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Model for scheduling multi-skilled personnel

at the Department of Clinical Neurophysiology

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Master Thesis Health Sciences

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I. Summary

This study is performed at the Department of Clinical Neurophysiology in Enschede. It is a self-operating department within Medisch Spectrum Twente where the functioning of the central and peripheral nervous system is examined by lab assistants. Within the department there is a need for improving the process of creating the personnel schedule, since the schedule is currently made manually by a lab assistant, which is time-consuming and complex.

The purpose of this study is to investigate whether it is possible to find a simple, clear and quick way to create a personnel planning. With the method found, a decision support model (also called personnel planning tool) is designed to help the planner creating a schedule. The planning tool should provide the planner with a weekly schedule in which the tasks in specific examination rooms are assigned to an available employee with the right skills. The input parameters are employees, examination rooms, shifts and skills. Output variables are an automatic generated week schedule, and an overview of the over- and under capacity.

First, the problems at the department are indicated by a context analysis. Relevant for the planning tool are the big differences in the skills levels and the unclear digital system in which the planning currently is made. Other problems, more relevant to patient appointment scheduling, are identified as well.

Second, a literature study is conducted to find an appropriate method to solve the problem. The goal is to assign an employee that is available during a shift and has the right skill to perform the examination to every examination room where examinations are scheduled. We find that integer linear programming is a suitable method to solve the problem. The method can solve optimization problems by using an objective, decision variables and constraints. The objective is to minimize the unfulfilled positions in examination rooms and to minimize the number of employees that are more than two times per week in the same examination room, in order to obtain a schedule in which employees are assigned to needed examination rooms and that it offers variation to the employees. The modeling environment AIMMS 3.12 is used to implement the model.

The conclusion is that the new planning tool can make a week schedule in a matter of seconds, when using standard input data of the department. Changes, like sudden absence of an employee, can be easily processed in the model after which the model provides the planner with a new day and/or week schedule.

It is recommended to improve the model and investigate whether the decision support model can be extended for the use at other departments in the hospital with comparable scheduling problems. Furthermore, it is advised to print out the schedules for the employees, to ensure that they do not have to log onto the computer when they want to see to which rooms they have to go.

II. Samenvatting

Dit onderzoek is uitgevoerd op de afdeling Klinische Neurofysiologie in het Medisch Spectrum Twente te Enschede. Het is een afdeling waar door laboranten het functioneren van het centrale en perifere zenuwstelsel wordt onderzocht. Binnen de afdeling bestaat de behoefte om het proces van het creëren van het personeelsrooster te verbeteren. Momenteel wordt het schema handmatig gemaakt door een laborant, wat een tijdrovende en complexe taak is.

Het doel van het onderzoek is om te kijken of het mogelijk is een simpele, overzichtelijke en snelle manier te vinden om de personeelsplanning te maken. Met de gevonden methode wordt een model (ook wel planning tool genoemd) gemaakt waarmee de planner automatisch een schema kan samenstellen. De planning tool moet de planner voorzien van een weekschema waarin de taken tijdens bepaalde diensten in specifieke onderzoekskamers worden toegewezen aan een beschikbare werknemer met de juiste vaardigheden. De input parameters zijn werknemers, onderzoekskamers, diensten en vaardigheden. Output variabelen zijn een automatisch gegenereerde weekrooster en een overzicht van de over- en ondercapaciteit.

De problemen op de afdeling zijn inzichtelijk gemaakt door het uitvoeren van een context analyse. Relevant voor de planning tool zijn de grote verschillen in de beheerste vaardigheden en het onduidelijke digitale systeem waar in gepland wordt. Er zijn ook andere problemen geïdentificeerd, maar deze zijn relevanter voor de patiënten planning dan voor de personeelsplanning.

Een literatuurstudie is uitgevoerd om een goede methode te vinden. Het doel van het model is dat aan elke onderzoeksruimte een werknemer toegewezen moet worden die aanwezig is tijdens een bepaalde dienst en de juiste vaardigheid heeft om het onderzoek uit te voeren. We hebben gevonden dat integer lineair programmeren een goede methode is om het probleem op te lossen. De wiskundige methode kan met behulp van een doelfunctie, beslissingsvariabelen en voorwaarden optimalisatievraagstukken oplossen. De doelfunctie is het minimaliseren van onvervulde posities in onderzoekskamers en het minimaliseren van het aantal werknemers dat vaker dan twee keer per week in dezelfde onderzoekskamer werkt, zodat er een schema verkregen wordt waarin de werknemers aan de benodigde onderzoekskamers zijn toegewezen en het schema variatie biedt. Het programma AIMMS 3.12 is gebruikt om het model te maken en te implementeren.

De conclusie van het onderzoek is dat het gemaakte model met de standaard input data in enkele seconden een optimaal week schema kan maken. Veranderingen, zoals een plotselinge afwezigheid van werknemers, kunnen gelijk verwerkt worden in het model. Hierna geeft het model gelijk een nieuw dag- of weekschema.

Aanbevolen wordt om het model te verbeteren en te onderzoeken of het beslissingsondersteunende model uitgebreid kan worden naar andere afdelingen in het ziekenhuis. Verder wordt het aangeraden om de automatisch gegenereerde schema’s uit te printen voor de werknemers, zodat zij niet meer hoeven in te loggen om te zien naar welke onderzoekskamers zij moeten gaan.

III. Preface

Making a work schedule for ten employees might not always be as easy as it sounds. This is certainly true for the Department of Clinical Neurophysiology at Medisch Spectrum Twente, where every examination room must be provided with an available employee with the right skill to perform specific examinations. So, the last five months I have been working on an automatic solution to this problem. I am very proud to present the decision support model to you in this report, which also is the final step in obtaining my masters' degree for Health Sciences at the University of Twente in Enschede.

A few people were essential for bringing this master to a good end. I like to thank Ingrid Vliegen for her knowledge, enthusiasm, and positive attitude, and also Maarten IJzerman for his contribution in supervising. Annet Tackenkamp and Mirjam Stappenbelt supported me practically at the department and were always open for questions. During the development process of the actual model, Gerhard Post helped me to bring linear programming in practice. I'd like to thank my colleagues of the department of CNPH and CHOIR at the University of Twente for their support and advice.

Besides these advisors, I would like to thank a number of people who encouraged me during my studies. Floris Koopman, for his love and patience (we were also rebuilding our house in the meantime). Once a week, I had the best lunch time with Hester Meijer, which always gave me new energy. I like to thank several friends, for taking the effort of reading my thesis and giving advice about writing in English. I would also like to thank my dear family, friends and others that supported me in any way, but remain unnamed here.

Bibianne Geerts

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IV. List of Abbreviations

ABPI	Arterial Brachial Pressure Index
AFT	Autonomic Function Test
BAEP	Brainstem Auditory Evoked Potentials
BEP	See BAEP
CNPH	Clinical Neurophysiology
CTS	Carpal Tunnel Syndrome
ECAR	Name of examination room where Duplex is performed
EEG	Electro Encephalography
EMG	Electro Myography
ENG	Electro Nystagmography
EP	Evoked Potentials (examination room)
HTG	Hematotachography (or Doppler)
LP	Linear programming
ILP	Integer linear programming
MEP	Motor Evoked Potentials
MSLT	Multiple Sleep Latency Test
MST	Medisch Spectrum Twente
SER	See SSEP
SSEP	Somato Sensible Evoked Potentials
T3	Portable Sleep Monitor (used for Polysomnography)
VER	Visual Evoked Response

Chapter 1: Introduction

This study comprehends finding a time saving and simple way to create a week schedule for the lab assistants at the department of Clinical Neurophysiology or, in other words, allocating the available employees with the right skills to an examination room.

This chapter starts with an overview of the department in Section 1.1. In Section 1.2, the problem is defined and in Section 1.3 the methodological approach is described. In the last section, Section 1.4, the restrictions of this study are explained.

1.1 Department of Clinical Neurophysiology

Medisch Spectrum Twente (MST) is a top clinical hospital with more than 4,000 employees, 1,070 beds and 250 medical specialists to support the care of patients. Every year there are around 33,000 intakes and close to half a million visits at the outpatient clinics of MST. It is one of the biggest nonacademic hospitals in the Netherlands. With five locations in the region of Twente, situated in Enschede, Oldenzaal, Losser and Haaksbergen, the hospital offers medical care to close to circa 264,000 citizens (MST, 2011).

This study is performed at the department of Clinical Neurophysiology (CNPH) in Enschede. It is a self-operating department in MST where the functioning of the central and peripheral nervous system is examined. The tests are performed by lab assistants, but also neurophysiologists, physician assistants and student lab assistants play an important role at the department. All kinds of patients, elective and emergency, are referred by a specialist or a general practitioner for an examination at the department. More than twenty different examinations are performed by ten lab assistants and three student lab assistants, whom are at different levels in their study progress. The lab assistants are supervised by several neurophysiologists and two physician assistants, who also work part of their time at the department of Neurology. The requests for examinations are handled by the secretary (CNPH, MST, 2012).

1.2 Problem definition

Within the department there is an existing need for an improvement in creating the personnel schedule. Here, scheduling is defined as assigning an appropriate number of workers to the tasks during each day for a certain planning horizon. The schedule is currently made manually by a lab assistant. Developing this schedule is complex and time consuming; time that could otherwise be used for the care of patients and maintaining high quality of the examinations.

The digital system X/Care, in which the schedule is made, is very unclear and inconvenient as it is meant for patient appointment planning and not for personnel planning. In this report, a clear system means an accessible and understandable tool for making and reading the personnel schedule.

At the department, there are several factors which make scheduling personnel difficult and time consuming, namely: the skill levels of lab assistants, availability of lab assistants, fixed programs in examination rooms, and keeping the experience level up to date.

The planner schedules only the lab assistants and tries to bear in mind all the above mentioned factors, as well as the wishes of the lab assistants. The rules for planning the personnel, however, are mostly in the mind of the planner and therefore it is hard to take over the scheduling task in case of absence of the planner.

The problem can be defined with a research objective, and is formulated as follows:

The focus of this research is to improve the process of personnel scheduling at the department of Clinical Neurophysiology by creating a clear, less time consuming, and simpler method.

1.3 Methodological approach

In this study four steps are performed to reach the research objective.

1. Defining the scope of the study
2. Finding methods and specifications for the model
3. Developing the actual planning tool
4. Testing the model

Before designing a new planning tool, first an analysis of the department is performed to find the scope of the problems. This part of the study will provide insight into the processes, planning and control, and the performance of the department.

Once the scope and problems are identified, the second step is to determine what method should be used to design a model for solving the planning problem. The most suitable method is used by performing a literature review. The specifications for the model are found by interviews with the planner, the head of the department and the lab assistants.

With the method found, a decision support model is developed to help the planner creating a schedule in a simple and less time consuming way. The goal of the planning tool is to provide the planner with a weekly schedule in which the tasks in specific examination rooms are assigned to an available employee with the right skills.

Finally, during the last step the designed tool can be used by the planner to save time in solving the complex puzzle of scheduling employees. A model can also be used to test different situations which may lead to improvements in the schedule itself, not only in the process of scheduling.

1.4 Restrictions

Two important restrictions apply to this study. First, in the time that is available, this research concentrates on the process of personnel planning, not on patient appointment planning, improvement of work processes or reduction of examination time. However, improving those areas altogether could increase the productivity and efficiency of the department. For this study those directions were considered, but a suitable solution for the process of scheduling the personnel is what is needed most by the planner and the head of the department.

A second restriction is that the new planning method should not lead to a lower quality of the examinations. Therefore, the new planning tool should vary in allocating the employees to different examination rooms to keep all the skills up to date.

Other, more specific, constraints and requirements are described in the remainder of this thesis, which is structured as follows. Chapter 2 presents the context analysis and Chapter 3 describes a literature review. Next, the model design for the planning tool is set out in Chapter 4. Several what-if analyses are described in order to find improvements for the schedule, which are described in Chapter 5. The results of the analyses and the limitations of the model are provided in Chapter 6, after which conclusions and recommendations are given in Chapter 7.

Chapter 2: Context analysis

In this chapter the context of the problem is analyzed. This analysis is performed to describe the processes at the department, and to find the bottlenecks for employee scheduling. The current process of patient appointment scheduling is described in Section 2.1, followed by a description of the main subject of this research, the current process of employee scheduling, in Section 2.2. Finally, a conclusion is given in Section 2.3.

This research has been performed using the hospital information system of the MST, named DataWarehouse. This system is integrated with X/Care, the patient appointment system from which all the data about the patient appointments is gathered. With this system several overviews have been generated with data relevant to the department from January 2009 till March 2012.

2.1 Process of scheduling patients

The process at the department, including patient and employee scheduling, looks in short like shown in Figure 2.1. In the following sections the steps of a patients' way through the department (encircled) are explained in detail. After the patients'appointment is scheduled, the employees can be scheduled since the demand is then known (the number of patients appointments determine the demand). This process will be explained in Section 2.2.

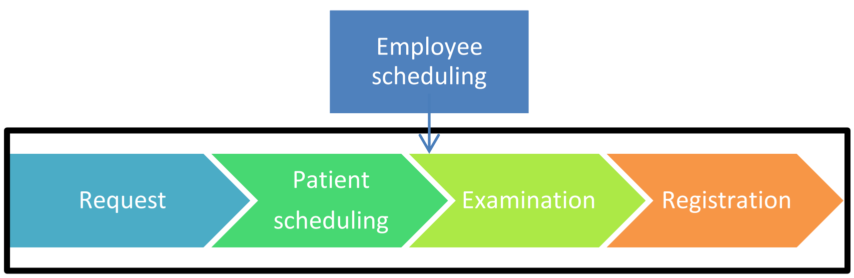

Figure 2.1 Brief overview of the process at the department of Clinical Neurophysiology.

2.1.1 Request

The requests for the medical examinations come in at the central point of the administration office. There are three ways in which a request can be made and each apply has a specific process.

Internal request

A specialist from the hospital refers the patient for examination to the department of Clinical Neurophysiology. Yellow request forms are filled out and send to the secretary of Clinical Neurophysiology. The secretary looks in the patient planning system when a room is available and schedules the patient in the first available time slot. The patient can shift the appointment by calling the secretary.

The examinations can be requested by any specialism. The total number of requests in 2010 were 21,673 and it declined in 2011 to a number of 19,272 (DataWarehouse, MST). These numbers include appointments with clinical neurophysiologists and physician assistants, not solely for examinations which are performed by lab assistants.

In 2011, most examinations that were requested were by the neurology department (37.8%), followed by the lung department (19.5%) and the general practitioners (17.1%), as shown in Figure 2.2. Also, vascular surgery requested a lot of examinations, but since some standard tests in 2011 were performed at their department (and therefore registered at vascular surgery) the percentage declined from 24.0% to 9.8%. There are reserved blocks, available for all patients, for tests that are performed very regularly.

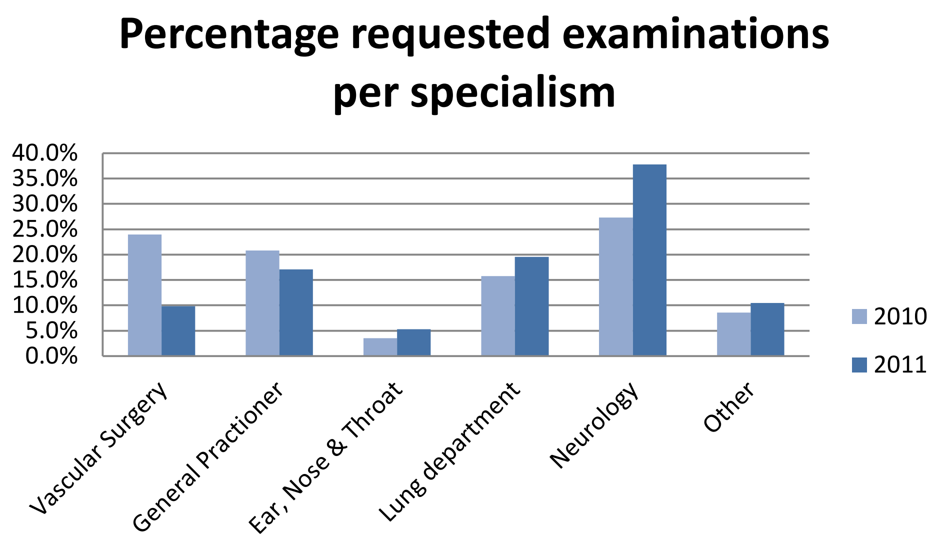

Figure 2.2 Overview of requesting specialisms. From DataWarehouse, MST.

Request by a general practitioner

Patients can also be referred directly by the general practitioner, who can refer patients to a fast-track care path like the Carpal Tunnel Syndrome (CTS) track. In the agenda a standard time block is reserved for requests directly from the general practitioner. The patient calls the secretary directly to make an appointment for examination.

Urgent request by a specialist

The last way of requesting an appointment is via the process for urgent requests. Most of the times an urgent (also called emergency) request is announced via the telephone, but the official yellow request form should always be filled in and brought to the department. The secretary calls the runaround (a lab assistant with the task to handle the urgent examinations) or looks for another available lab assistant, and sends the lab assistant to the emergency case. When there is an emergency request from the intensive care unit (ICU), the specialist can also approach a lab assistant themselves. This is later registered in the system.

There are a few rules of thumb for emergencies. The only emergency test that needs to be performed immediately is when a patient has an insult in status. Other emergency tests need to be performed within the same day if possible. If not, it can be planned for the next day in an available time slot. There is a 24 hour service for Duplex examinations, which means that an examination room for this test is reserved every day.

Since the beginning of 2012, the emergency requests are registered in X/Care. Before, the examination was registered afterwards as an appointment in the agenda in X/Care on the day it was performed but not marked as an urgent request. In Figure 2.3, the numbers of urgent requests from January 2011 till February 2012 are provided.

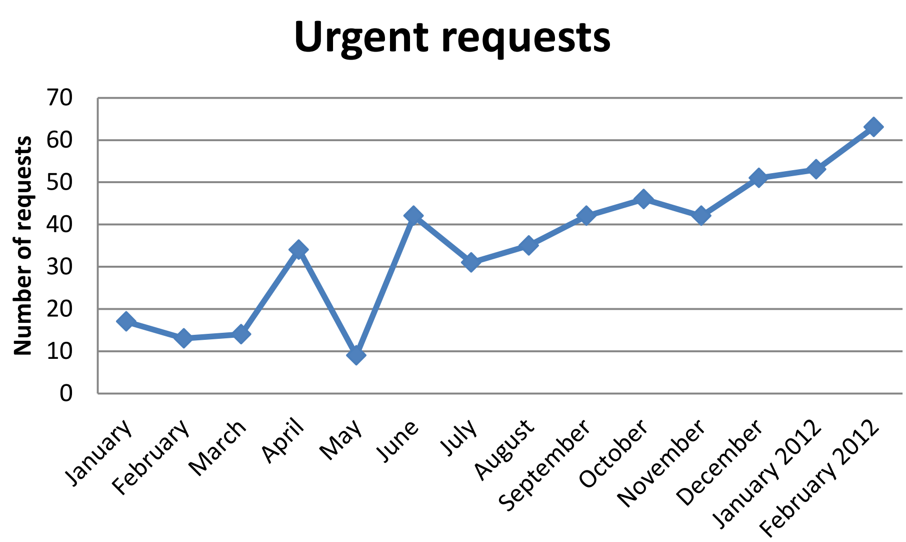

Figure 2.3 Number of emergency (or urgent) requests from January 2011 till February 2012. From DataWarehouse system, MST.

Since the requests are marked properly, the numbers are increasing. In May 2011 only 9 urgent requests were registered, this might be due to lack of registering or a decrease in requests. We assume that in the last month, February 2012, every request is marked properly. We see that the number of urgent requests is 10% of the total number of requests. The average number of requests per month in this timeframe is in total is 623.

2.1.2 Patient scheduling

The consequence of patients that come from different departments, described in the previous paragraph, is a diverse case mix. In 2011, 54.4% of the patients were male and 45.6% were female. Furthermore, lab assistants have to deal with very young children up to immobile elderly patients. These differences between patients leads to deviations of the standard scheduled time for examinations and are taken into account when scheduling.

Patients can be divided into four different categories:

- *Clinical patients who are staying in the hospital*
  Clinical patients can be visited at the nursing department, as often happens to perform the Arterial Brachial Pressure Index (ABPI) examination, or they can be brought to the department for an appointment.
- *Clinical patients who need an examination during surgery*
  Patients who are operated on their carotid arteries are monitored during the surgery by a lab assistant from Clinical Neurophysiology. These surgeries are planned ahead and the needed equipment is reserved.
- *Outpatients that come to an appointment at the clinic*
  Outpatients visit the clinic for all sorts of tests or for certain fast-track care paths like the CTS or vascular track. Tests are performed to help the general practitioner or specialist to decide on the best treatment or what may cause some specific symptoms.
- *Emergency or urgent patients that have to be examined at their department*
  Patients in need of an urgent examination, for example patients who come in at the intensive care unit (ICU), are examined at the department where there are. Often these patients are too ill to move.
  The runaround is always available for emergencies and could be called to go to the ICU to make an EEG or to perform another needed test. There is one mobile device of the EEG, which is taken up to the ICU where everything is connected to the patient to start the measurement. Other emergency tests are performed at the department, which means that the patients are brought to the department by patient transport.

2.1.3 Examinations

After the appointment is scheduled according to the patients' needs, the examination can be performed. In this paragraph is explained which medical examinations are performed by lab assistants at the department of Clinical Neurophysiology. Also a description is given of the locations where the examinations are performed.

Medical examinations

At the department of Clinical Neurophysiology, there are more than twenty types of medical examinations that can be performed. Those examinations test the functioning of the brain and nerves in the human body. Some tests are performed daily, others are performed more irregularly. A few tests have different forms in which it can be performed, like a limited or extended version.

In 2009, 2010, and 2011 on average 12,000 examinations per year were executed by lab assistants. In Figure 2.4 the percentage of examinations performed in 2011 is given for the different types of examination. Explanations for the abbreviations of examinations can be found in the List of Abbreviations (p. 8). EMG, Doppler and EEG tests with respectively 31.6%, 20.9% and 18.6% are requested most. Some very specific examinations like the Botox treatment and AFT were not performed very often in 2011.

Medical examinations in 2011

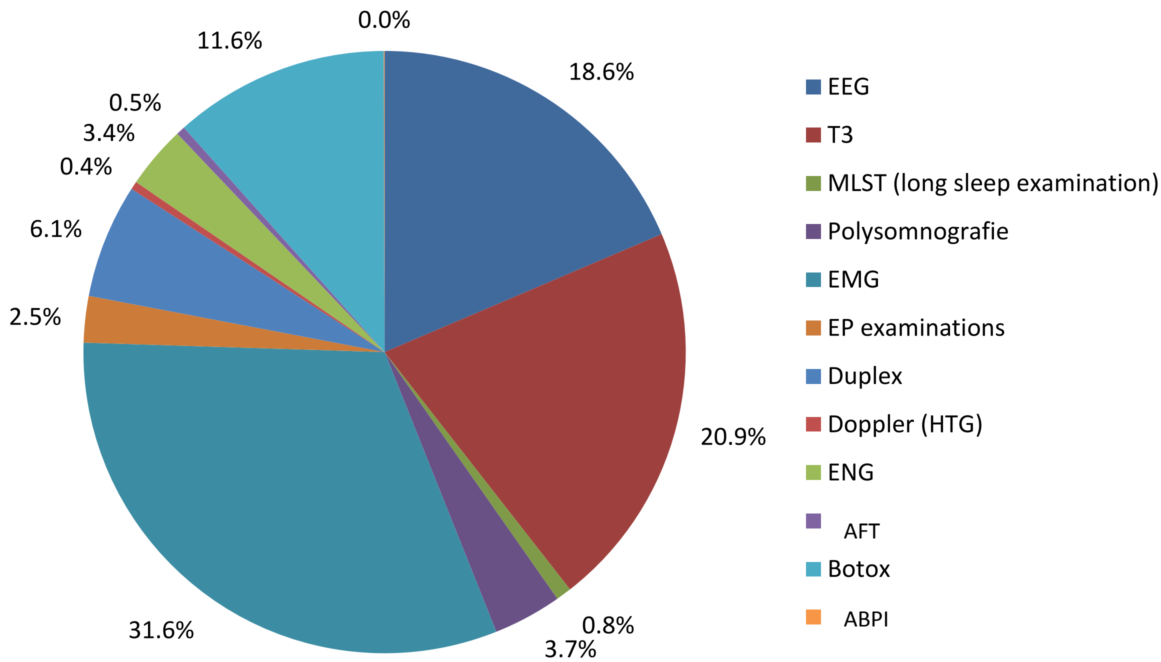

Figure 2.4 Performance percentages per medical examination for 2011. From DataWarehouse system, MST.

The staff that is available at the department consists of neurophysiologists, physician assistants, lab assistants, student lab assistants, students, secretary and clinical researchers. Lab assistants conduct the examinations. Currently, ten lab assistants (6.82 FTE) and three student lab assistants (2.91 FTE), which are at different levels in their study progress, are working at the department. The lab assistants who perform the examinations are assisted by several neurophysiologists and two physician assistants, who also work part of their time at the department of neurology. The requests for examinations are handled by the secretary (1.87 FTE).

Most of the medical examinations are performed by one lab assistant, although sometimes working with two lab assistants is preferred, depending on the kind of test. Furthermore, for some tests like the EMG, the presence of a neurophysiologist or physician assistant is required. Lab assistants specialized in clinical neurophysiology are scarce. That is the reason for MST to recruit one student lab assistant per year to guarantee the continuity of qualified lab assistants.

Locations

There are several locations where examinations are performed. In Enschede, at the department of Clinical Neurophysiology, the main part of the examinations is performed. External examination rooms are available in Oldenzaal; Doppler, EMG and EEG are accomplished there a few times per week. These frequently requested examinations are offered closer to home to deliver service for the patients. In Figure 2.5 the total number of examinations in Oldenzaal and Enschede are presented. In

2010, more examinations were performed in Oldenzaal than in 2011. This is caused by recent reorganization of the hospital in Oldenzaal. In the near future, the facilities in Oldenzaal will be improved with the goal to perform more examinations.

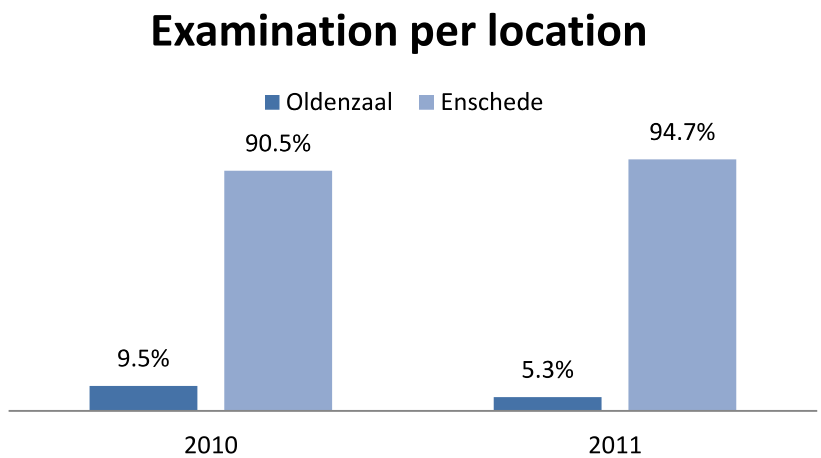

Figure 2.5 Examinations performed in Enschede and Oldenzaal in 2010 and 2011.
From DataWarehouse, MST.

Within the hospital in Enschede examinations are also performed at other departments, such as at Vascular Surgery or Intensive Care Unit. On specific days, lab assistants go to the other departments to perform the tests in reserved examination rooms. These examinations are often registered in the agenda of the other department.

At the department of Clinical Neurophysiology itself are eight examination rooms available, all differently equipped, to perform the examinations. These examination rooms are described in detail in Appendix A, Section 2. “Occupancy of examination rooms”.

2.1.4 Registration

Once the patient underwent the examination, the secretary registers in the appointment in X/Care that the examination has been performed. In case the patient did not show up, that is registered as well. This information is automatically sent to the financial department. Sometimes urgent requests are registered after the examinations already have been performed.

The outcome of the test is examined by the lab assistant after the patient leaves the examination room. A short report is written in X/Care or in a shared folder in order to let the specialist assess the results.

2.1.5 Conclusion

The key issues in the process of patient appointment scheduling are listed in Table 2.1. They concern the steps of requesting examinations, actual patient scheduling, examinations and locations, and registration.

Table 2.1
Problems found in the process regarding patient appointment scheduling.

Process	Problem
Request	There is no clear guideline for requesting an urgent examination.
Patient scheduling	Urgent patients cause variability and uncertainty for the personnel planning, even with the runaround, because not every lab assistant that is runaround can perform all the tests. This causes waiting times for the patient and unclear situations for the personnel.
Examination & Locations	When lab assistants have to go to other departments or an external location, they cannot assist other colleagues with their examinations if needed. Furthermore, anticipating on incoming emergency tests is more difficult.
Registration	The registration of urgent examinations is not always performed consequently, which causes difficulties in forecasting the amount of time that must be reserved for urgent cases. For instance, if it is necessary to have a one lab assistant standby all day for emergencies.

These problems are identified in the processes related to patient appointment scheduling. Other problems in the performance of the department are identified as well, but they are outside the scope of this study. However, they are too serious to stay undisclosed. An overview of the conclusions about these problems can be found in Appendix A, Section 6. “Conclusion”. We recommend that the problems are studied in another research.

2.2 Process of scheduling lab assistants

This section describes how the process of employee scheduling, the assignment of lab assistants with a skill to a specific examination in a specific examination room, currently is performed at the department (see Figure 2.6). By performing this analysis, bottlenecks for scheduling lab assistants can be found.

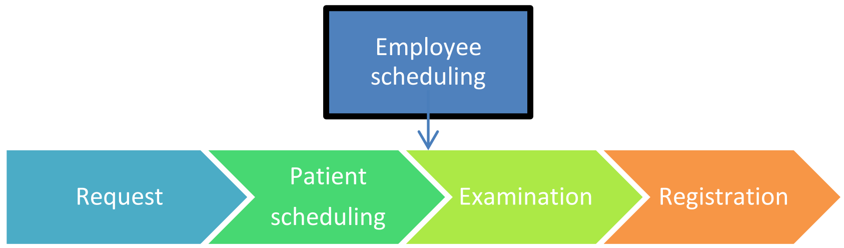

Figure 2.6 Brief overview of the process at the department of Clinical Neurophysiology.

2.2.1 Manual scheduling approach

Currently, the personnel's planning is made by a lab assistant (hereafter called planner) who tries to perform this task in between scheduled examinations. These moments are chosen ad hoc, and in this time as many days as can be scheduled are settled. At least four hours per week are spent to make the schedule. The schedule is made in the patient appointment program X/Care (McKesson) which has no function to schedule employees automatically.

The planner has to take into account several conditions: skills, availability and the appointments in examination rooms (demand). These conditions are described in the following sections. Currently, all this needed information for scheduling employees is not written down, but is memorized by the planner.

Also, the planner has to take into account the wishes of employees. To register a special event for a staff member or a request for an off day or holidays, the so called 'black agenda' is used. This is a big, physical agenda that lies in the multifunctional room so everyone can write their requests or special events in it. The planner and the secretary use this agenda to process the special events into the schedule.

The actual scheduling is performed by looking which lab assistants are available, in which examination rooms appointments are planned and which skills are needed. The planner tries to get an overview by opening all the agendas of examination rooms. The planner schedules manually by putting the initials of lab assistants above an examination room in the agenda in X/Care, so the lab assistants are assigned to the appointments in that room. The lab assistants are scheduled in different rooms for the morning and afternoon shift, to ensure variation.

Altogether, the process of scheduling manually consists of puzzling the pieces of information into a non-accessible schedule in X/care. This is time consuming, complex and sometimes frustrating.

2.2.2 Scheduling in X/Care

As mentioned previously, the schedule for personnel can be viewed in a digital patient appointment agenda, but it is not an accessible overview. X/Care is a care management system used to register, plan and charge patients in the hospital. This system has no special function for scheduling personnel, but is still used to schedule the lab assistants. In the patient appointment program X/Care, it is possible to make different agendas. One can make an agenda per room, per doctor or doctors' assistant, or per outpatient clinic or treatment. In the current procedure the appointments are scheduled per room.

The available rooms can be made visible in an agenda overview, with a maximum of eight rooms. The secretary knows in which room certain tests can be performed and schedules a patient in a room for the specific examination. They also know when the fixed programs take place and they also schedule the lab assistants for other locations, like Oldenzaal or Vascular Surgery. When an appointment for a patient is made, the secretary chooses the first available timeslot in which a room with the right equipment is available.

For every request the secretary decides how much time is needed for a certain test. This is based on experience and knowledge, but mostly the maximum time for the examination is scheduled. When it is difficult to decide how much time is needed, a neurophysiologist or lab assistant is consulted. Table 2.2 gives an overview of the current minimal and maximal times per treatment. Differences in times are determined by the type of patient, for example children or elderly, and what examination needs to be performed.

Table 2.2

Overview of examinations with minimum and maximum time standards.

Examination **Time (min)**	**EEG**	**EEG sleep deprivation**	**EEG home**	**EEG operation room**	**AFT (EEG + blood pressure)**	**Duplex**	**MAG/STIM**	**HTG**	**VEP**	**SSEP**	**BAEP**	**ENG**	**EMG**	**Polygraphy at home**	**ABPI**	**Emergency ICU**	**Doppler**
min	45	60	60	-	60	30	45	10	30	45	25	60	15	60	10	-	20
max	60	120	105	-	90	45	90	30	60	90	45	90	30	80	30	-	45

After patients are scheduled, the planner can schedule lab assistants to an examination room by putting the initials above a day part in the agenda. An example of a week schedule for five rooms is presented in Figure 2.7. As can be seen, it is unclear which room it is and hard to read the initials. These initials are mostly copied to the next week, but this often leads to errors. There are three blocked times in the agenda a day, namely two coffee breaks and one lunch break. The lab assistant switches from task after the lunch break, so the work will not get boring, too heavy or difficult. Also, rooms can be blocked if there is no sufficient number of personnel or scheduled patients.

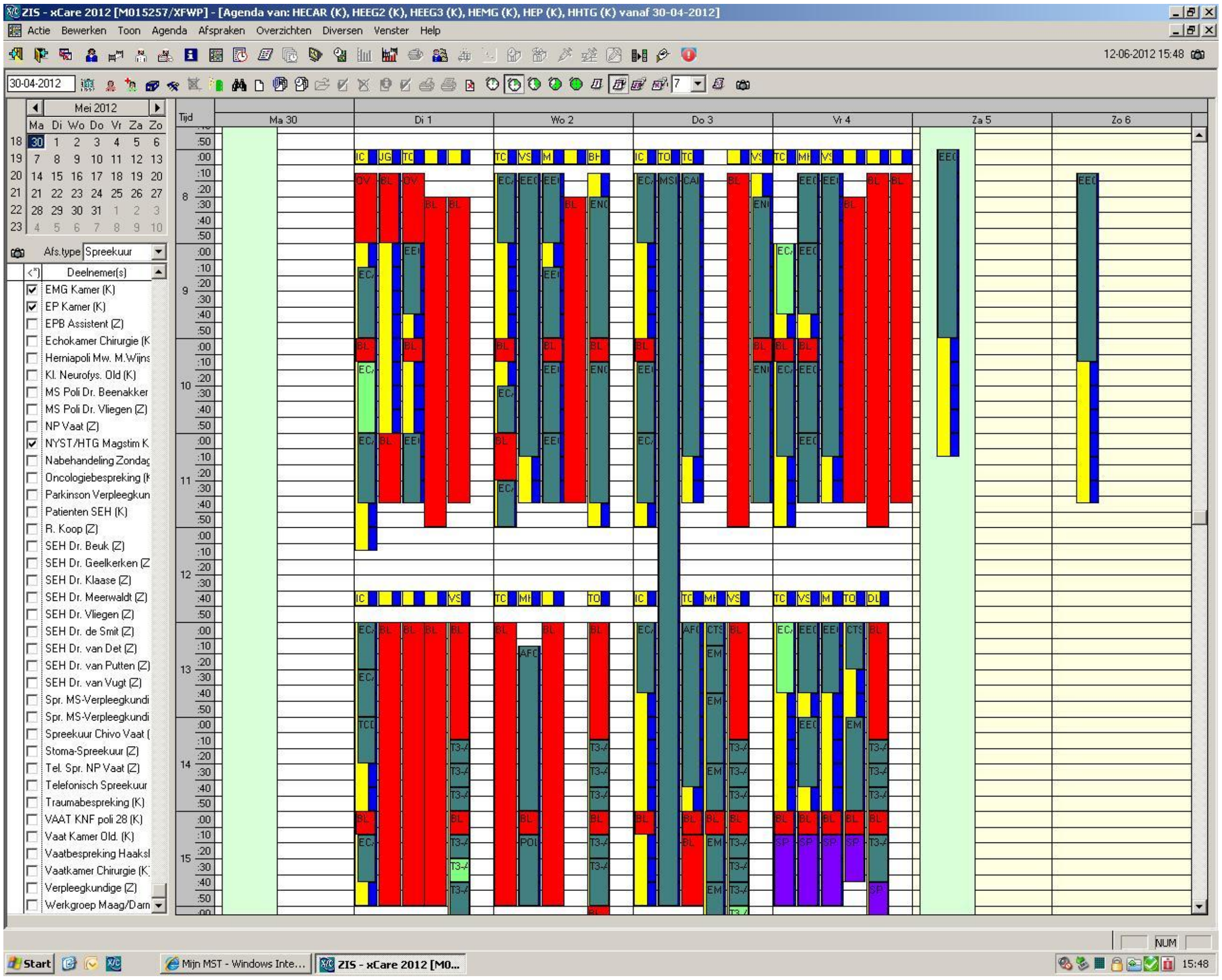

Figure 2.7 Agenda in X/Care with five examination rooms opened. Above the day parts the initials of the lab assistants are put in the yellow blocks. Red blocks indicate that the rooms are closed, grey blocks are the appointments.

2.2.3 Skill levels

The skill levels of the lab assistants are not equal. In total, ten experienced lab assistants are working at the department, and three student lab assistants are taught by assisting during examinations. Of the three student lab assistants, two can perform several basic examinations on their own; the other walks along with the experienced lab assistants.

The number of skilled lab assistants per examination type is displayed in Figure 2.8. Most lab assistants can perform an EEG examination, but only four can perform Duplex and three a Single Fiber examination. To perform the tasks of the runaround, a lab assistant must master all the examinations. This is a lab assistant is available for emergency cases and performs the ABPI tests. Often, this test is performed at the nursing department during the morning program. However, most of the lab assistants are not able to perform the Duplex and Single Fiber tests but are scheduled for runaround anyway. In 2011, Single Fiber was only requested 23 times by specialists and therefore three lab assistants are sufficient. For the Duplex, that is requested increasingly, four lab assistants are probably not sufficient.

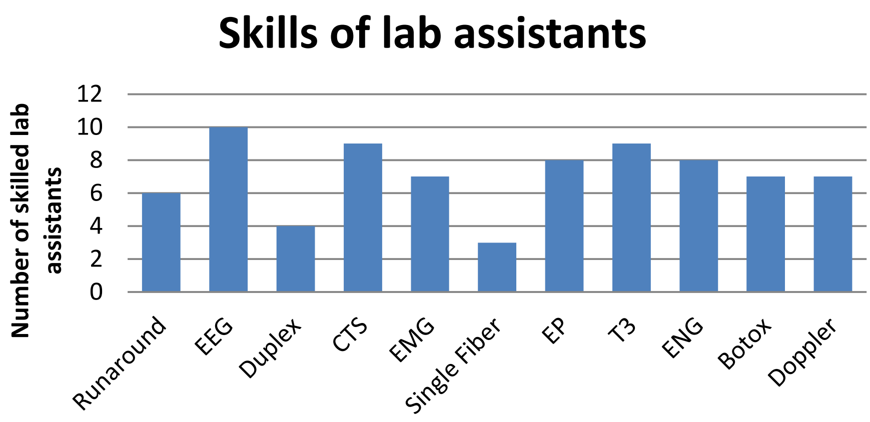

Figure 2.8 Number of skilled lab assistants that can perform specific examinations.

The process to learn how to perform a specific examination is very time consuming. This is caused by two factors: there is not enough time for a lab assistant to walk along with an experienced lab assistant because of their own program and the process is very difficult to learn and requires a lot of practice. Furthermore, a lab assistant must first know the theory about the specific examination before he starts in practice. This makes it very hard to make a personnel planning in which every employee gets enough exercise for all the tests and, at the same time, cover all the requests made by the specialists.

2.2.4 Demand – fixed programs in examination rooms

In Table 2.3 an overview of the current programs of the department is presented. In the left column, all the frequently scheduled programs and examination rooms are listed. The days are divided into a morning and afternoon shifts.

Blue blocks represent the fixed programs; these are obligated due to agreements with other departments or due to fast-track clinical care paths. These care paths are relevant for Duplex, EMG, CTS, Doppler, Botox and surgeries. For the Doppler test at the department of Vascular Surgery, sometimes two lab assistants are needed to perform the examinations.

Green blocks in the table represent programs that are necessary, but can be closed (or blocked) in case of capacity problems, unexpected events or the absence of a neurophysiologist. The programs are so called optional. The EEG test can be performed in three rooms, but as a rule always just two rooms are available in the agenda.

Table 2.3

Overview of the current programs at the department of Clinical Neurophysiology.

Shift	Monday		Tuesday		Wednesday		Thursday		Friday	
Examination room / Program	morning	afternoon	morning	afternoon	morning	afternoon	morning	afternoon	morning	afternoon
Runaround										
ECAR										
EEG 1										
EEG 2										
EMG										
CTS										
EP										
ENG										
Vascular Surgery (Doppler)										
Botox										
Oldenzaal Doppler										
Oldenzaal ENG										
Oldenzaal EMG										
OR Carotid Arteries	*Uneven week*		*Even week*				*Uneven week*		*Even week*	
Total fixed programs	3	4	4	5	3	2	3	4	4	3
Total programs	8	8	8	8	8	7	9	9	9	8
Total need lab assistants	8	8	8	9	8	7	9	10	9	8

Note. Blue = fixed program or room; green = optional program or room.

2.2.5 Availability of personnel

Almost all lab assistants work part time. There is also a difference between their schedule in even and uneven weeks. This is not automatically processed in the current schedule, so the planner must keep it in mind. The lab assistants know for themselves when they have to work each week. When they arrive at work they look in X/Care in which examination room they have to be.

There are many fixed programs in the agenda of the department. This is due to the agendas of other departments in the hospital, to the availability of a specialist or to programs that are part of a fast-track clinical path. In Figure 2.9 the capacity is shown. Presented are how many fixed programs there are per shift, how many programs (or rooms) could be open on a certain day (optional programs) and what the current capacity in terms of available lab assistants is (present lab assistants). The availability of personnel is shown according to the current schedule. In this figure the student lab assistants are not included, because they are still learning to perform the examinations solely.

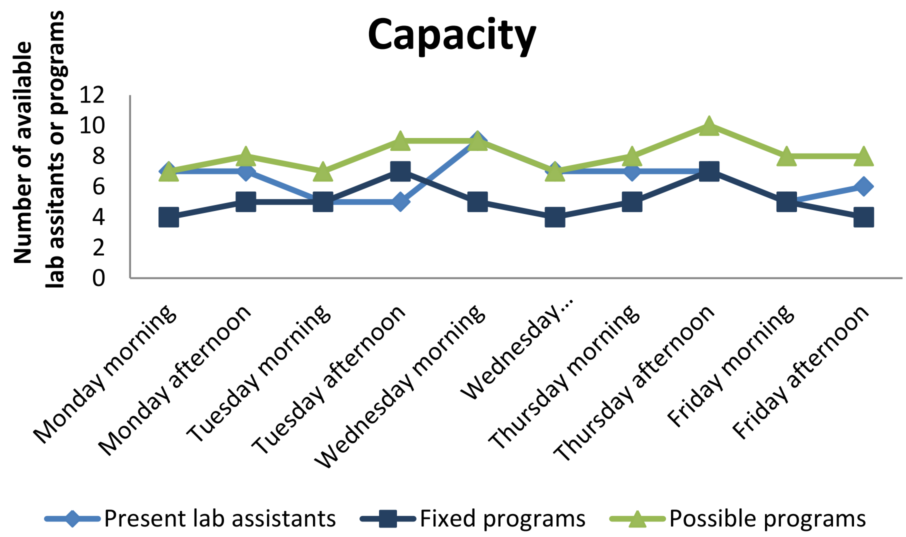

Figure 2.9 Overview of minimal and maximum number of programs and available lab assistant in a week.

From this figure one can see that on Tuesday afternoon the capacity is always too low, even for the fixed programs. Furthermore, there is no capacity for emergencies on Tuesday morning, Thursday afternoon and Friday morning. On the other days the capacity is sufficient, but it is never possible to open all the examination rooms. One can see a peak of available personnel on Wednesday morning, although the number of fixed programs is average. When there is a shortage of personnel, this is currently solved by using the most skilled student lab assistants for examinations which they do not master completely, or hire a flex worker.

The fixed programs are a constraint for this study, although rearranging them might solve problems with the capacity. However, that will be very difficult to realize because the programs are bounded with other departments with complex rosters.

2.2.6 Control

The manual constructed schedule is planned ideally six weeks ahead. Therefore, employees must apply their off days minimal six weeks ahead in the black, physical agenda. The schedule for the next week is always checked again and often adjustments are done. This can be very time consuming in the case of big adjustments, for instance sudden absence of a specialist.

Currently, there is no tactical planning with certain goals or the use of performance indicators. Occupancy rates, absence, waiting times, or costs indicators are not regularly checked to control the right capacity. With the current schedule it is a challenge to find the right number of lab assistants with the skills that are needed. In Appendix A the current performance indicators are discussed.

2.3 Conclusions

The context analysis leads to the conclusion that there are several bottlenecks at the department which cause creating the personnel schedule to be time consuming and complex. For these bottlenecks a solution must be found to make the scheduling process of employees less time consuming and complex. The following main problems in the process for scheduling the employees can be identified and are listed in Table 2.4:

Table 2.4

Problems found in the process regarding employee scheduling.

Process	Problem
Scheduling manually	The roster in X/Care makes the schedule very unclear to understand. It is difficult to make the schedule because there is no simple overview. This makes it very confusing for the planner. Furthermore, the schedule needs to be adjusted often, meaning that a long term schedule is not possible at this moment.
X/care	To make the personnel schedule in X/Care is complex due to its unclear overview and confusing interface.
Skills	The skill levels of the lab assistants are very different. Not all lab assistants can perform every task. This makes it hard to make a schedule in which the tasks are equally divided and the knowledge of the examinations stays up to date. Also, there is not always the right skills are available to cover the fixed programs. This problem is intensified with the fact that most of the lab assistants work part time.
Availability	At several days the capacity is too low to fulfill the fixed programs and there is never enough capacity to open all the examination rooms. The part time availability of lab assistants and the difference between even and odd weeks make scheduling more complex.
Control	It often shows that the schedule needs to be adjusted a week before. This costs extra time.

From the key issues listed above we can conclude that task allocation of lab assistants and an unclear system are the main problems which make employee scheduling at the department time consuming and complex.

Chapter 3: Personnel scheduling in healthcare

In the previous chapter the main bottlenecks for constructing the personnel schedule for the department of Clinical Neurophysiology were analyzed. In this chapter, we provide an overview of relevant literature on this subject to find a solution technique that can be applied in a decision support model and examine their suitability for the application on the specific situation at the department.

In Section 3.1, a framework for health care planning is presented to outline the position of the scheduling problem. In Section 3.2, we summarize the most common problems of personnel scheduling in health care. After this overview we present relevant literature about methods and models that apply to our scheduling problem in Section 3.3. Finally, we explain the method that is used for this study in Section 3.4.

3.1 Framework for healthcare planning

Hans, van Houdenhoven, and Hulshof (2012) list manufacturing planning and control frameworks that are applied in health care planning and control. In this literature review the researchers found that not all managerial areas were taken into account in the existing frameworks, which led them to developing a new framework. The new framework, showed in Figure 3.1, covers the most important areas of hierarchical and managerial levels in health care planning and control. This framework can be used to position our problem.

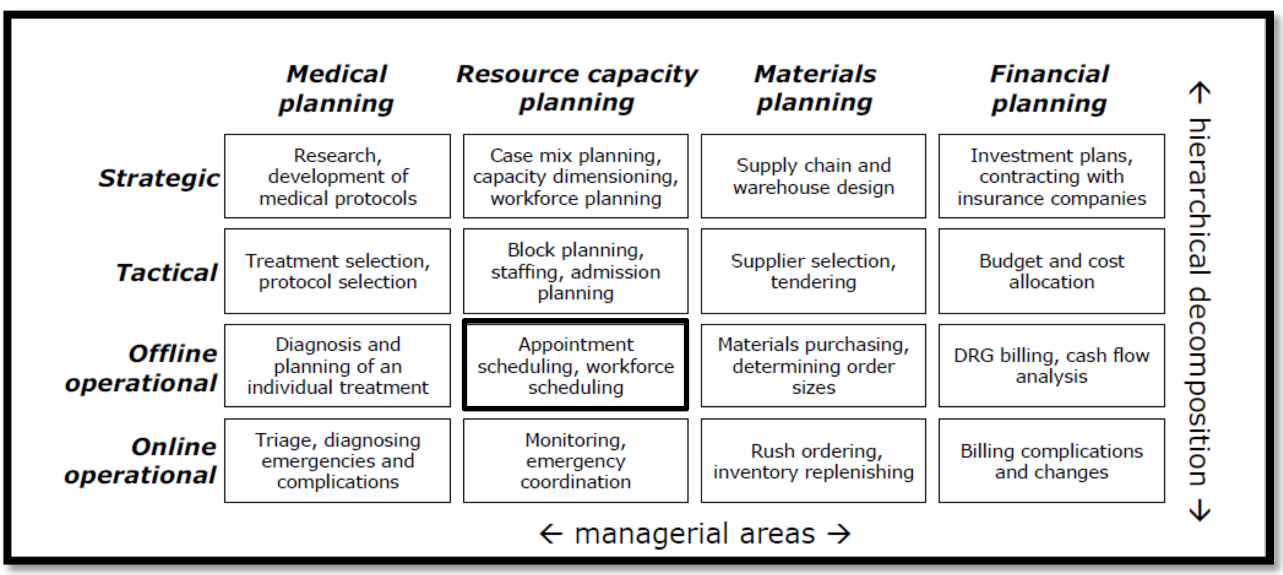

Figure 3.1 Example of an application of the framework for health care planning and control to a general hospital.

In the vertical direction the problem can be placed in the strategic, tactical or operational (online and offline) section. Strategic decisions are made for the whole organization for years in advance, tactical decisions are made weeks or months in advance and the offline operational level is about short time decision making (days or a week in advance). Online operational decision making is about the reaction on unforeseen or anticipated events.

Currently, the scheduling at the department is performed at the online operational level as it is made on ad hoc basis. Many problems, like sick leave, are unforeseen and are solved immediately, but can be anticipated if the scheduling is performed at a higher level. From the context analysis we can conclude that there is no advance planning at the level of tactical and offline operational planning. The placement of the problem in the hierarchal decomposition is therefore in the offline operational section, although there are also some problems at a tactical level.

The managerial areas are medical planning, resource capacity planning, materials planning and financial planning. To place our problem in the right managerial area the article of Smith-Daniels, Sweickhart, and Smith-Daniels (1988) is considered. In the article it is explained that capacity management has three types of resources: workforce, equipment and facilities. In our study the equipment and facilities are predetermined factors, and the focus of this study is on the workforce. Therefore, we are able to conclude that our research problem is positioned in the managerial area of resource capacity planning. According to Hans et al. (2012) the resource capacity planning focuses on the dimensioning, planning, scheduling and monitoring and control of renewable sources, which includes staff.

In Figure 3.1, the corresponding area is marked with a thick line. It points out that this area treats (patient) appointment and workforce scheduling. In the following section relevant literature on the subject of workforce scheduling, also referred to as staff, personnel or employee scheduling, or rostering.

Positioning of the problem

In the field of personnel scheduling in health care, different problem areas can be defined. The position of the problem is important for finding suitable approaches to solve the scheduling problem. Hulshof, Kortbeek, Boucherie, and Hans (2011) constructed a framework to categorize papers for different problem areas. As defined by the framework of Hans et al. (2012) there are four managerial levels. Hulshof et al. use these levels to create the new framework for categorizing relevant papers about Operations Research and Management Science (OR/MS) in the service industry of health care. The managerial levels strategic, tactical and operational (on- and offline) are on the vertical axis of the framework. For the horizontal axis the researchers define six categories of care services in which the papers are placed, namely ambulatory, emergency, surgical, inpatient, residential and home care services.

At the grounds of the delivered service in health care, the department of Clinical Neurophysiology is placed in the ambulatory care services category. This is derived from the idea that the department can be compared with the department of endoscopy, radiology and radiotherapy, which are departments in a hospital that also positioned in the ambulatory care category by Hulshof et al. (2012).

Common problem areas in healthcare like nurse, resident and physician scheduling are discussed briefly in the next section. In Section 3.3 we give an overview of possible models and methods that relate to our personnel scheduling problem.

3.2 Scheduling problems in healthcare

Now we know in what area and at which level we have to look for suitable literature, the next step is to find feasible methods from the literature to make an employee scheduling tool for the department of Clinical Neurophysiology. Feasible implies in this study that the method is understandable for the end user and it should be executable in software that can be easily implemented at the hospital department.

Patient appointment scheduling

Scheduling problems in health care have a broad perspective. Recent reviews that provide many relevant papers on scheduling in health care are performed by Burke, de Causmaecker, Berghe, and van Landeghem (2004) and Cheang, Li, Lim, and Rodrigues (2003). A lot of literature about scheduling problems in healthcare considers patient appointment scheduling and scheduling operating rooms. Therefore, it is important to make a clear distinction between personnel and patient planning in healthcare.

The goal of patient appointment scheduling is often to reduce patient waiting times through matching demand with the (resource) capacity and better utilize the resources. Personnel scheduling is a reoccurring and time-consuming task for the healthcare managers and demand skills to determine an optimal schedule. The focus in this particular area lies on reducing the waste of resources and revenue, by finding an optimal schedule and saving time making the schedule (Ozcan, 2009). So the objectives for outcomes in patient appointment scheduling are different than for personnel scheduling, but literature can be confusing. However, both scheduling problems are connected with each other since gaining efficiency of a new personnel planning method has a strong cohesion with the patient volume and the case mix (van Oostrum, van Houdenhoven, Wullink, Hans, & Kazemier, 2006).

Patient appointment scheduling of the department is outside the scope of this study. However, our opinion is that in this area there is a lot of space for improvement at the department of Clinical Neurophysiology. For instance, the employees experience an unequal workload and the waiting times for patients are for some examinations increasing up to four weeks or more (see Chapter 2 “Context analysis”). See the literature review performed by Cayirli and Veral (2003) for an overview of the techniques used in the area of patient appointment scheduling.

Nurse rostering problem

According to Ernst, Jiang, Krishnamoorthy, and Sier (2004) personnel scheduling is the process of constructing work timetables for its staff so that an organization can satisfy the demand for its services. Most studies in the area of personnel scheduling in healthcare look into staff scheduling in care services, with a focus on inpatient care services like nurse rostering (Ernst et al., 2004). The main problems in nurse rostering are the 24-hours coverage, acceptable rest between shifts and reasonable workload. Meanwhile, the planner must do this while observing regulations and accommodate holidays and other kinds of absence. Furthermore, often nursing departments have difficulties with shortages or finding competent nurses. According to Ernst et al., rostering problems in healthcare are over-constrained.

Solutions for the nurse rostering problem are found for example by the application of cyclical scheduling (Maier-Rothe & Wolfe, 1973), optimization techniques (Wright, Bretthauer, & Côté, 2006) or queuing theories (Yankovic & Green, 2007).

Resident rostering problem

Residents or student nurses are complex to schedule because they have different experience levels and internships at more than one specialty. Furthermore, they still have to learn and therefore they have to perform certain activities within a time limit. In the study performed by Dexter, Wachtel, Epstein, Ledolter, and Todd (2010), a method to create hybrid rotations of two specialties is described, in order to optimize the number of days that the residents stay on their own schedule. To reach this goal, integer linear programming is used to calculate a maximum number of residents that can be scheduled for a specialty and the daily assignments. Ovchinnikov and Milner (2008) solve the problem of assigning medical residents in radiology to on-call and emergency rotations by using spreadsheet optimization modeling. According to their paper, it provides an easy implemented solution for scheduling problems of a smaller scope.

Physician rostering problem

Papers in which scheduling of physicians is concerned are Beaulieu, Ferland, Gendron, and Michelon (2000), and Brunner and Edenharter (2011). Physicians are expensive and therefore need to be scheduled cost efficiently. Beaulieu et al. (2000) describe a mathematical programming approach for scheduling physicians in the emergency room. Their approach leads to a significant reduction of the time and effort that is required to construct the schedule. The model developed by Brunner and Edenharter tackles long term scheduling of physicians with different experience levels for flexible shift scheduling. They demonstrate that their model is useful as a decision supporting tool for hospital managers that have to deal with staffing decisions.

Ambulatory care department rostering problems

In comparison with the literature available for the specific scheduling problems named above, the literature about personnel scheduling at ambulatory departments in hospitals seems scarce. There are only a few papers about scheduling staff at comparable departments (Brunner, Bard, and Kolisch, 2011; Ernst et al., 2004; Ozcan, 2009).

Nevertheless, the papers on different subjects yield the essence of the problem of this research. That is, the complexity of the allocation of the employees is mainly caused by the different skill levels and the part-time availability. Topaloglu (2009) addressed the problem of scheduling employees with different seniority levels and proposed a multi-objective programming model to automate the schedule generation process. These kinds of solutions are considered and described in the following section.

3.3 Scheduling approaches

This section discusses the methods and models for solving personnel planning problems at departments like Clinical Neurophysiology. Ernst et al. (2004) review rostering problems in specific areas like call centers, transportation systems and health care, and discuss solutions in terms of models and algorithms. Solution techniques that they name are mathematical programming, branch and bound techniques, goal programming, iterative algorithms, (meta) heuristics, simulation techniques and queuing models. In the previous section various methods were already discussed. Several relevant models are further investigated to find the most appropriate model for this research problem. The literature shows that the methods are heavily skewed towards mathematical programming and metaheuristic approaches for rostering as opposed to other techniques.

Column generation

An important factor we must take into account when planning the lab assistants, are their differences in the level of experience. Brunner and Edenharter (2011) present column generation as a solution for scheduling physicians with different experience levels. Column generation is used for large scale linear problem in which only the variables that have the potential to influence the objective function are considered. Their model makes a distinction between high experience levels (specialists) and low experience levels (residents). It is demonstrated that the model can be used as a decision supporting tool for making staffing decisions by the hospital management.

Constraint programming

Ovchinnikov and Milner (2008) use a spreadsheet optimization model to solve the problem of assigning medical residents of the radiology department to on-call and emergency rotations. They argue that it is suitable for smaller scaled problems, where specialized medical-scheduling software is rarely available for because of its substantial costs. This spreadsheet model, solved with the constraint method (linear program with only hard constraints), takes into account differences between four levels of residents and a whole list of constraints. Constraint methods have also been applied in the assigning-resident problem by Weil, Heus, Françios, and Poujade (1995) and Topaloglu

(2009), which also take into account different experience levels. Constraint programming is closely related to mathematical programming.

Mathematical programming

According to Williams (1999), mathematical programming approaches are widely used models in OR/MS and in many cases become an accepted routine planning tool. Especially linear programming is often used for resource allocation in health care (Ozcan, 2009). Constraints for experience levels, availability of personnel and task allocation can be imbedded in the model. The constraint method is also advised by Krass and Ovchinnikov (2006) for their easy to set up and because it is easy to explain to personnel.

Mathematical programming is not in the sense of computer programming, but of making a planning model that involves mathematical relationships such as logical dependencies, equations etc. and involve optimization by maximizing or minimizing an objective function (Williams, 1999). Three sorts of mathematical programming models can be classified: linear programming (LP), non-linear programming (NLP) and integer linear programming (ILP). In LP, all conditions are assumed to be linear. If non-linear terms are incorporated in the model, we call it a NLP model. Finally, in LP it is assumed that variables are continuous. For scheduling employees it is not desirable that solutions yield fractions. Therefore, LP can be extended by enforcing the variables take integer values (whole numbers)(Ozcan, 2009).

The allocation of staff in a mental health facility was already in 1976 solved by Lyons and Young using (mixed) integer programming and from the literature this still seems to be a rather simple but effective method. Since ILP is a model that is easily applicable for practical planning problems with integer variables, this method is chosen to be used in this research. In the next section is described how ILP works.

3.4 Integer linear programming

Optimization problems with integer values can be modeled with the mathematical model ILP. A model consists of decision variables, constraints and an objective function. Parameters are the given integer values of available resources, such as available employees or examination rooms. Due to its nature in LP, the constraints are linear functions and stand for the wishes and requirements. The values of the decision variables are determined by the outcome of the model and are nonnegative, such as the allocation of employees. The objective function indicates which decision variables must be minimized of maximized, without exceeding the constraints, to obtain an optimal solution. In the optimization model the parameters can be used to emulate so called “what-if” situations in order to find alternative solutions for the problem (Ozcan, 2009).

Chapter 4 Model design

This chapter focuses on the model, which is used to solve the problem. In Section 4.1, we describe the modeling environment. The requirements of the model are described in Section 4.2. In Section 4.3, the basics of the integer linear programming model are outlined. In Section 4.4, input and output parameters are discussed, after which a conclusion is given in Section 4.5.

4.1 Modeling environment

In the current situation, the planner at the department constructs the personnel schedule manually which is very time consuming. An automatic digital system is needed to solve the scheduling problem without consuming a lot of time. In the literature review we concluded that the most suitable solution for the situation is ILP. A software program is needed to design the optimization model. There are several programs that are suitable for designing an automatic system to schedule the employees at the department of Clinical Neurophysiology.

Microsoft Excel can be used for small scale ILP problems and for more complex problems a special modeling environment is more suitable. In Microsoft Excel the number of constraints of this scheduling problem could, however, lead to a nontransparent and unmaintainable planning tool (Ovchinnikov and Milner, 2008). Therefore, we chose to use AIMMS (Paragon Decision Technology B.V.) for its calculation power and the ease to create more dimensions.

4.2 Requirements

The new planning tool must fulfill the requirements of the planner. The basic requirements are given by the planner and the head of the department and are conducted from the conclusions of the contextual analysis:

1. *Input of data.* The model should be easy to use and be capable to cope with the changes that are common in the patient program of the department. It should be possible to adjust the assignment of the (student) lab assistants on a daily basis. Furthermore, there must be a possibility to indicate new gathered skills and to change the daily demand. Therefore, the model should give the opportunity to adjust the input parameters easily.
2. *Task allocation.* The new tool should save time. Most of the time is spent by assigning the lab assistants according to their availability, skills and wishes. This process must be solved quickly by using the model. In our model the objective is to use the capacity optimally and, also, to bring variation into the schedule.
3. *Interface.* The new planning tool should be accessible and clear. This means that the tool works fluently and is capable to solve the problem with the given input parameters or else explain why the model cannot solve the problem. Furthermore, the actual schedule has to give a clear overview of the allocation of lab assistants.

Since the goal is simple and quick assignment of the employees, there is no objective to minimize the costs of the personnel, although this is often a goal in employee scheduling models using optimization models (AIMMS Employee Scheduling, n.d., Williams, 1999). In our model the objective is to use the capacity optimally, and to bring variation into allocated examinations.

In this study the most important goal is reducing the time of allocating the lab assistants. Consequently, the model should take into account the skills of the lab assistants, the shifts and the demand. The final product is a planning tool in which the planner just has to tick off the needed examination rooms, and the tool will solve the problem of one day with the (standard) given availability and skills of the employees.

4.3 Model description

In this section the linear programming model is discussed. First, a general description of the model for generating an employee schedule is given. Secondly, different parts of the model are discussed. These are the sets, indices, parameters, variables, constraints, and the objective.

General description

The goal of the model is to provide the planner with a weekly schedule in which as many tasks as possible are assigned to a specific employee. To every needed examination room *r* an employee *e* must be assigned that is available in shift *sh* and has the right skill *sk* to perform the examination. The objective of the model is to find a schedule with the minimal number of unfulfilled positions and to minimize the number of employees that are more than two times per week in the same examination room, in order to obtain a schedule in which employees are assigned to needed examination rooms and that it offers variation to the employees. With this planning tool the planner can easily solve problems like creating a week schedule, planning holidays or deal with unexpected absence of employees. The notation to formulate the model in this study is as follows:

Entities

R Set of examination rooms with specific equipment (r = 1,…,10)
E Set of employees (e = 1,…,14)
SH Set of shifts of employees (sh = 1,…,10)
SK Set of skills of employees (sk = 1,…,23)

Parameters

$\mathrm{Demand}_{r,\,sh,\,sk} \geq 0$ Demand for skill sk in a specific examination room r during shift sh
$\mathrm{Skills}_{e,sk} = \{0,1\}$ Specific skills sk of employees e
(1 = employee has skill; 0 = employee does not have skill)
$\mathrm{Shifts}_{e,sh} = \{0,1\}$ Availability of employees e during shift sh
(1 = available; 0 = not available)

Decision variables

1. *Assignment (r, e, sk, sh)* indicates whether or not an employee e with skill sk is assigned to an examination room *r* during shift *sh.*

$$Assignment\ (r, e, sk, sh) = \begin{cases} 1\ \ if\ an\ employee\ e\ with\ skill\ sk\ is\ assigned \\ \quad to\ examination\ room\ r\ during\ shift\ sh \\ 0\ \ otherwise \end{cases}$$

2. *Unfulfilled (r, sh, sk)* ≥ 0 indicates the number of unfulfilled positions for skill *sk* in examination room *r* during shift *sh* after assignment of available employees.

3. *UnfulfilledTot* is the sum of *Unfulfilled (r, sh, sk)*. This decision variable indicates the total of unfulfilled positions during the planning horizon in all examination rooms where skills were needed after the assignment of available employees.

$$UnfulfilledTot = \sum_{r=1}^{10} \sum_{sh=1}^{10} \sum_{sk=1}^{23} Unfulfilled(r, sh, sk) \tag{1}$$

4. *Overcapacity (e, sh)* indicates per employee *e* whether he/she is not allocated although he/she was available during shift *sh.*

$$Overcapacity\ (e, sh) = \\ Shifts\ (e, sh) - \sum_{r=1}^{10} \sum_{sk=1}^{23} Assignment(r, e, sk, sh) \qquad for\ all\ (e, sh) \tag{2}$$

5. *OvercapacityTot* is the sum of *Overcapacity (e, sh)* which indicates the total of employees *e* that were not allocated to an examination room although they were available during the planning horizon.

$$OvercapacityTot = \sum_{e=1}^{14} \sum_{sh=1}^{10} Overcapacity(e, sh) \tag{3}$$

6. Decision variable *EmployeeRoomTot* counts for every employee *e* and every examination room *r* how many times an employee with skill *sk* has been allocated to a certain examination room during the planning horizon. This provides an overview of the variation in examination rooms for employees.

$$EmployeeRoomTot = \sum_{sk=1}^{23} \sum_{sh=1}^{10} Assignment(r, e, sk, sh) \qquad for\ all\ e, r \tag{4}$$

7. *Variation Room (e, r)* ≥ 0 indicates which employee e has been more than 2 times in a specific examination room r. This variable is used in constraint 4 in Equation 8.

Constraints

1. The demand must be satisfied. When the demand cannot be satisfied, the model applies variable 7 to find the most valid solution.

$$\sum_{e=1}^{14} Assignment(r, e, sk, sh) = Demand(r, sh, sk) - Unfulfilled(r, sh, sk) \quad for\ all\ r, sk, sh \tag{5}$$

2. An employee can only be scheduled during shifts he/she is available.

$$\sum_{r=1}^{10} \sum_{sk=1}^{23} Assignment(r, e, sk, sh) \leq Shifts(e, sh) \quad for\ all\ e, sh \tag{6}$$

3. An employee can only be scheduled if he/she has the needed skill.

$$Assignment(r, e, sk, sh) \leq Skills(e, sk) \quad for\ all\ r, e, sk, sh \tag{7}$$

4. This constraint is meant for bringing variation into the roster. Therefore, an available employee should not be scheduled more than two times in the same examination room during the planning horizon. If needed for an optimal solution, the model uses variable 7 to obtain a valid solution.

$$\sum_{sk=1}^{23} \sum_{sh=1}^{10} Assignment(r, e, sk, sh) \leq 2 + Variation\ Room\ (e, r) \quad for\ all\ e, r \tag{8}$$

Objective function

The goal is to assign to every examination room *r* that is needed during shift *sh* an employee *e* that is available during that shift and has the needed skill *sk*. The objective of the model is to minimize the unfulfilled positions in examination rooms and to minimize the number of employees that are more than two times per week in the same examination room. It is two times more important that there are no unfulfilled positions than that there is variation in the allocation of employees to examination rooms, which is determined with a sensitivity analysis. The objective function is noted as follows:

$$Min\ Z = 2 \cdot Unfulfilled\ Positions + \sum_{e=1}^{14} \sum_{r=1}^{10} Variation\ room\ (e, r) \tag{9}$$

Execution

The model is built in the optimization software AIMMS and is performed on a Fuijtsu Siemens laptop with a dual-core Pentium with a CPU of 1.86 GHz and 2.00 Gb RAM. AIMMS provides many different solver add-ins and the modeling environment automatically chooses which solver suits the problem best. In this research the solver CPLEX 12.4 is used.

4.4 Input and output variables and assumptions

The department provides input for the availability and the skills of the employees; the occupation of the examination rooms is determined by the patient appointment schedule. All required input is available at the department.

Input parameters

- Demand
  The demand is determined by the patient appointment schedule. For every examination at least one lab assistant is needed, but for specific examinations two lab assistants are preferred. Every number of needed employees (nonnegative) can be put into the model. The demand is investigated in the context analysis of the department (Section 2.2.4).
- Employees
  Employee input exists of the lab assistants and the student lab assistants.
- Skills
  The skills of the employees are determined by the planner and the head of the department.
- Shifts
  The shifts of the employees are given by the head of the department. The days are divided in a morning and afternoon shift, which respectively last from 8.00 till 12.30 hours and from 13.00 till 16.30 hours. We assume that every employee works a complete part of a day. For example, we do not take into account working times until 14.30 hours. This is seen as only a morning part. In the weekend only one employee is needed for the runaround function and is not scheduled in the model.

  Adding new input parameters

  This option in the end interface makes it easy for the planner to add a new parameters when the situation at the department changes.

Output variables

- Calculated week schedule
  A calculated schedule for a whole week in which an employee can quickly see at which shift, in which room he or she has to be, and which skill he or she has to use.
- Overcapacity
  When more employees with the right skills are available than needed it is noted as overcapacity.

The name of the employee and the shift are displayed by the model. One can see quickly if it is possible to open an extra room of to double in a specific examination room.

- Undercapacity

  The unfulfilled positions are seen as under capacity, since there are not enough employees with the right skills to fulfill the demand. The model shows in which room and which skill is still needed during a specific shift.

Assumptions

- Variation is established by a constraint which ensures that an employee is not placed more than two times per week in the same examination room.
- Every employee works in shifts of whole day parts. However, in reality some employees work also parts of shifts, like starting late in the morning shift.
- It is assumed that in a morning or afternoon shift only one skill is performed. In reality, several skills can be planned in a specific examination room for a certain shift. The planner should choose the most difficult skill to guarantee that the allocated employee can also perform the other examinations.

4.5 Conclusion

The model in this chapter is developed to assign available employees with the needed skill to examination rooms. The objective is to minimize the unfulfilled positions in examination rooms and to minimize the number of employees that are more than two times per week in the same examination room.

In Figure 4.1 a schematic overview of the model with the input parameters and the output variables is provided:

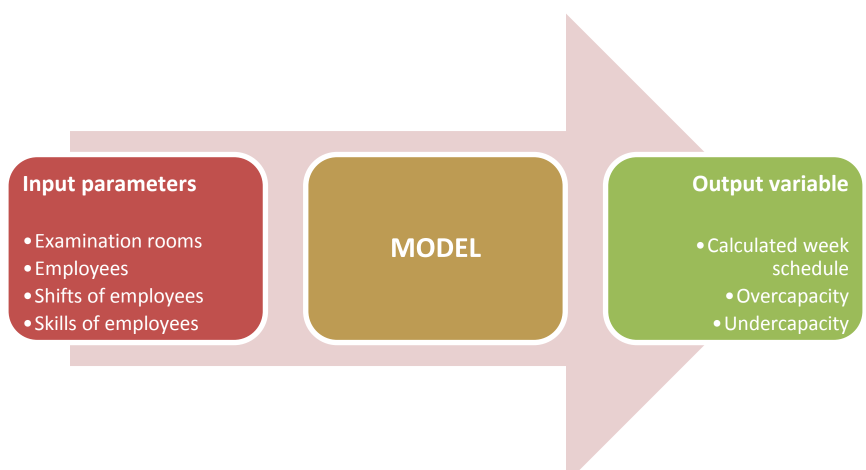

Figure 4.1 Schematic overview of the integer linear programming model.

CHAPTER 5 OUTCOME ANALYSIS

In this chapter the model is tested to find whether the outcomes of the model are realistic and usable. In the first section, Section 5.1, the model is validated. The second section, Section 5.2, describes a sensitivity analysis. In Section 5.3, several what-if analyses are described that can be used to check the performance of the model. Also, analyses are performed to see the effect of alternative schedules.

5.1 Validation of the model

The validity of the schedule is important, because it shows whether the behavior of the model resembles actual situation. In this process we can see whether the model serves its intended purpose along the requirements of this study (Law, 2008).

According to Williams (1999), there are three possible outcomes of model: infeasible, unbounded or solvable. The model is tested to be feasible by using input parameters of which are known to be realizable and this also proofs that the model is not unbounded. Conclusively, the model is solvable.

The validity is checked by the planner and the head of the department, by scheduling the employees with the new planning tool instead of manually. The model satisfies the basic requirements stated by the planner and the head of the department (A. Tackenkamp & M. Stappenbelt, personal communication, June 26, 2012). However, during interviews with the stakeholders several limitations of the planning were found, and therefore improvements are suggested. These possible improvements are described in Section 6.3 “Limitions of the model” and in Section 7.2 “Recommendations”.

5.2 Sensitivity analysis

In order to find the sensitivity of the model, an analysis is performed to adjust the model optimally. In Chapter 4 the constraint for variation (Equation 8) and the objective function (Equation 9) are described, and are shown below. These linear functions are dependent of number x_1 or x_2 to give it a certain weight, and thus influence the optimal outcome.

Variation constraint $$\sum_{sk=1}^{20} \sum_{sh=1}^{10} Assignment(r, e, sk, sh) \leq \boldsymbol{x2} + Variation\ Room\ (e, r) \quad (8)$$

Objective function $$\boldsymbol{x1} \cdot Unfulfilled\ Positions + \sum_{e=1}^{14} \sum_{r=1}^{10} Variation\ room\ (e, r) \quad (9)$$

In Table 5.1, the sensitivity of the objective function and the variation constraint are determined. The table shows when the lowest outcome, meaning as little over- and undercapacity as possible, is reached. Therefore, the optimal weights in the functions are x_1 = 2 and x_2 = 2. These numbers in the functions yield the most variation, but let the assignment come first.

Table 5.1

Optimal weights for variation constraint and objective function.
Outcome stands for Undercapacity/Overcapacity.

Objective function x_1	**100**	**50**	**10**	**2**	**1**
Variation x_2					
2	14/1	14/1	14/1	14/1	17/1
3	14/1	14/1	14/1	14/1	15/2
4	14/1	14/1	14/1	14/1	14/1

Variation

Using the weights found above, we can check whether the variation constraint in the model works precise. By using the current input data, the variation of the allocated examination rooms of the modeled schedule is shown in Table 5.2.

In this table we see the distribution among the employees is fair, and only employees with fewer skills are allocated more than two times to the same examination room. We observe no change if we increase the variation constraint. Only if the availability increases or the demand decreases the unfulfilled positions are minimized to zero. For this, see respectively Section 6.2.2 and Section 6.2.1.

Table 5.2

Distribution of allocated examination rooms among the employees in the modeled scheduled with given datasets (availability and demand).

Examination room / **Employees**	**ECAR**	**EEG 2**	**EEG 3**	**EMG 1**	**EMG 2**	**ENG**	**EP**	**Oldenzaal**	**Runaround**	**Vascular**
E1		2	2			1	2		3	
E2	2	2	1	1					2	
E3	2	1	1	2	1	1	1			
E4	1		1	1		1			1	1
E5		2					1	1		1
E6		1	2	1				1	1	2
E7	2		1	1		1				1
E8				1		2		1	1	1
E9							4			
Total unfulfilled	3	2	0	1	1	0	1	1	2	3

Speed of model

With the given datasets presented in Table B.1 to Table B.13, the average calculation speed of the model with CPLEX 12.4 Solver is 0.38 sec. The number of iterations is 198. The solution is found by varying the constraints and variables respectively 35,063 and 34,923 times.

When the standard data file is loaded and minor changes (for instance absence) are inserted, the actual scheduling time can be less than 5 minutes. This is significantly faster than scheduling manually, which often takes a minimum of 4 hours per week.

5.3 Design of what-if analyses

When the so-called what-if analyses are performed, input parameters demand, shifts, or skills are adjusted. What-if analyses with the model are performed to see whether certain changes in the current schedule lead to a better schedule, meaning less over- or undercapacity. With this knowledge, we can find what changes are needed to achieve an improved schedule. Below, we describe several experiments.

What-if analyses are based on the input data presented in Appendix B, Table B.1 to Table B.13 (for even weeks). The results of the experiments are presented in the following chapter.

Fulfilling demand

The first what-if scenario concerns the maximum demand. In this situation, all the examination rooms and programs of fast-track pathways that can be opened are opened (see Section 2.2.1). With this scenario we can find what changes in availability of the permanent employees (students are disregarded) are needed to cover the full demand of the department every day of the week. With this scenario we can provide the best schedule to cover the current demand. Furthermore, we look into possibilities of adjusting the demand distribution to the current capacity.

Maximum availability

This what-if scenario describes a situation where all lab assistants work fulltime. The student lab assistants are excluded from this experiment, as it is desired to have the students as overcapacity. With this experiment we can find whether the demand (Table B.4 to Table B.13) is covered with fulltime employees.

Mastering all the skills

This analysis discovers if skills determine the coverage of the demand. In this situation all the employees master all the skills and are the known demand of fixed programs and the employees with part-time availability still the same. This unfolds the following experiment: one in which all the permanent employees are able to perform all skills (excluding the students).

Duplex

A current issue is the shortage of skilled Duplex lab assistants. This is an important skill since there is a 24 hour service. Unfortunately, the examination skills for Duplex are new and up to now only four employees can perform the test. These are too few employees to cover the demand in a fair distribution among the employees. With how many added skilled employees is the problem solved?

Improving current schedule

In the analyses described above, only one of the input parameters is adjusted. Altogether, certain (small) changes in the parameters might lead to a better schedule in which the requirements of the hospital and the wishes of the employees are honored. We aim to find a solution of several bottlenecks, for instance shortage due to high demands or low availability, in order to improve the current schedule.

Chapter 6 Results

In this chapter the results are provided. These outcomes will provide insight into the performance of the model, the influence of input parameters and possible improvements of the planning tool. First, a comparison between manually scheduling and scheduling with the planning tool is made in Section 6.1. After that, the results of the what-if analyses are shown in Section 6.2. In Section 6.3 the limitations of the model are described.

6.1 Comparison

The model output data of the system is compared with the output collected from the actual system. To compare the results of the model with the outcome of the schedule that is constructed manually, a comparison is performed. The input data of a random week in history (May 7 until 11, 2012) is imported into the planning model and the outcomes are compared on similarity between allocated lab assistants to examination rooms and the number of unfulfilled positions (named "blocked rooms" in the manually constructed schedule).

In Appendix B, Table B.1, an overview of the datasets for the model is presented. To perform the comparison, the input parameters of the actual schedule are used. The availability of employees, the skills of the employee and the demand are imported in the model. The student lab assistants are also available to perform examinations with the skills they already master, but the constraint of maximum two times in the same examination room also applies to them. They are also assigned to examination rooms in the manually scheduling method.

The outcomes of the comparison are provided in Table 6.1. Differences in the allocation of employees to specific examination rooms between the manual and automatic method are large: the highest similarity is 42.9%. This means that more than 50% of the employees are allocated to a different room than in the manually constructed schedule. Still, all employees are allocated to an examination room in which they have to use their already learned skills. This means that only the distribution of the employees over the examination rooms changed.

Furthermore, the planning tool finds a schedule in which there is a decrease in unfulfilled positions. The planning tool can make a more optimal schedule because it assigns lab assistants (and students) according to the best distribution of skills and rooms.

The new planning model provides a schedule that allocates the employees to examination rooms better than the manual method, only with a different distribution. With fewer unfulfilled positions, the planning tool uses the skills of the available employees more effectively.

Table 6.1

Outcomes of a comparison between a manually constructed schedule and one computed by the planning tool.

	Similarity (%)	Unfulfilled positions manual	Unfulfilled positions planning tool	Decrease in absolute numbers	Decreased unfulfilled positions (%)
Monday Morning	33.3	2	0	2	100
Monday Afternoon	28.6	2	1	1	50
Tuesday Morning	0.0	1	0	1	100
Tuesday Afternoon	42.9	1	0	1	100
Wednesday Morning	12.5	3	2	1	67
Wednesday Afternoon	42.9	2	0	2	100
Thursday Morning	42.9	1	1	0	0
Thursday Afternoon	16.7	3	0	3	100
Friday Morning	0.0	2	0	2	100
Friday Afternoon	0.0	2	0	2	100

6.2 What-if analyses

When executing the what-if analyses, one dataset (for even weeks) is used and adjusted. The remaining input data stays according to Table B.2 and Table B.3.

6.2.1 Fulfilling maximum demand

This what-if analysis shows what changes in availability (in an even week) of the permanent employees can be made to cover the full demand of the department. Students are disregarded to show actually how much the department is dependent of them for fulfilling the demand. In the current situation examination rooms are closed if there are not enough employees and/or students available. With this analysis we can define the best schedule to cover the current maximum (thus desired) demand.

The difference between the needed employees to cover demand and the current availability, per week, is presented in the first three columns of Table 6.2. On 7 day parts an undercapacity of at least 1 or 2 employees is observed. The total shortage is 11 day parts, which equates to 44 hours or 1.22 FTE (with 1 FTE being 36 hours).

The current personnel schedule does not fulfill the requirement of the demand. By this we mean the examination rooms of which the planner and the head of the department think should be open for the best productivity. A new shift schedule could solve the undercapacity.

In the model we experimented with which schedule the demand is covered. The experiments start with adding days to the availability of every employee so that every employee works at least 3.5 days, first adding days on which capacity is needed most. The availability of employees that already work more than 3.5 days remains the same. In the last three columns in Table 6.2 one can see the effect of scheduling every employee at least 3.5 days and so on.

With a shift schedule of minimal 3.5 days per permanent employees, there is a decrease in unfulfilled positions, but an undercapacity of 0.44 FTE still exists. A shift schedule with minimal 4.0 days almost solves the undercapacity and even creates overcapacity at certain day parts. With a schedule whereby every employee works minimal 4.0 days or more, the current capacity covers the demand. Wednesday afternoon and Friday afternoon are the bottlenecks for the fulfillment of the demand within the current capacity.

Table 6.2
Results for fulfilling maximum demand.

Shift	Needed employees to cover desired demand	Current availability	Difference needed - available	Difference needed – available minimal 3.5 days	Difference needed – available minimal 4.0 days	Difference needed - available > 4.0 days
Monday morning	6	6	0	0	-1	-1
Monday afternoon	8	6	2	0	0	0
Tuesday morning	6	6	0	0	-1	-1
Tuesday afternoon	8	6	2	0	0	0
Wednesday morning	8	7	1	1	0	0
Wednesday afternoon	7	5	2	1	1	0
Thursday morning	7	7	0	0	-1	-1
Thursday afternoon	9	7	2	1	-1	-1
Friday morning	7	6	1	0	0	0
Friday afternoon	8	7	1	1	1	0

The following table (Table 6.3) proposes a new shift schedule in which adjustments are solely made in input of availability to cover the maximum demand. It is based on at least 3.5 days per lab assistant. In the fourth column of Table 6.2 one can see that there are 4 day parts left unfulfilled. To fulfill these shifts, employees are chosen that are not yet available in that shift and have the most skills (see Appendix B). We also regarded a fair distribution of added shifts.

The “x” in Table 6.3 represents the added shifts, in total 11 shifts or 1.22 FTE. With this schedule the demand can be fulfilled by only the permanent lab assistants. However, this schedule does not take into account the wishes of the employees; therefore it is not likely that this schedule will be accepted.

Table 6.3

A proposed new shift schedule to cover the maximum demand.

Employees	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	
Shift										**Total shifts**
Monday morning	*	*	*	*	*	*				6
Monday afternoon	*	*	*	*	*	*	x	x		8
Tuesday morning	*		*	*	*		*	*		6
Tuesday afternoon	*	x	*	*	*	x	*	*		8
Wednesday morning	*	*	*	x	*	*		*	*	8
Wednesday afternoon	*	*	x		x	*		*	*	7
Thursday morning	*	*	*	*		*	*		*	7
Thursday afternoon	*	*	*	*	x	*	*	x	*	9
Friday morning	*	*	*			*	*	*	x	7
Friday afternoon	*	*	*	x		*	*	*	*	8
Total days	5.0	4.5	5.0	4.0	3.5	4.5	3.5	4.0	3.0	

6.2.2 Adjusting demand to current schedule

With the current availability, there is a permanent shortage on certain days and the demand cannot be covered. In the previous section we looked for a new schedule to cover the maximum demand. If the department does not want to implement this schedule, but stay with the current, what can then be done about the demand to solve the problem of shortages?

The fixed programs that determine the demand are: runaround, ECAR, EMG, CTS, Botox, Vascular Surgery, T3 and surgeries. We investigate which rooms or programs could close in order to adjust the demand to the current availability, even if there fixed. At this moment is decided ad hoc which rooms are blocked for a specific week.

In Table 6.4 a proposition is made for closing examination rooms. By closing in total 6 rooms per week, the demand is adjusted to the current availability. By closing the ECAR room 3 times per week, the 24 hour service can still be offered in the remaining 7 shifts. When the runaround program is closed in the afternoon 2 times per week, this lab assistant can fulfill a task in an examination room where a lab assistant is needed. By closing the EP room on Wednesday morning, there are still 4 other shifts left to perform the examinations. Since EP examinations are only 2.5% of the total requested examinations (Section 2.1.3), this should cover the requests.

Table 6.4

Proposed closed rooms to adjust demand to current availability.

Shift	Needed employees to cover desired demand	Current availability	Close	
Monday morning	6	6	-	
Monday afternoon	8	6	ECAR	Runaround
Tuesday morning	6	6	-	
Tuesday afternoon	8	6	ECAR	Runaround
Wednesday morning	8	7	EP	
Wednesday afternoon	7	5	ECAR	
Thursday morning	7	7	-	
Thursday afternoon	9	7	ECAR	Runaround
Friday morning	7	6	ENG (even week)	
Friday afternoon	8	7	ECAR	

6.2.3 Maximum availability

Within the current shift schedule, a great part of the employees is only available part-time. When all lab assistant should work fulltime, the demand could be covered. This is the ideal situation from the view of the hospital, but does not regard the wishes of the employees. Furthermore, the problem of only having part-timers is often put forward as the explanation for the shortage, thus with this analysis we discover whether this explanation is really true.

With a maximum availability of the current employees, more examination rooms can be opened during the day. This will have a positive effect on the productivity and the reduction of patient waiting times before getting an appointment. Here, fulltime stands for all day parts, which are 40 hours.

With 9 fulltime employees and the current demand, 14 times an employee is not needed to fulfill the current demand. The employees that are overscheduled are shown in Table 6.5. Consequently, at those day parts other examination rooms can be opened. This could increase the productivity of the department. The table sums the number of extra rooms per day part that can be opened due to the overcapacity when 9 employees work fulltime.

Table 6.5

Overcapacity if all employees work fulltime with the current demand.

Shifts Employees	Monday morning	Monday afternoon	Tuesday morning	Tuesday afternoon	Wednesday morning	Wednesday afternoon	Thursday morning	Friday morning	Friday afternoon
E1			*						
E4	*								
E5							*		
E8	*				*	*			
E9	*	*	*	*		*	*	*	*
Total extra rooms	3	1	2	1	1	2	2	1	1

On the other hand, with only fulltime employees the current demand could be covered with fewer employees. According to the outcomes of the model, 8 employees are needed if only full-timers are hired. The model shows that with 8 fulltime employees one day part is not fulfilled (EEG room, Thursday afternoon), but also 3 employees are not scheduled in 5 occasions.

6.2.4 Mastering all the skills

In this what-if situation we analyze if the planning tool can make a better schedule if all permanent employees were able to perform all skills.

In the case that all permanent employees master all the skills, leaving the input for availability and demand the same, the model calculates that there are still 13 unfulfilled positions. Mastering all skills does not seem to make a big difference, since the undercapacity with the current skills is 14.

Duplex

In this section we assess the current shortage for performing the Duplex test that is exclusively performed in the ECAR room. In this experiment we examine with how many added employees, skilled for Duplex, the problem can be solved. In the model, we add (one by one) skilled Duplex employees until a deficit is no longer observed. Currently, four lab assistants can perform a Duplex test. In Table 6.5 is presented how often the planning tool allocates an employee to the ECAR room to perform the Duplex test, taken into account the overall demand at the department. Since this analysis is very dependent of what lab assistant is chosen, we first choose lab assistant that master all the skills but Duplex. After that, lab assistant are added that already master the most skills.

With 1 extra employee that can master the skill of performing the Duplex examination, there is a deficit of 1 day part per week. This is a decrease of 2 unfulfilled positions in the ECAR room with respect to 4 skilled Duplex employees. The distribution between 5 skilled Duplex employees stays fair (see Table 6.6). However, the allocation to the ECAR room is heavily dependent on the other demanded skills, since the employee with the new Duplex skill is no longer available for a maximum of two other examinations. When 2 or more employees are skilled for Duplex, the planning tool does not even schedule those employees. It schedules a maximum of 5 employees per week to the ECAR room.

In Table 6.6 this effect is visible by the increase of unfulfilled positions when more employees learn the skill for Duplex. This is caused by the missing function of prioritizing the rooms. Obviously, with the new added Duplex skills, the planning tool allocates the lab assistants to other, also unfulfilled, rooms creating an even larger deficit for the ECAR room. When a function in the model whereby a priority of open examination rooms is added, then 5 employees with a Duplex skill should cover the demand.

Table 6.6

Increasing the number of employees with the skill for performing Duplex and the influence on the unfulfilled positions.

Examination room	ECAR + 1 skilled employee	ECAR + 2 skilled employees	ECAR + 3 skilled employees
Employees			
E1			
E2	2	2	2
E3	2	2	1
E4	1	1	1
E5	2	1	1
E6		2	1
E7	2		
E8			
E9			
Total unfulfilled Duplex	1	2	4

6.2.5 Improving current schedule

In the what-if analyses performed above, none of the situations (covering current demand, closing rooms, working fulltime or mastering all the skills) is either feasible or very realistic. However, these situations would be ideal for the hospital, since combined it ensures the most productive schedule. To find a realistic schedule in which the deficits can be solved, the wishes and the abilities of the lab assistants should be taken into account. Therefore, small changes can be investigated in order to improve the current situation. In this section we study how the largest bottlenecks can be overcome. In Table 6.7 the bottlenecks following the context analysis and what-if analysis are listed.

Table 6.7

Overview of bottlenecks in the current employee schedule.

Input parameter	Bottleneck
Skills	Duplex
Availability	Difference between even and odd weeks
	Distribution of shifts part-timers
Demand	Monday morning
	Tuesday afternoon
	Wednesday morning
	Wednesday afternoon
	Thursday afternoon
	Friday morning
	Friday afternoon

Improvements for the current schedule are assessed by analyzing the bottlenecks. In the previous section, Section 6.2.4, we already determined that one extra lab assistant should learn to perform the Duplex examination to solve the shortage.

The availability and demand must be taken into account at the same time because they should be balanced. The even and odd week schedule is mainly caused by the surgery schedule of another department, but this can be anticipated by switching those operation shifts by a fixed program.

The fixed programs of the demand are: runaround, ECAR, EMG, CTS, Botox, Vascular Surgery, T3 and surgeries. These are 8 programs which can be hardly covered by 9 permanent part-timers when they occur on one day. Mostly this is the case on the days when the bottlenecks arise.

The following interventions are performed to decrease the undercapacity:

- Every day one student is assigned for performing examinations, the others can learn.
- The ECAR room is closed in the afternoon. A 24 hour service can still be guaranteed.
- The hours of the employees are the same every week. This means that two employees work on one day during their workweek half a day, instead of a whole day in the even week and an off day in the odd week.

When these interventions are performed in the current schedule, this leads to a schedule without undercapacity. This steers the middle course between a small decrease in demand, increasing availability by allocating a student lab assistant and learning new skills. With these measures the deficiency of 1.22 FTE can be intercepted.

6.2.6 Conclusion

Several possible what-if analyses have been performed with the decision support model. The following recommendations can be concluded from the analyses:

- One lab assistant should learn the skill for Duplex
- With 1.22 FTE extra the undercapacity for the current demand can be solved.
- Incorporating current student lab assistants on permanent days into the personnel schedule, to solve the undercapacity.
- Permanently closing several examination rooms helps to achieve the right capacity and cover the demand.

Using the model for scheduling (with given datasets) is significantly faster than scheduling manually.

With the current amount of FTE's combined with the same number of fixed programs, it is hard to find a schedule that covers the complete program. Therefore, another solution can be to hire a new employee or let one current permanent employee increase the workweek with at least one workday.

The students are in most experiments not included because they are seen as overcapacity. However, in a rather short period of time at least one student finishes his/her study. It would be wise to hire the student, which then is assumed to master most skills and to fulfill the undercapacity of at least 1 FTE. The shortage left can be fulfilled by a permanent employee. In between, a fulltime flex worker can fulfill the undercapacity until the student has finished the study.

6.3 Limitations of the model

While performing the what-if analyses, limitations emerged. Due to the model being an imitation of reality, it is not a perfect tool and therefore comes with limitations. Some limitations can be solved by adjusting or expanding the model. Other limitations are related to the implementation of the model. Therefore, several options are provided that can improve the model.

Model

Since it is an optimization model, the program always chooses the optimal solution. However, it is not preferable that the model always assigns the same employees to the same examination rooms, every week. This might become boring for the employees and might have a negative effect on the quality of the skills of other examinations. Partly, the model solved this problem by a constraint that allows the allocation of employee to only two of the same examination rooms per week. It would be better to create randomness in the schedule by designing constraints which, for instance, always assigns a different skill than the skill in the day part before.

In reality, the planner knows which examination rooms are allowed to be blocked and which rooms must stay open under all circumstances. In the model, every examination room is the same. An unfulfilled position is based on the available skills and not on the importance of examination rooms.

This function would improve the model drastically, because than the planner does not have to adjust the demand input in the model until there are no unfulfilled positions left.

In the model it is assumed that during one day part only one skill is used in a specific examination room. However, often several examinations are scheduled in one day part. Since most examinations in a room are related to each other, it seems sufficient to choose the hardest skill in order to cover the other skills needed in that day part. When more skills can be combined for one employee in one specific room, the resemblance to reality would be greater.

Implementation

The implementation of this model is associated with high costs for the license of AIMMS, since this software program, unlike Microsoft Excel, is not widely used. The outcome, the personnel schedule, can be copied to Excel and spread further among the employees. Still, the costs for automatic personnel scheduling of one department with only ten permanent employees, are extremely high. Other options would be adapting the model for the use at other departments in the hospital, or to spend the same amount of money at professional software solutions for scheduling personnel in hospitals.

The last limitation is the fast changing situation at the department of Clinical Neurophysiology, and in healthcare. It is possible that the solution found in this research, the planning tool, must be adjusted after a certain time.

It is recommended to implement the functions described above to improve the performance of the model and therefore the usefulness of the planning tool. Furthermore, other departments with the same problem of allocating the personnel to certain rooms can easily adopt this model by adjusting the input parameters in the model.

Chapter 7 Conclusions and recommendations

In this last chapter we present the conclusions and recommendations of this study about the design of a decision support model for the department of Clinical Neurophysiology. The conclusions are presented in Section 7.1. After that, the recommendations for the department and for further research are provided in Section 7.2.

7.1 Conclusions

The process of manually allocating available lab assistants with the right skills to specific examination rooms is a time-consuming and complex task for the planner of the department. Therefore, the goal of this study is to develop a decision tool which supports the personnel scheduling process. From the literature study we concluded that the use of integer linear programming is an appropriate method for solving personnel scheduling problems in healthcare.

The designed planning tool performs according to the set objective of the study, namely assigning the employees to a specific examination room and taking into account the availability and skills of employees. This model saves a lot of time when scheduling the employees: when the standard data file is loaded and minor changes (for instance absence) are inserted, the actual scheduling time can be less than 5 minutes. Scheduling manually takes on average one day part per week, which is 4 hours.

The modeling tool fulfilled the requirements of the planner and the head of the department: the planning tool is simple, quick and clear. However, improvements can be made to ensure the produced schedule does not need any manual adjustments. For instance, the model does not prioritize between the examination rooms. In the case of undercapacity, the model randomly blocks an examination room. In reality, this is an important factor since some examination rooms may not be closed.

The experiments suggest that currently the department is faced with an undercapacity of 1.22 FTE. Solutions can be found in hiring a fulltime lab assistant, in incorporating students partly in the schedule, and to teach one lab assistant the skills for performing a Duplex examination.

The model is becoming a part of the planning process, by solving the complex personnel scheduling puzzle in a matter of seconds. This saves valuable time and because the software interface is simple, so in the future, more employees can schedule personnel. An adjusted version of the decision support model can be used at other departments in the hospital and other hospitals, which have to deal with the same sort of complex scheduling problems.

7.2 Recommendations

For the department

The results of the study lead to the following recommendations for the department of clinical neurophysiology.

First, teach one lab assistant the skills for performing a Duplex examination.

Second, hire a fulltime lab assistant which masters all the skills or incorporate the students into the planning on permanent days.

Third, let the planning tool be modified by a student with a mathematical background. Then other departments can use an adapted version of the planning tool too, and the rather high costs for the license of the program could be shared.

Fourth, the patient appointment schedule at the department is still an interesting matter, in which improvements always can be made to increase occupancy or reduce patient waiting times. The master thesis of Van Dijk (2010) on optimization of the occupancy of the physical therapy department of ZGT can be used as an inspiration for formulating the problem and possible outcomes.

Fifth and last, the context analysis shows that there are no tactical or strategic goals for the production or productivity of the department. Defining such goals can support the decrease of patient waiting times and the increase of utilization of the examination rooms. This saves costs and improves the quality of care.

For further research

In the field of operational research a lot of literature can be found on patient scheduling, but in comparison the literature about personnel scheduling in health care is rather scarce. Often these articles are about case studies, so for further research it can be suggested to find models which are applicable to general scheduling problems in hospitals and then can be easily implemented in practice. Furthermore, articles about personnel scheduling, not patient scheduling, at departments like Clinical Neurophysiology are hard to find. More research can be performed in these areas.

It can be advised to let more students study the improvements that can be made in the area of patient scheduling at the department. These kinds of studies can have a positive effect on the access times of patients and the utilization of the examination rooms. Joustra, Wit, Struben, Overbeek, Fockens, and Elkhuizen (2010) use integer linear programming and discrete event simulation to find scenarios in which the access times could be reduced using the same capacity and equipment.

The planning model designed in this study can be further improved. With more constraints the model can be even more adjusted to the reality. To accomplish this improved schedule, it is advised to employ an applied mathematics student with affinity for operations research in health care. A number of adjustments can be made:

- including weekend and night shifts
- randomizing the allocation of employees (variation)
- connecting the planning software to X/Care
- easy end-user interface in which employees can set their availability
- let the model close the least important examination room in the case of under capacity

Another problem experienced is that there is a feeling among the lab assistants that the workload is unequally spread over the day and week. Sometimes there are rooms available when no experienced lab assistants are present and the other way around. The lab assistants experience a combination of peaks in workload and continuous changes in capacity. This results in patient waiting time and unsatisfied personnel. It is advised to study the needed time for the examinations, for example with a stop-watch study. With these outcomes it might be possible to create a patient scheduling system which influences the productivity and the utilization of the examination rooms positively.

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Appendix A Performance

In this appendix the current performance of the department is discussed. The measurement of the performance is necessary in order to get feedback about the processes. With performance indicators it is possible to see chances to control and improve the performance. The indicators presented in Table A.1 are defined in the following sections to evaluate the current success of the department. These indicators are relevant to the head of the department, the personnel and the patients.

Table A.1
Indicators to evaluate the success of the department of Clinical Neurophysiology

Indicator	Definition
Production	Number of examinations per type and per room
Average occupancy rate per room	Percentage
Average sick leave	Percentage
No shows	Number of no shows
Scheduling time	Needed time to make the schedule
Waiting time	Indirect waiting time for appointment per examination

1. Production figures

As shown in Section 2.1.3 (Examinations), a lot of different examinations are performed at the department. The number of examinations per year differs, due to recent developments of new technologies and because some tests are fully replaced by other tests.

The production figures consists of the number of examinations (per type) performed. This number is important to the head of the department, in order to keep track of the differences between years. These differences can be used to adjust strategically of tactical plans. In Table A.2 the numbers of examinations are shown for 2009, 2010, and 2011, categorized per examination type.

In this table, the examinations are clustered per examination type. Per type there are different examinations that can be performed. For example, there are many different EEG examinations. Consequently, there are many tests that are not performed often. The numbers for Doppler and ABPI in 2011 are probably incorrect, because they are now registered at another department.

The total number of performed examinations, excluding patients that did not show up at the appointment, was 12,717 appointments in 2009, 12,661 in 2010 and 7809 in 2011. This comes down to an average of more than five examinations per hour. This number is strongly influenced by the variable duration of the treatment. The duration between examinations differ, but also the duration within the same examinations can be different.

Table A.2
Production figures of the department of clinical neurophysiology per examination type in 2009, 2010, and 2011. From the DataWarehouse, MST.

Examination type	2009	2010	2011
EEG	2796	2960	3266
EMG	5100	5272	3337
EP	174	202	183
DUPLEX	286	397	450
HTG	259	297	279
BOTOX	0	0	274
DOPPLER	2263	1831	17
ABPI	1839	1702	3
Total	12717	12661	7809

The decrease in production can be caused by certain changes in administration. For instance, in 2011 the tests performed at the vascular surgery department are no longer registered on the account of the department of Clinical Neurophysiology, although the tests are performed by the clinical neurophysiology lab assistants.

Other useful production figures can be the time spent on the treatment. Unfortunately, these numbers are not available in the digital system of the MST.

2. Occupancy of examination rooms

The occupancy rate is the number of performed examinations in relation to the (theoretical) number of examinations that can be performed in a specific examination room. This percentage can be used to identify management goals. First, the physical positions of the examination rooms are presented, followed by the occupation rates.

Position of rooms

To perform the examinations, eight examination rooms are available to the lab assistants. Those rooms are all equipped differently. This means that certain tests cannot be performed simultaneously, because the equipment for those tests are in the same room, as presented in Table A.3. This table provides an overview of the available rooms with the possibilities to perform tests. Not in every room all examinations can be performed, and some rooms at the department are not used. The reason for this is the shortage of equipment, shortage of qualified personnel, or shortage of workspace. Often, the rooms are not all occupied at the same time, or the rooms are empty awaiting patients.

Table A.3

Overview of examination rooms with current possible examinations.

Examination room	Name of examination type
ECAR	Duplex
EEG room 2	EEG AFT
EEG room 3	EEG AFT
EMG	CTS clinic regular EMG
EP	VEP SEP BEAP T3
Oldenzaal	Walking test EMG EEG
Vascular surgery room 1	Walking test
Vascular surgery room 2	Walking test
ENG	Nystagmo MAG Stim

There are three rooms for the EEG examinations of which one room can be used for AFT, one room for the Duplex, two rooms for the EMG tests, one room for ENG tests and one room for Sleep Apnea and EP examinations (see Figure A.1). Within the MST there are also examination rooms at the outpatient clinic of Vascular Surgery, where two rooms are available for Doppler and ABPI tests one day per week. A lab assistant from the department goes to the clinic to perform medical examinations over there. Furthermore, there is a small outpatient clinic in Oldenzaal where most medical examinations are performed by one lab assistant two days per week. Some days the examination rooms are blocked in the schedule and then can be used as office.

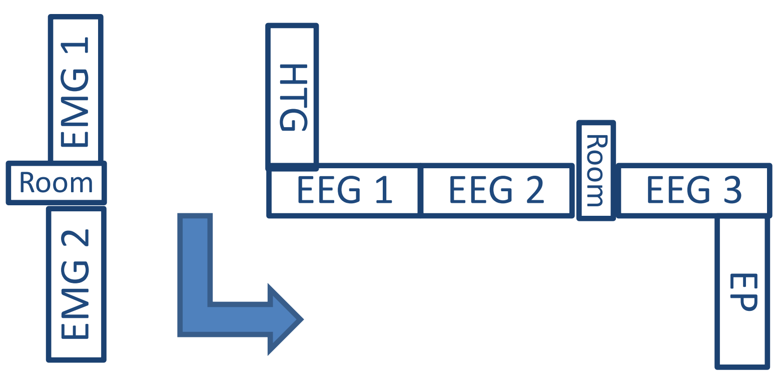

Figure A.1 Physical position of the examination rooms at the department of Clinical Neurology.

Figure A.1 illustrates how many examinations were performed in 2011 in each room. In this overview, two rooms are missing because they are not used in practice. This is one room where EMGs can be performed and one room to perform EEGs. The so called runaround is not a room, it is an available lab assistant booked as a room in the agenda to schedule the examinations, and therefore can have an occupancy rate. The lab assistant that is the runaround has to look for a room that is not occupied to perform the test. This method was introduced in April 2011.

Occupancy rate

In Table A.4 and Table A.5, the occupancy rates for the locations Enschede and Oldenzaal are presented. In Enschede, the rooms with the highest occupancy are the EMG room and the EEG room 2. The room with the lowest occupancy, with an average of 16 examinations a month (4 per week) is the HTG room (DataWarehouse, MST). Another room with a very low occupancy is the one at Vascular Surgery. However the room is not on the department of Clinical Neurophysiology and therefore the occupancy rate is hard to influence. The ECAR room, in which the Duplex test is performed, has a low occupancy as well, although this number is increasing due to a new 24 hours service. With a maximum of 54 Duplex examinations per month, which is about 3 per day, the optimal occupancy is not reached.

Table A.4
Occupancy per room in Enschede in 2011 from DataWarehouse, MST.

Examination room	Number of minutes occupied	Number of available minutes	Occupancy rate (%)
ECAR	15750	56355	27.95
EEG 2	53980	104985	51.42
EEG 3	51580	105690	48.80
EMG	54165	81135	66.76
EP	37785	108920	34.69
HTG	14445	52195	27.68
Vascular (Doppler)	9850	34690	28.39

Table A.5
Occupancy per examination in Oldenzaal in 2011 from DataWarehouse, MST.

Examination room	Number of minutes occupied	Number of available minutes	Occupancy rate (%)
EEG	1215	8460	14.36
EMG	830	1480	56.08
ENG	0	240	0.00
Vascular (Doppler)	0	10	0.00

In Oldenzaal, three out of four examinations have a very low occupancy rate. Only the EMG room is occupied more than halve of the available time. Currently, it is not a goal to reach a high occupancy rate in Oldenzaal, because service to examine close to home must be available. However, this is not efficient for the EEG, ENG and Doppler examinations.

3. Personnel leave

When personnel are absent, it causes immediate capacity problems at the department. Per year, the average percentage sick leave per department in the hospital is 3.5%, the time for study is 1.5% and the holiday leave is 8% (from DataWarehouse, MST). In 2011 the department had difficulties dealing with absent personnel, because it was with 5.8 % higher than the norm at the hospital.

The current capacity is too low to handle these situations of shortage of personnel. The method at this moment is to close some rooms when the employee is sick for a longer period of time, or to use the runaround to take over the examinations that are planned for the sick colleague.

4. No shows

'No shows' are patients that do not show up, that are dismissed from the hospital without notice to the department, or that are occupied because of other important or delayed treatments or examinations (Cayirli, 2003). The lab assistant suddenly has to look for another task to fill the time. In most cases the lab assistant cleans the equipment of earlier examinations, helps a colleague with an examination or writes a report for the neurophysiologist.

The data presented in the figures in this chapter included the number of requests with no shows. Figure A.2 displays how many no shows occurred per year from a specific specialism. Most patients that do not show up were referred by the neurology department, the general practitioners, and lung department. The reasons for the no shows could not be studied from the production figures of the DataWarehouse system.

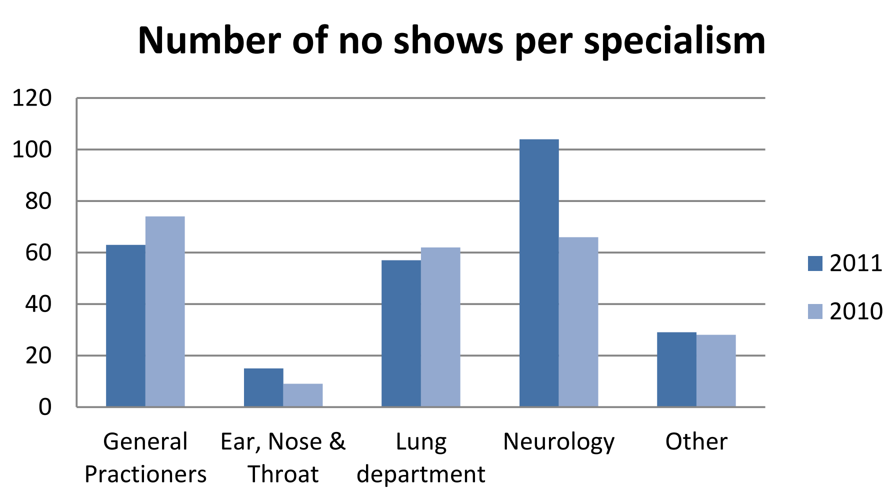

Figure A.2 Number of no shows categorized per department or specialism.

5. Access times

The average access times are estimated to be three to four weeks for a short examination, and almost two to three months for a long sleep examination (X/Care, MST). These access times lead to unsatisfied patients and higher costs. The patients stay longer outside of the care system and their symptoms could aggravate which could lead to higher costs to cure the patient.

6. Conclusion

Here, conclusions are given about the performance of the department of Clinical Neurophysiology. Currently, there is no tactical planning to reach certain goals by using performance indicators. Occupancy rates, absence, waiting times, or costs indicators are not regularly checked to control the right capacity. The main problems of some performance indicators and recommendations are described in Table A.6.

Table A.6

Occupancy per examination in Oldenzaal in 2011 from DataWarehouse, MST.

Performance indicator	Problem & Recommendations
Occupancy rate	Examination rooms can only be used for certain examinations and that can be a reason why the occupancy of the rooms at the department is low. Furthermore, several rooms are not used or not used optimal, while the waiting times for patients are three to four weeks to get an examination. When the patients are allocated more optically to the available rooms, the waiting times for the patients can reduce.
Personnel leave	There are no official rules or guidelines what to do with the schedule when a colleague is on sick leave. This can lead to inefficient decisions.
Access times	The access times are long. When the patient appointment scheduling process becomes more efficient, the access times could increase.

Other problems found in the context analysis, more related to patient appointment scheduling, are described below:

- *Handling emergency requests*
  The requests for emergency examinations are now performed by a runaround. There might be a more efficient method to deal with the emergency examinations, without switching tasks between lab assistants or reserving capacity only for emergencies. This also leads to the perception of unequal workload.
- *Efficient patient planning system*
  An efficient patient planning system could increase the low occupancy of the examination rooms, while using the same capacity. Subsequently, the waiting times for the patients can be reduced and the service times are improved.
- *Productivity*
  Combining the proposed improvements above may lead to higher production figures. In the MST Lean/Six Sigma projects already started, and therefore it is advisable to implement those

concepts at the department for reduction of waiting times and higher quality of care (Borghuis-Lub, 2011).

Appendix B Input data model

Table B.1

Overview of the input parameters for the decision support model.

Examination rooms	Employees	Shift		Skills
ECAR	Employee 1 (E1)	Monday	Morning	EEG
EP	Employee 2 (E2)	Monday	Afternoon	Duplex
ENG	Employee 3 (E3)	Tuesday	Morning	CTS
Vascular Outpatient Clinic	Employee 4 (E4)	Tuesday	Afternoon	EMG
Runaround	Employee 5 (E5)	Wednesday	Morning	MagStim
Oldenzaal	Employee 6 (E6)	Wednesday	Afternoon	VEP
EEG 2	Employee 7 (E7)	Thursday	Morning	BEAP
EEG 3	Employee 8 (E8)	Thursday	Afternoon	SSEP
EMG 1	Employee 9 (E9)	Friday	Morning	T3
EMG 2	Student 1 (S1)	Friday	Afternoon	Single Fiber
	Student 2 (S2)			Botox
	Student 3 (S3)			AFT
	Student 4 (S4)			Walkingtest
	Flexworker 1 (F1)			PSG
				Watching
				OL Vascular
				Runaround
				Operation room
				Oldenzaal EMG/EEG
				ABPI
				ENG
				MSLT
				Sleep deprivation

Table B.2

Overview of the input data of the availability of employees, which is in some shifts different in even and odd weeks.

	Employees	E1	E2	E3	E4	E5	E6	E7	E8	E9	S1	S2	S3	S4	F1
Availability															
Monday	**Morning**	*	*	*	*	*	*					*	*	*	
Monday	**Afternoon**	*	*	*	*	*	*					*	*	*	
Tuesday	**Morning**	*		*	*	*		*	*		*	*	*	*	
Tuesday	**Afternoon**	*		*	*	*		*	*		*	*	*	*	
Wednesday	**Morning**	*	*	*		*	*		*	*	*	*	odd	*	
Wednesday	**Afternoon**	*	*				*		*	*	*	*	odd	*	
Thursday	**Morning**	*	*	*	*		*	even		*	*	*	*	*	
Thursday	**Afternoon**	*	*	odd	*		*	even		*	*	*	*	*	
Friday	**Morning**	even	*	*			*	*	*		*	even	*	*	
Friday	**Afternoon**	even	*	*			*	*	*	*	*	even	*	*	

Table B.3

Overview of the input data of the skills of the employees, with variation in odd and even weeks.

Employees	E1	E2	E3	E4	E5	E6	E7	E8	E9	S1	S2	S3	S4	F1
Skills														
EEG	*	*	*	*	*	*	*	*		*	*	*		*
AFT	*	*	*	*	*	*	*	*		*	*			*
Sleep deprivation	*	*	*	*	*	*	*	*						
PSG	*	*	*	*	*	*	*	*		*	*			*
MSLT	*	*	*	*	*	*	*	*						
CTS		*	*	*	*	*	*	*		*	*			*
EMG		*	*	*	*	*	*	*		*	*			*
Single Fiber			*		*	*								
Botox		*	*	*	*	*	*	*						
ENG		*	*	*	*	*	*	*						
MagStim	*	*	*	*	*	*	*	*						
VEP	*	*	*	*	*	*	*	*						
BEAP	*	*	*	*	*	*	*	*						
SSEP	*	*	*	*	*	*	*	*						
T3	*	*	*	*	*	*	*	*	*	*	*	*		*
Duplex		*	*	*	*	*	*							
Walking test		*	*	*	*	*	*	*		*	*			*
Runaround	*	*	*	*	*	*	*	*						
ABPI	*	*	*	*	*	*	*	*						

Employees	E1	E2	E3	E4	E5	E6	E7	E8	E9	S1	S2	S3	S4	F1
Skills														
Operation room	*	*		*	*	*	*	*						
OL Vascular		*	*	*	*	*	*	*						
OL EMG/EEG		*	*	*	*	*	*	*						
Watching										*	*	*	*	

Table B.4

Demand on Monday morning, n=7.

Skills	AFT	Duplex	CTS	VEP	Runaround	Walking test	Operation room
Examination room							
EEG 2	1						
EEG 3							odd
ECAR		1					
EMG 1			1				
Runaround					1		
Vascular						1	
ENG				1			

Table B.5

Demand on Monday Afternoon, n=8.

Skills	AFT	Duplex	Runaround	Walking test	EMG	T3	PSG	ENG
Examination room								
EEG 2	1							
EEG 3							1	
ECAR		1						
EMG 1					1			
Runaround			1					
Vascular				1				
ENG								1
EP						1		

Table B.6

Demand on Tuesday morning, n=7.

Skills	AFT	Duplex	Runaround	Walking test	CTS	VEP	Operation room
Examination room							
EEG 2	1						
EEG 3							even
ECAR		1					
EMG 1					1		
Runaround			1				
Vascular				1			
EP						1	

Table B.7

Demand on Tuesday afternoon, n=8.

Skills	AFT	Duplex	Runaround	Walking test	EEG	EMG	T3	Botox
Examination room								
EEG 2	1							
EEG 3					1			
ECAR		1						
EMG 1						1		
Runaround			1					
Vascular				1				
EP							1	
EMG 2								1

Table B.8

Demand on Wednesday morning, n=8.

Skills	AFT	Duplex	Runaround	EEG	EMG	T3	Botox	OL EMG/EEG
Examination room								
EEG 2	1							
EEG 3				1				
ECAR		1						
EMG 1					1			
Runaround			1					
EP						1		
EMG 2							1	
Oldenzaal								1

Table B.9

Demand on Wednesday afternoon, n=7.

Skills Examination room	AFT	Duplex	Runaround	T3	Walking test	PSG	OL Vascular
EEG 2	1						
EEG 3						1	
ECAR		1					
Runaround			1				
EP				1			
Oldenzaal							1
Vascular					1		

Table B.10

Demand on Thursday morning, n=7.

Skills Examination room	AFT	Duplex	Runaround	Walking test	SSEP	OR	OL EMG/EEG	ENG
EEG 2	1							
EEG 3						odd		
ECAR		1						
Runaround			1					
EP					1			
Oldenzaal							1	
Vascular				1				
ENG								1

Table B.11

Demand on Thursday afternoon, n=9.

Skills Examination room	AFT	Duplex	Runaround	Walking test	OL EMG/EEG	ENG	EMG	T3	Sleep apnea
EEG 2	1								
EEG 3									1
ECAR		1							
Runaround			1						
EP								1	
Oldenzaal					1				
Vascular				1					
ENG						1			
EMG 1							1		

Table B.12

Demand on Friday morning, n=8.

Skills	AFT	Duplex	Runaround	Walking test	ENG	EMG	SSEP	Operation room
Examination room								
EEG 2	1							
EEG 3								even
ECAR		1						
Runaround			1					
EP							1	
Vascular				1				
ENG					1			
EMG 1						1		

Table B.13

Demand on Friday afternoon, n=8.

Skills	AFT	Duplex	Runaround	Walking test	ENG	EMG	T3	PSG
Examination room								
EEG 2	1							
EEG 3								1
ECAR		1						
Runaround			1					
EP							1	
Vascular				1				
ENG					1			
EMG 1						1		

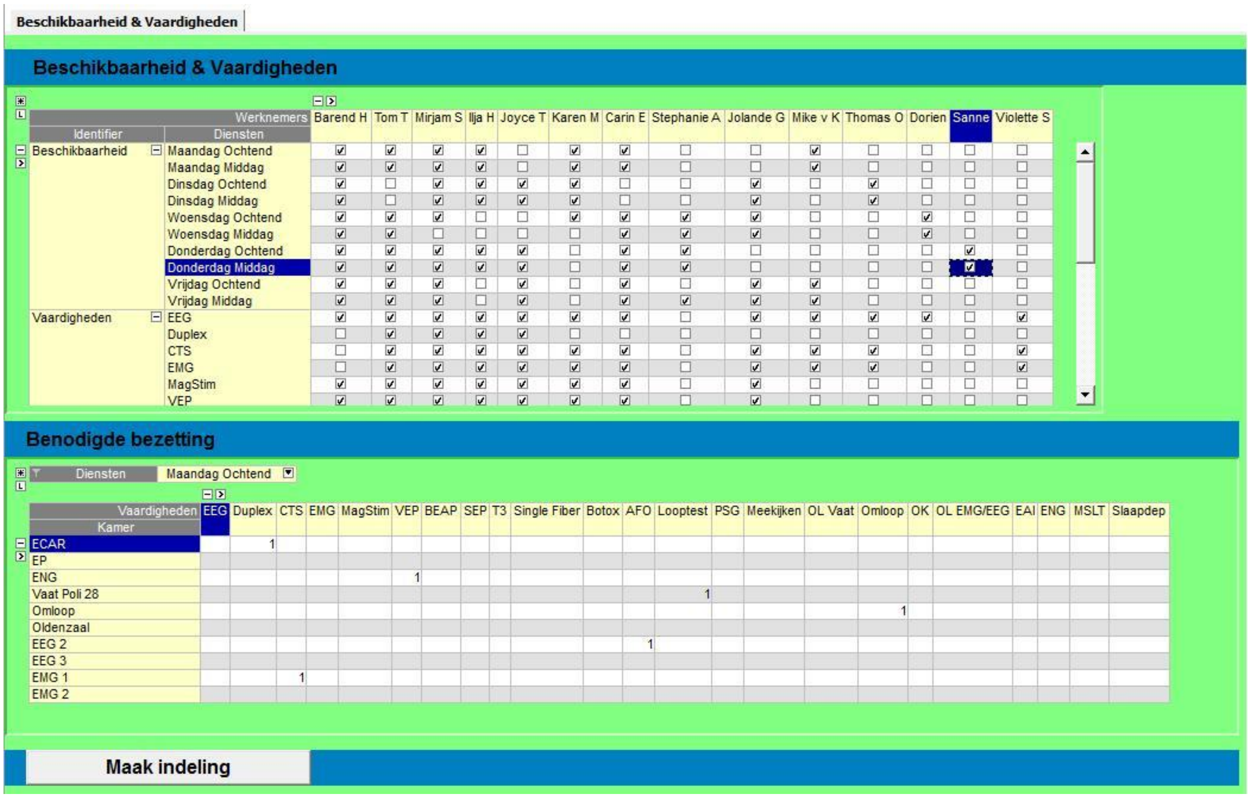

Figure C.1

Interface planning tool in AIMMS Page 1

Figure C.2

Interface planning tool in AIMMS Page 2

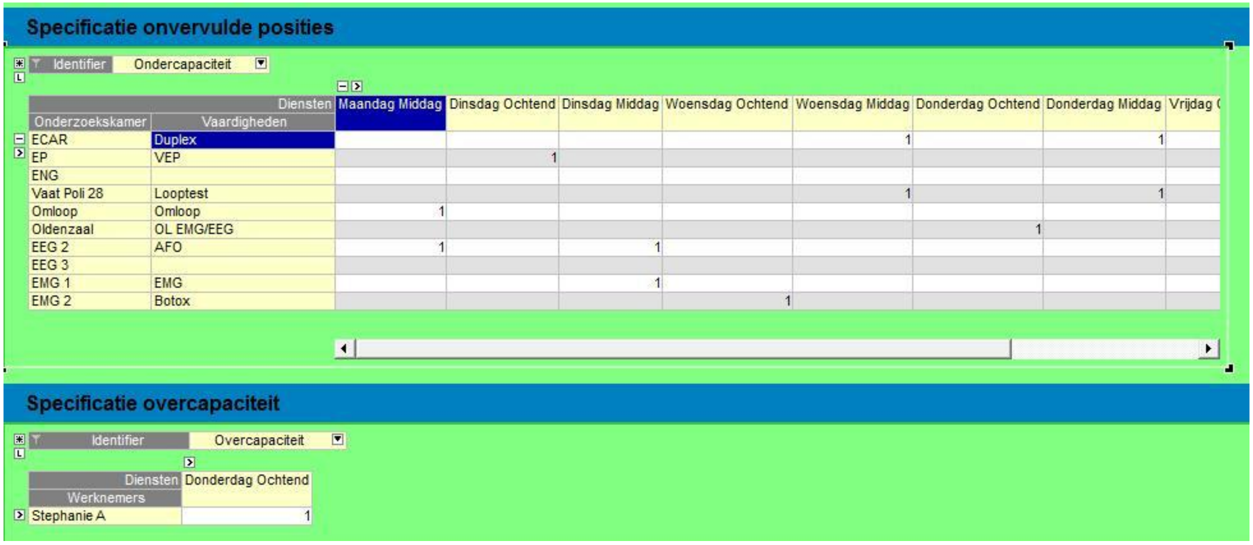

Figure C.3
Interface planning tool in AIMMS Page 3

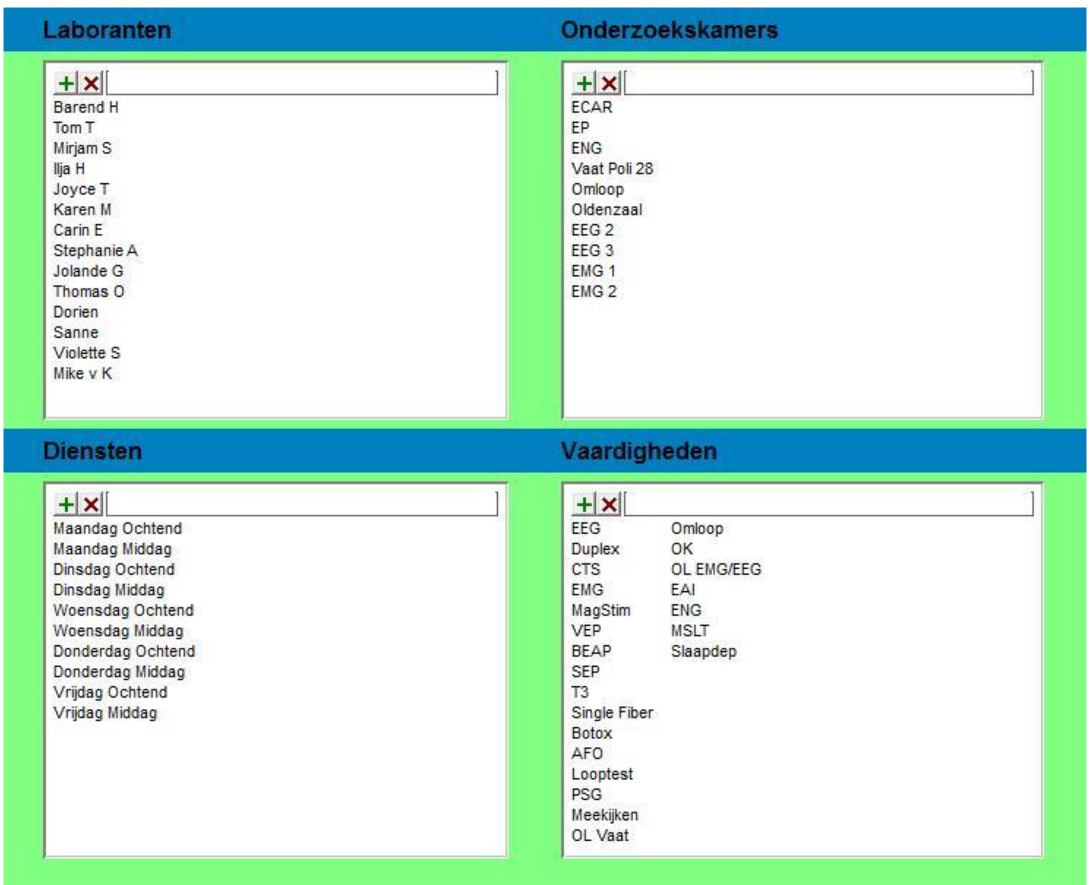

Figure C.4
Interface planning tool in AIMMS Page 4

Appendix D Implementation

The goal of the study is to design a decision support model for employee scheduling, to be used by the planner and the head of the department of Clinical Neurophysiology. This tool supports the planner in making the schedule by supplying the optimal solution. It reduces time and effort in comparison to constructing the schedule manually. The ILP model described in Chapter 4 is suitable and supplies schedules quickly, although there are high software costs and restricting for easily sharing the schedules. The model solves the problem easily, quickly and provides a clear output of the schedule (see Appendix C for the end user interface).

In Figure D.1, the new scheduling process is briefly described. The first step is to collect the correct input data about the availability of employees (agenda), the needed examination rooms (X/Care) and if there is an update for the skills.

The second step involves the entry of data in the model. The end user interface exists of four pages (see Appendix C). It starts with a page for the input data demand, skills, and availability. A standard data case can be loaded in order to save time if only minor corrections are needed. After this is filled out, the model runs by pressing the allocation button. On the second page the outcome, the allocation of the employees, is presented in a table. Furthermore, the total under and overcapacity is shown. The third page shows a specification of the under and overcapacity. The last page allows the planner to add new input parameters.

Figure D.1 New scheduling process.

The planner must check whether there is an under or overcapacity and can, if needed, adjust the input parameters on the first page. The provided schedule from the second page can be copied to Excel. With the current version of the model there is no priority in examination rooms. When it is needed, the planner can adjust the schedule in Excel manually. After the schedule for a specific week is correct, it can be printed or emailed to the employees.

A right implementation process is needed, since the exploratory research of Kellogg and Walczak (2007) stated that only 30% of the models that academics have produced are actually used in practice. This decision supporting tool still needs little adjustments before it can be used successfully in practice. Holidays can be much quicker planned and in the case of unexpected absence of personnel a new allocation of employees can be quickly produced.

Future situation with students

In the future (maximum of four years), assumingly, all students graduate, master all the skills and are hired fulltime at the department. This creates changes for increasing the productivity of the department. In this situation, 27 day parts can still be fulfilled. Conclusively, almost every day up to 4 examination rooms more can be opened.

Meanwhile, not yet graduated student lab assistants can help relieving the under capacity at the department. The planner can make appointments with one student for one permanent day per week, to incorporate the student in the personnel schedule. In the planning tool, at this day the availability of the student is marked (since on the other days the students are not taken into account for the personnel schedule, but only for watching and assisting). The already mastered skills are also ticked off. The planning tool will automatically take the student into account for the schedule. Students in their last year can be scheduled for independent examinations twice per week, with the other days remaining to learn. An example is displayed in Table D.1.

Table D.1

An example of incorporating students, one or two days in the week, in the personnel schedule.

Student	**S1**	**S2**	**S3**	**S4**
Day				
Monday	EMG			
Tuesday		CTS		
Wednesday			EEG	
Thursday				T3
Friday	EEG			