54 hours and 15 minutes. Thus, the vertical clusters that can be seen in Figure 4.21 are expected, since multiple rooms being open for the entire day was common.

There was a very high positive correlation between the total daily number of hours and the total daily examination rate, which was seen in Figure 4.21. There is a linear upwards trend, and the variation is the highest around 54 hours, which corresponded to 7 rooms being open the entire day. The variation is high around 46 hours as well, corresponding to 6 rooms being open the entire day. Here is also where most of the data lie, so it is not surprising that the variation is higher here.

Other sources that could affect the examination rate   When looking at the ratio of the staff's time that was used for examinations, it was found that this ratio was relatively stable from day to day. When averaging the ratio over all the rooms, the standard deviation was lower compared to those of the individual rooms. This showed that how much of the staff's time that was used for examinations in the individual rooms did not vary at the same time. On average, 84% of the staff's time was used for examinations when averaging over all the rooms, and the standard deviation of this ratio was 9 percentage points. Thus, the standard deviation is relatively small compared to the mean, and it is therefore not likely that this ratio affected the daily total examination rate much.

Similarly to the ratio of the staff's time that was used for examinations, the daily average examination duration did not vary much from day to day when averaged over all the rooms. Again, the standard deviation when averaged over all the rooms were lower compared to the standard deviations of the individual rooms, which showed that the daily average examination duration of the individual rooms did not vary at the same time. Since the standard deviation of the daily average examination duration averaged over all the rooms was small compared to the mean, it is not likely that it affected the daily total examination rate of the MRI unit significantly.

The discrepancy between the schedule data and the examination data most likely affected the correlation between the daily total number of hours the rooms were open and the daily examination rate. Many rooms had days where examinations were done without any scheduled staff. This means that the number of hours the rooms were open should be higher, resulting in a less steep slope in Figure 4.21, i.e. fewer examinations per hour open. The rooms with a higher discrepancy between the schedule and examination data in general had a lower correlation coefficient for the correlation between the daily number of open hours and the total examination rate, as shown in Table 4.5. r51, s17, s18 and smr1 were the rooms with the highest correlation coefficients, and these rooms had few days when examinations without scheduled staff were done. smr1 and r51 had no such days, and s17 and s18 had 4 and 2 respectively. In contrast, the rooms s14, r52, s13 and s19 had lower correlation coefficients and had between 6 and 10 days where examinations were done without scheduled staff. This suggests that if the schedule more correctly reflected when the rooms were staffed, the correlation coefficient for s14, r52, s13 and s19 would be higher, which would also result in a higher correlation between the total number of hours and the total examination rate. The correlation between the daily number of hours that s23 was open and the total examination rate was negligible, and since s23 was closed and unused on most days, it did not impact the overall correlation much.

When looking at the examination rate and how much the rooms were open, and the correlation between these two, two groups within the examination rooms emerges. There is one group of rooms that are open on most days, and have a low variation in their examination rate, and this group consists of s18, s17, r51 and smr1. The other group consists of rooms that have a higher variation in examination rate and how much they are open, and have a lower correlation between the daily number of open hours and the examination rate as well as higher discrepancy between the

schedule and examination data. These rooms are s19, s14, s13 and r52. s23 is very different to the other rooms in that is open and used for examinations on very few days, and does not fit into any of these groups. The existence of these two groups show that some rooms are prioritized for staffing and usually assumed to be used every day, while the rooms in the other group are used more sparingly, perhaps only when there is a need for one of these rooms in particular. As was mentioned in Section 2.3, sometimes rooms that were not scheduled to be staffed could be opened when an examination was needed to be performed in that room and staff was available. This most likely happened more often for the group with the rooms that were not open as much, since the discrepancy between the schedule and examination data was higher for these rooms.

6
Conclusion

In this chapter the research questions will be answered, and sources of error and suggested future work will be discussed.

The first research question was "What is the examination rate of the MRI unit?". The total average examination rate at the MRI unit, which consisted of nine examination rooms, was 59.31 examinations per day during the regular work days, and 17.50 examinations per day during the holiday period. The standard deviation during the regular work days was 10.44 examinations per day, and the standard deviation during the holiday period was 19.13 examinations per day. The regular work days consisted of 55 days, and the holiday period of 10 days.

The second research question was "How much are the examination rooms open?". An examination room was open if there was at least one employee scheduled to work in it. The total number of hours that the examination rooms were open per day was 49.79 hours during the regular work days, and 13.95 hours during the holiday period. The standard deviation was 7.76 hours per day during the regular work days, and 17.26 hours per day during the holiday period.

The third research question was "How does the number of hours the examination rooms are open explain the examination rate?". Pearson's correlation coefficient for the correlation between the total daily number of hours the rooms were open and the total daily examination rate was 0.95, which showed a very high positive correlation. Thus, the number of hours the examination rooms were open explained the examination rate very well. This does not say anything about the efficiency of the MRI unit, it says that if room hours are added/removed, the number of examinations will go up/down with little variation, making it easy to predict the effects of opening and closing rooms.

Three other factors that could affect the examination rate was investigated as well, and these were the daily ratio of the staff's time that was spent on examinations, the daily average examination duration, and discrepancies between the schedule and the examination data. The variation of the total daily ratio of the staff's time that was spent on examinations and of the daily average examination duration was low, and did therefore not affect the total daily examination rate much. The discrepancy between the schedule and the examination data was relatively high, in 4 of the examination rooms there were between 6 and 10 days when examinations were performed without any scheduled staff. If the schedule more accurately reflected

when the rooms were open, it is likely that the correlation between the total daily number of hours the rooms were open and the total daily examination rate would have been higher.

The fourth and final research question was "How is the examination rate affected by demand of care not being considered when scheduling?". Since the correlation between the total daily number of hours the rooms were open and the total daily examination rate was very high, not considering the demand of care when scheduling did not seem to affect the stability of the examination rate much. Also, the ratio of the staff's time that was used for examinations was high, which shows that the employees time was well-utilized. Since Sahlgrenska Hospital is a busy hospital with a high waiting time for specialized care compared to other hospitals in Sweden, this could mean that the inflow of referrals is so high that there always will be examinations available to perform in any of the examination rooms, at any time. Taking the demand of care into account when scheduling is most likely more important at a less busy hospital, since then there is a higher probability of not having examinations that need to be performed by the scheduled staff.

Since the number of hours the rooms were open explained the examination rate well, it seems relatively safe to hire new employees, more staff hours will likely yield more examinations. Usually one or two of the examination rooms were closed every day, and hiring two more employees to be able to have one more room open would most likely generate a higher total examination rate. The ratio of the staff's time that was used for examinations were high for all the individual rooms apart from s23, and thus it seems that it is relatively easy to schedule examinations to any of the rooms, apart from s23.

Another reason for increasing the amount of employees is to make more time for the employees to be trained on the MRI scanners. The more scanners the employees can operate, the easier it is to schedule the staff, and the unit would be less affected by employees being absent. A high level of competence among the staff will also increase patient safety, helping to ensure all patients get equal treatment.

In this thesis, only one part of what leads to an efficient MRI unit has been investigated. To yield sustainable results, factors such as employee satisfaction, the employees' influence over their work situation and patient satisfaction must also be taken into consideration.

6.1 Sources of error

The discrepancy between the schedule and performed examinations is a source of error in this study. Using a time-clock system to get the actual time when the staff started and finished their work would give a clearer picture of how the staffing affects the examination rate.

6.2 Future work

The results of this thesis mainly serves as a way to understand the current situation at the MRI unit, it does not immediately support the scheduling process. To connect the schedule to the demand of care, understanding the inflow of referrals and being able to see the waiting referrals when scheduling would be valuable. For example, since brain examinations is the most common examination type, an understanding of the inflow of these referrals could be used to decide which or how many rooms to open. Even though the goal is to have as many examination rooms open as possible, it is rare that enough employees are available for all rooms to be open, and therefore a choice must be made on which rooms to open.

It would be interesting to make a linear model to explain the daily examination rate using all the factors investigated in this study. This could more clearly determine which factors affect the examination rate the most and show if there are any dependencies between the factors. This could also be used to simulate the examination rate with different numbers of employees. To include more KPIs in the model such as time between examinations and time between image series, as suggested by Mengqi et al. [15], could give a better understanding of the examination process and help identify bottlenecks. Another KPI to look at is the scan times, and how they relate to the full examination duration. This could show potential variation in e.g. patient preparation and in the setting up of the scanner protocol.

One area where lean methodologies could be applied to is the definition of referral types. Part of the lean methodology is to standardize processes, and what was found was that several referral types overlapped or had identical definitions, which is something that adds unnecessary complexity and hinders standardization. Having a clear definition of each referral type without any overlap could simplify the prioritization of examinations by cutting down the number of referral types.

Computing and comparing the same KPIs as was used in this study for the other units at the radiology department, as well as radiology departments of other hospitals, would be very interesting and could help in deciding what to focus improvement measures on. The CT unit in particular would be interesting to compare with, since CT and MRI imaging can be used for similar examination types. As MRI scan times decreases, examinations that are usually done with CT imaging can be done with MRI instead, and understanding the overlap between the two imaging techniques will be important in deciding where to schedule examinations.

58

Bibliography

[1] Göran Stiernstedt, Anna Ingmanson and Daniel Zetterberg (2016). *Effektiv vård*. Stockholm.

[2] Agneta Larsson (2018). *Capacity Planning in Specialized Healthcare*. PhD Thesis, Chalmers University of Technology, Göteborg.

[3] Swedish Agency for Health and Care Services Analysis (2013). *Ur led är tiden – Fyra utvecklingsområden for en mer effektiv användning av läkares tid och kompetens*. Stockholm.

[4] Wlad T. Sobol (2012). *Recent advances in MRI technology: Implications for image quality and patient safety*. Saudi Journal of Ophthalmology Volume 26, Issue 4.

[5] Jerry L. Prince and Jonathan M. Links (2006). *Medical Imaging Signals and Systems*. New Jersey, U.S.: Pearson Prentice Hall Bioengineering,.

[6] Xiaoguan Zhao, Guangwu Duan, Ke Wu, Stephan W. Anderson and Xin Zhang (2019). *Intelligent Metamaterials Based on Nonlinearity for Magnetic Resonance Imaging*. Advanced Materials Volume, Issue 49.

[7] Joseph R. Corea, P. Balthazar Lechene, Michael Lustig and Ana C. Arias (2016). *Materials and methods for higher performance screen-printed flexible MRI receive coils*. Magnetic Resonance in Medicine Volume 78, Issue 2.

[8] Sally Brailsford and Jan Vissers (2011). *OR in healthcare: A European perspective*. European Journal of Operational Research Volume 212.

[9] Margaret L. Brandeau, Francois Sainfort, William Pierskalla (2004). *Operations Research and Health Care*. U.S.: Springer.

[10] Abdur Rais, Ana Viana (2010). *Operations Research in Healthcare: a survey*. International Transactions in Operational Research Volume 18, Issue 1.

[11] Yu-Li Huang and Justin Marcak (2013). *Radiology scheduling with consideration of patient characteristics to improve patient access to care and medical resource utilization*. Health Systems Volume 2, Issue 2.

[12] Jonathan B. Kruskal, Allen Reedy, Laurie Pascal, Max P. Rosen, Phillip M. Boiselle (2012). *Quality Initiatives – Lean Approach to Improving Performance and Efficiency in a Radiology Department*. RadioGraphics Volume 32.

[13] Brooke V. Wessman, Andrew K. Moriarity, Vanda Ametlli, David J. Kastan (2014). *Reducing Barriers to Timely MR Imaging Scheduling.* RadioGraphics Volume 34.

[14] John F Krafcik (1988). *Triumph of the lean production system.* Sloan Management Review Volume 30, Issue 1.

[15] Mengqi Hu, William Pavlicek, Patrick T. Liu, Muhong Zhang, Steve G. Langer, Shanshan Wang, Vicki Place, Rafael Mrianda, Teresa Tong Wu (2011). *Informatics in Radiology – Efficiency Metrics for Imaging Device Productivity.* RadioGraphics Volume 31.

[16] National Electrical Manufacturers Association (2020). *Digital imaging communication in medicine: NEMA Standard Publication PS 3.* Rosslyn, VA: National Electrical Manufacturers Association.

[17] Papiya Bhattacharjee and Pradip Kumar Ray (2014). *Patient flow modelling and performance analysis on healthcare delivery processes in hospitals: A review and reflections.* Computers & Industrial Engineering Volume 78.

[18] Sveriges Riksdag (2017). *SFS 2017:30. Hälso- och sjukvårdslag.*

[19] Johan Flarup (2020). *Välkomna till Västra Götalandsregionen.* Västra Götalandsregionen.

[20] Västra Götalandsregionen (2020). *Befolkningsprognos Västra Götaland 2020-2040.* VGR Analys 2020:32.

[21] Maria Telemo Taube and Josefine Sternvik (2020). *Hälso- och sjukvårdsrapporten 2020, SKR.* Koncernavdelning data och analys, Västra Götalandsregionen.

[22] M.M Mukaka (2012). *A guide to the appropriate use of Correlation coefficient in medical research.* Malawi Medical Journal Volume 24, Issue 3.