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Master's Thesis

Therapist Capacity Planning

How can therapist capacity planning improve the execution of the adult therapy programs in the Roessingh Rehabilitation Clinic?

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Title Page

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Introductie

Dit onderzoek is gericht op de verbetering van de huidige capaciteitsplanning in het Roessingh. Het Roessingh is een groot revalidatie centrum gelegen in Enschede en biedt hoogwaardige revalidatieprogramma's aan voor poliklinisch en klinische patiënten met verschillende aandoeningen. Dit onderzoek zal zich bezig houden met de uitvoering van revalidatieprogramma's voor volwassenen. Deze programma's kunnen een aantal weken duren tot meer dan een half jaar. Op dit moment staat de organisatie voor de uitdaging om de revalidatieprogramma's adequaat te plannen. Dit rapport doet verslag van de huidige prestaties en de mogelijkheden voor verbeterde capaciteitsplanning van therapeuten.

Probleem beschrijving

De volgende doelen zijn gesteld: het aanbieden van hoog kwalitatieve zorg, snelle toegang tot zorg, efficiënte inzet van middelen en het behalen van de productieafspraken, die zijn gemaakt met zorgverzekeraars. Therapeuten zijn ingedeeld in specialistische teams die verantwoordelijk zijn voor de behandeling van één of meerdere diagnose groepen. De wekelijkse vraag naar behandelingen fluctueert als resultaat van onzekere aankomst van nieuwe patiënten en een wisselende vraag naar zorg van de huidige patiënten. Als de vraag de capaciteit van therapeuten in een specialistisch team overstijgt, kunnen niet alle afspraken worden gepland. Patiënten ondervinden dan dat hun therapie programma niet volledig gerealiseerd wordt, wat kwalijk is voor de kwaliteit van hun behandeling. Verder zien we een structurele onderbezetting van therapeuten en een sterk fluctuerende werkdruk.

Methoden

Een analyse is uitgevoerd van het revalidatie proces, planning en management, de huidige knelpunten en prestatie-indicatoren. Gebaseerd op deze analyse is een methode ontwikkeld om de toewijzing van therapeuten aan specialistische teams te verbeteren. Ook is de impact onderzocht van het beleid om meer of minder specialistische teams to vormen. In deze methode de toewijzing is gemodelleerd als MINLP probleem en dit wordt opgelost met een Simulated Annealing heuristiek.

Resultaten en Aanbevelingen

Allereerst wordt de toewijzing van therapeuten besproken. Experimenten tonen aan dat de nieuwe toewijzing van therapeuten aan specialistischs teams leidt tot meer gelijke behandeling van patiënten en de hoeveelheid niet verroosterde afspraken halveert in de meeste disciplines.

Als tweede is het beleid voor het vormen van specialistische teams onderzocht. Experimenten tonen aan dat het vormen van zeer specialistisch teams en/of het toewijzen van teams aan alleen poliklinische of klinische patiënten de hoeveelheid niet verroosterde behandelingen vergroot, wat leidt tot een lagere bezetting van therapeuten en een lagere realisatie van therapie programma's. Het meest flexibele beleid is om één groot team van generalisten te vormen. Dit leidt tot de beste prestaties: de hoeveelheid niet verroosterde fysiotherapie kan tot wel 86% afnemen. Echter, het vormen van specialistische teams is bevorderlijk voor de kwaliteit van de behandelingen. Daarom wordt er voorgesteld om een team van generalisten te vormen als aanvulling op de specialistische teams. Dit team kan de behandelingen overnemen die niet meer bij de specialistische teams gepland kunnen worden. Als 80% van de fysiotherapieën uitgevoerd wordt door hoog specialistische teams kan een realisatie graad van 93% behaald worden bij een bezettingsgraad van 80%. Deze prestatie is maar iets lager ten opzichte van het meest flexibele beleid (dan een kan een realisatie graad van 97% bij een bezettingsgraad van 83% behaald worden). Daarom raden wij het Roessingh aan een aanvullend team van generalisten te vormen naast hoog specialistische teams omdat dit het beleid is met de beste afweging tussen kwaliteit van zorg en efficiënte inzet van therapeuten. Bovendien is hierbij een minimale hoeveelheid extra training van therapeuten vereist.

De toegangstijd is niet bestudeerd in detail, toch kan er op basis van de experimenten in hoofdstuk 5 geconcludeerd worden dat variabiliteit van de werkdruk af zal nemen en daarmee de toegangstijd voor nieuwe patiënten.

De maximaal planbare fractie directe tijd wordt op dit moment gehanteerd als de norm voor de bezettingsgraad, maar experimenten tonen aan dat gerealiseerde bezettingsgraad altijd lager is. Als deze planbare fractie verhoogd wordt, kan de bezettingsgraad verbeterd worden. Maar er is een limiet ten opzien van deze verbetering, omdat de huidige arbeidskracht te groot is voor de huidige vraag naar zorg.

Een laatste aanbeveling is om zoveel mogelijk afspraken als groepstherapieën uit te voeren, omdat therapeuten dan meerdere patiënten tegelijkertijd kunnen behandelen.

Conclusie

In dit onderzoek is aangetoond dat verbeterde capaciteitsplanning bijdraagt aan hogere kwaliteit van revalidatie programma's, efficiëntere inzet van therapeuten en verbeterde toegang tot zorg.

Management Summary

Introduction

This study focuses on improving the capacity planning of therapists in the Roessingh Rehabilitation Centre (RRC). The RRC is a large rehabilitation centre in Enschede, the Netherlands, that offers highly sophisticated, multidisciplinary rehabilitation therapy programs for in- and outpatients with various diagnosed conditions. The focus of this study lies on the execution of adult therapy programs, which can take a few weeks up to more than half a year. Currently the organization is facing the challenge to adequately schedule the patients' therapy programs. In this report we evaluate the current performance and research the possibilities of capacity planning of therapists.

Problem description

The following objectives for capacity planning have been defined: delivering high quality of care, guaranteeing quick access for new patients, making economic use of the resources and meeting the production targets that were agreed with health care insurers. Therapists are organized in specialized teams which are responsible for the treatment of one or more diagnosis groups. The weekly demand for therapy fluctuates as a result of the uncertain arrival new patients and patients who need changing therapies. Unscheduled therapy occurs when therapy demand exceeds the capacity of a specialized team. Patients currently experience incomplete realization of their therapy programs which negatively influences the quality of care. Furthermore we see a structural underutilization of therapists and a highly fluctuating workload.

Methods

We analyzed the rehabilitation process, planning and control, the current bottlenecks and established performance indicators. Based on this analysis we developed a method to improve the allotment of therapists to specialized teams and we researched different policies for the formation of specialized teams. In this method the allotment is modelled as a MINLP problem and solved with a Simulated Annealing heuristic.

Results & Recommendations

First the improved allotment of therapists to specialized teams is regarded. We found that alternative allotment plans generated by our method lead to more equal treatment of patients and successfully decrease the average amount of unscheduled therapies by 50% for most disciplines.

Secondly we researched the policies for the formation of specialized teams. Experiments show that forming more specialized teams and/or dedicating teams to either in- or outpatients increases the amount of unscheduled therapy, which leads to a lower utilization of therapists and a lower realization level of therapy programs. The most flexible policy to leads to the best performance is to form one large team of generalists; the amount of unscheduled physiotherapy can be reduced by as much as 86%. However, forming specialized teams is beneficial for the quality of the therapies. Therefore a further option is to form a team of generalists in addition to the specialized teams; this team can intercept all demand that cannot be scheduled in the specialized teams. If 80% of the therapies are conducted by highly specialized teams a realization level of 93% of the therapy programs can be achieved with a physiotherapists' utilization of 80%. This performance is only slightly lower compared to the best policy (then a realization level of 97% and a utilization of 83% can be achieved). Therefore we believe that deploying highly specialized teams plus an additional team of generalists is the best suited policy with the best trade off between quality of care and efficient deployment of therapists with a minimal amount of retraining of therapists required.

The access time for therapy has not been studied in detail; however, based on the analysis presented in Chapter 5 it follows that forming less specialized teams will reduce workload variability, which will in turn decrease the access time to the therapy centre.

The load is currently used as the standard for the utilization; however, experiments show that actual utilization will always lower. The utilization can only be increased when the schedulable load is increased. However, the utilization can only be improved to a certain limit, because the current workforce is too large the current workload to meet the utilization targets.

Lastly we recommend executing as many group therapies as possible, because therapists can treat multiple patients simultaneously during these appointments.

Conclusion

In this study we have shown that tactical capacity planning of therapists can effectively improve the execution of adult therapy programs in terms of quality of care, economic deployment of therapists and access to care.

Terminology and abbreviations

	Abbreviations
RRC	Roessingh Rehabilitation Centre
AO	Orthopaedics or Amputation
MPZ	Spinal cord injury
NAH	Non congenital brain damage

NCVA	Stroke
NMA	Neuromuscular disorders
NMAFL	ALS
V-MS	Multiple Sclerosis
V-PAR	Parkinson's Disease

	Frequently used terms
Rehabilitation (therapy) programs	Rehabilitation programs consist of weekly protocols stating type and duration of therapy for the individual patient, who can be given individual or group appointments. Patients often receive therapies in multiple disciplines at the same time.
Diagnosis groups	Patients can be characterized by their diagnosed conditions and divided into so called diagnosis groups.
In and outpatients	Inpatients are patients that are admitted to the RRC's clinic during their treatment; outpatients are hospitalized and visit the RRC by appointment.
Specialized teams of therapists	Therapists work for one of the disciplines. Within a discipline they are allotted to a specialized team which is responsible for the treatment of one or more diagnosis groups. A team that treats all diagnose groups is called a team of generalists.
The therapists' load	Therapists normally spend a certain fraction of their working hours directly on treating patients and another fraction on administrative tasks that are directly related to the therapies. Management has set a standard for the maximum fraction of hours that therapists may be scheduled for therapies. This fraction will be referred to as the load. (In Dutch: de load is de maximale fractie directe tijd die therapeuten kunnnen realiseren)
Unscheduled therapy	When there is not enough time in the schedules of therapists in a specialized team to plan all therapy appointments, therapy appointments cannot be scheduled and this leads to incompletely realized rehabilitation programs for patients.
Realization level of therapy programs	The degree to which programs have been executed is called the realization level.
Utilization of therapists	The therapists' utilization describes how efficiently therapists are deployed; it is a measure of the realized therapies compared to the therapist work force.

Contents

1 Introduction

This study was commissioned by the Service Department of the Roessingh Rehabilitation Centre in Enschede[1] and will focus on the operations involved in the execution of rehabilitation programs for adult patients. The Roessingh Rehabilitation Centre is introduced in paragraph 1.1. In paragraph 1.2 the research motivation is explained and finally the research questions are defined in paragraph 1.3.

1.1 The Roessingh Rehabilitation Centre

People, who suffer from serious health problems such as, for example, MS or have survived a serious incident such as a stroke or an accident, often require special care. Rehabilitation therapies help to improve, support and restore their physical and mental functions to enable the patients to participate in society as best as possible.

The Roessingh Rehabilitation Centre (the RRC) offers highly specialized rehabilitation care and is one of the largest rehabilitation clinics in the Netherlands. The RRC is part of the Roessingh Concern. The Roessingh Concern has a long history of combining treatment, care and research for scientific and commercial purposes. The RRC is unique for its programs for pain, high spinal cord lesions and clinically treated children. The stroke patients are the largest group of patients within the RRC. The RRC serves a large area in the eastern part of Holland; as the next nearest rehabilitation centres are in Apeldoorn, Arnhem or Zwolle.

The RRC offers in- and outpatient treatment. An average of 186 inpatients and 1394 outpatients were in treatment at the same time in 2013. There are three different departments within the RRC: the inpatient department, the outpatient department and the therapy centre. Patients who require constant care by nurses during their treatment are hospitalized in the inpatient department. The

[1] In this research, the chronic pain and children division and the division in Winterswijk are not regarded.

outpatient department consists of a waiting room for outpatients and consultation rooms where appointments between the physicians and patients take place. The rehabilitation programs are carried out by therapists in the therapy centre. The therapies range from physical therapies such as physiotherapy to social and mental therapies such as career counselling and psychotherapy.

The medical staff within the RRC can be split in three categories: rehabilitation physicians, therapists and nurses. The goal of this research is to improve the planning and control of therapy programs, therefore this report concentrates on the operations in the therapy centre and not on the other departments of the RRC. Additionally this study only focuses on adult patients and is not concerned with pain programs and children rehabilitation.

Department	Medical staff	Type of patients
Inpatient department	Nurses and Physicians	Inpatients
Outpatient department	Nurses and Physicians	Outpatients
Therapy centre	Therapists	In- and outpatients

Table 1 Medical staff and patients types per department.

1.2 Research motivation

In recent years the RRC has started to offer more sophisticated therapies by highly specialized therapists. Patients that demand less complicated therapy are treated in nursing homes, so only the complex cases remain in the RRC Therefore appointment scheduling has become increasingly complex. The fact that the Dutch government has imposed stricter rules for the access to care and that health care insurers force health care institutions to deploy their resources more efficient increases the challenge for any health care institution. Health care institutions spend around 80% of their budget on staff, so consequently efficient deployment of staff is top priority for management. Within rehabilitation care, therapists form the largest group within the medical staff [Appendix B].

Currently the organization is facing the challenge to adequately schedule the therapy programs. Most problems are caused by inefficient capacity planning and become evident when the therapy programs are scheduled by the planning department. The therapy demand fluctuates as a result of the uncertain arrival process of new patients and due patients having a changing need for therapies during their rehabilitation program. Therapists work for one of the disciplines. Within a discipline they are allotted to a specialized team which is responsible for the treatment of one or more diagnosis groups. When there is not enough time in the schedules of therapists in a specialized team to plan all therapy appointments, therapy appointments are not scheduled and often not realized. In other words; the therapy demand exceeds the capacity of a specialized team. Patients currently experience incomplete realization of their therapy programs which has a negative influence on the quality of care. Furthermore we see a structural underutilization of therapists and a highly fluctuating workload.

Management is interested to find how capacity planning of their therapists can improve the execution of therapy programs. A lack of well defined objectives calls for quantified performance measures to substantiate the current discussions and research alternative planning.

1.3 Research question

The main research question is formulated as follows:

How can therapist capacity planning improve the execution of the therapy programs?

In order to answer this question, it is broken down into a series of smaller research questions, which will be answered in the corresponding chapters:

Chapter 2.1: What are the processes involved in the execution of rehabilitation therapies?
The characteristics of rehabilitation therapy and the resources involved are explored and described.

Chapter 2.2: What are the characteristics of the current planning and control functions?
All planning and control functions involved in the execution of therapy programs are explored in hierarchical order.

Chapter 2.3: What performance measures can be defined for the execution of rehabilitation therapies?
To substantiate the current discussions the objectives for the operations in the therapy centre are explored. The current performance is explored by an analysis of historic data.

Chapter 2.4: What are the current bottlenecks in the execution of therapy programs?
A bottleneck analysis is carried out of all planning and control functions in hierarchical order.

Chapter 3: Which methods for capacity planning in rehabilitation therapy have been proposed in the literature?
A literature review is conducted to provide a theoretic framework for capacity planning techniques and objectives in rehabilitation care. Due to a lack of available theory, capacity planning techniques in similar health services are also reviewed.

Chapter 4: How can the therapist capacity problem be modelled and solved?
The capacity problem is formally described and adequate solving methods are discussed.

Chapter 5: How does alternative capacity planning improve the performance?

Here the results of the new alternative therapist capacity planning are compared to the current situation under various alternative policies.

Chapter 6: What are the implementation considerations for alternative therapist capacity planning?

First, alternative allotment plans must be created; the new allotment method is integrated in a decision support tool. Secondly alternative capacity planning requires improved performance measurement. Finally, the re-allotment of therapists imposes implementation challenges for management.

Chapter 7: Which conclusions and recommendation follow from this research?

The findings of this research are recapped and discussed, recommendations for the RRC and directions for further research directions are discussed per hierarchic level.

2 Context analysis

In this chapter a context analysis of the rehabilitation process is described. The analysis focuses on the operations in the therapy centre, because there the rehabilitation therapies are executed. An extensive bottleneck analysis has been carried out across the organization with patients, physicians, therapists, management and administrative staff [Appendix H]. In paragraph 2.1 the processes involved in the execution of rehabilitation programs are described. Paragraph 2.2 explains how this process is planned and controlled. In paragraph 2.3 performance measures are formulated for the rehabilitation process. In paragraph 2.4 a bottleneck analysis of the current planning of rehabilitation therapies is carried out. In paragraph 2.5 the conclusions of the context analysis are drawn and the scope of the remainder of this study is delimited.

2.1 Process description

When a patient has been referred to the RRC by his general practitioner, a rehabilitation physician or another type of physician in the hospital, a first appointment is made for consultation with a rehabilitation physician. The time between referral and the first consultation is referred to as the **access time to the RRC**. The physician decides whether to admit a patients and if so, whether the patient should receive in- or outpatient treatment. Inpatients are hospitalized in the RRC's inpatient department. Outpatients stay at home during their treatment. During the first consultation the physician diagnoses the patient's condition and puts together a suitable rehabilitation program. The rehabilitation program is carried out by therapists and monitored by the rehabilitation physician. The physician sees his inpatients in the clinic and outpatients get regular consultations in the outpatient department.

A patient may have to wait for his rehabilitation program to start; this time is referred to as the **access time to the therapy centre.** When the patient is admitted to therapy, his therapy program is scheduled weekly. When the physician decides that a patient is sufficiently rehabilitated, he dismisses the patient. For an outpatient this means that his therapies stop. When an inpatient is dismissed from the clinic, he can continue his therapies as an outpatient or be dismissed completely. Both in- and outpatients visit the therapy centre by appointment; they share therapy facilities.

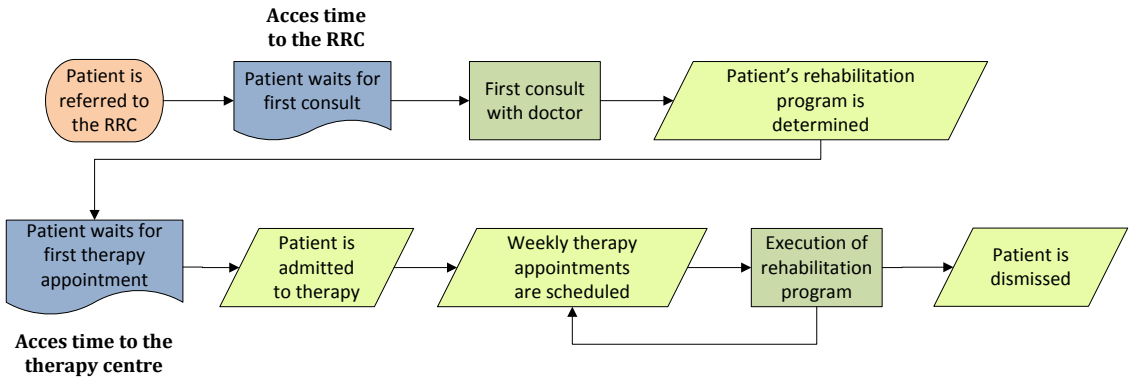

Figure 1 Chronological order of events in the rehabilitation process; go to Appendix I for a legend of the used shapes

In paragraph 2.1.1 the nature of rehabilitation programs will be discussed. The patient types and resources involved in the execution of rehabilitation programs are discussed respectively in paragraph 2.1.2 and 2.1.3.

2.1.1 (Standard) Rehabilitation Programs

As explained in the previous paragraph, a patient's individual rehabilitation program is determined in the first consultation with the physician. Rehabilitation programs consist of weekly protocols stating type and duration of therapy for the individual patient, who can be given individual or group appointments. These are group appointments such as "therapeutic walking" carried out by one or two therapists with up to 10 participants. Patients often receive therapies in multiple disciplines at the same time. A patient's rehabilitation program must be carried out without disruptions.

Therapy Discipline	Week 1	Week 2	…	Week 16
Activity therapy	5	5	…	1
Ergo therapy	4	3	…	3
…	…	…	…	…
Psychotherapy	2	2	…	0

Table 2 Example of a rehabilitation program of 16 weeks

During the weekly meeting, the physician and specialized team review all patients' progress and if necessary, small adjustments are made to their programs. Each six weeks a patient review meeting is organized which is attended by the patient. In this meeting the physician and therapist team discuss

the patient's progress and implement structural alterations to the programs. Medical staff explains that frequent adjustments are important because therapy programs need to be tailor made to the patients' needs [Appendix H]. Therefore the horizon of appointment planning is currently limited to one week.

In an effort to get grip of their operations, the RRC has formulated standard rehabilitation programs (SRPs) for the inpatients. Each inpatient is assigned to a limited number of predefined standard rehabilitation programs. SRPs have proven to be very helpful in reducing the patient's length of stay. By clearly defining the duration of the program, the patient and his therapists are more determined and focussed to achieve successful rehabilitation in the planned time span [Appendix H].

2.1.2 Patient Types

Patients can receive in- or outpatient treatment. Inpatients are usually physically and/or mentally weaker and require a higher amount of therapies than outpatients. Furthermore patients can be characterized by their diagnosed conditions and divided into so called diagnosis groups; all adult diagnosis groups are shown in the table below. Patients in the same diagnosis groups require similar therapies, e.g. non congenital brain damage patients generally need more cognitive therapies, whereas spinal cord injury patients need more physical training.

Diagnosis Group	Abbreviation	Type of Treatment
Orthopaedics or Amputation	AO	Inpatient / Outpatient
Spinal cord injury	MPZ	Inpatient / Outpatient
Non congenital brain damage	NAH	Inpatient / Outpatient
Stroke	NCVA	Inpatient / Outpatient
Neuromuscular disorders	NMA	Outpatient
ALS	NMAFL	Outpatient
Multiple Sclerosis	V-MS	Outpatient
Parkinson's Disease	V-PAR	Outpatient
Lungs and Respiratory system	V-RES	Outpatient

Table 3 Classification of patients by diagnosis group and type of treatment

2.1.3 Involved Resources

The resources involved in rehabilitation therapy can be split into physical resources and therapists. Physical resources include all therapy facilities like the appointment rooms, fitness devices, the swimming pool etc.

Therapists are employed for fixed hours per week and many therapists work part time. Therapists execute the therapies and in one of the disciplines: activity therapy, movement teaching, ergo therapy, physiotherapy, speech therapy, social work and psychology[2]. Within a discipline, therapists are allotted to specialized teams. These specialized teams are responsible for a number of diagnosis groups.

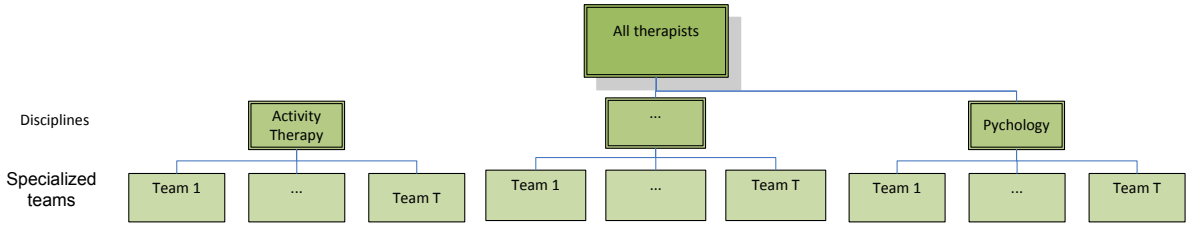

Figure 2 Subdivision of therapist work force

Therapists treat patient individually or in group appointments; they are able to treat multiple patients simultaneously during group appointments. Especially movement teachers and physiotherapists often treat patients in groups, whereas psychologists will typically only treat patients individually. Therapists normally spend a certain fraction of their working hours directly on treating patients and another fraction on administrative tasks that are directly related to the therapies. Management has set a standard for the maximum fraction of hours that therapists may be scheduled for therapies per discipline. This fraction will be referred to as the load. The load is discipline specific, for example psychologists has a lower load than physiotherapists, because psychologists need more time to document about their therapies.

[2] There are actually more small disciplines, such as cognitive therapy, dietetics, career counselling, therapeutic computer therapy etc. However, this study focuses on the 7 largest disciplines.

2.2 Planning and control

The control span of the RRC is divided over six profit centres [Appendix A]. Each profit centre has its own physicians, therapists and nurses, which are managed and controlled by process managers. Profit centre 3, 4 and 5 are concerned with adult rehabilitation care. Diagnosis groups that require similar treatment are assigned to the same profit centre.

Profit Centre	Diagnosis Groups
3	AO , MPZ , V-MS , V-RES, V-PAR
4	NCVA
5	NAH, NMA, NMAFL

Table 4 Assignment of diagnosis groups to the profit centres

The hierarchic framework for planning and control by Hans, Houdenhoven and Hulshof is used as guidance [1] to analyse the planning and control mechanisms of the rehabilitation process. The framework consists of the four managerial areas in health care; *medical, resource capacity, materials* and *financial*. The focus of this study is on resource capacity management, which is concerned with the planning and control of renewable resources.

	Medical Planning	**Resource Capacity Planning**	**Materials Planning**	**Financial Planning**
Strategic	Research, development of medical protocols	Case mix planning, capacity dimensioning, workforce planning	Supply chain warehouse design	Investment plans, contracting with insurance companies
Tactical	Treatment selection, protocol selection	Block planning, staffing, admission control	Supplier selection, tendering	Budget and cost allocation
Offline Operational	Diagnosis and planning of individual treatment	Appointment scheduling, workforce scheduling	Materials purchasing, determining order sizes	DRG billing, cash flow analysis
Online Operational	Triage, diagnosing emergencies and complications	Monitoring, emergency coordination	Rush ordering, inventory replenishing	Billing complications and changes

← Managerial Areas →

↑ Hierarchic decomposition ↓

Table 5 Hierarchic framework for planning and control [1]

The planning and control functions can further be characterized by the four hierarchical levels: *strategic*, *tactical* and *operational* planning, where the operational level can be divided in the *offline* and *online* operational planning. The subsequent planning levels relate to more operational concerns with a shorter planning horizon and increased availability of information [2]. All hierarchic levels of resource capacity planning are elaborated in the next paragraphs.

2.2.1 Strategic planning

Strategic planning involves investment decisions by the board of directors. This enhances production agreements, capacity dimensioning and the policy for the formation of specialized teams. Forming specialized teams is a strategic decision because it involves training of therapists.

Production agreements

Production agreements are made yearly with health insurers. The RRC aims to increase their production with 5% every year. Along with the production agreements management must decide which types patients they will treat. This patient mix is often referred to as the case mix. The production agreements and the case mix together determine the workload for the next year. The production agreements are split over the profit centres; each profit centre has their own production target.

Capacity dimensioning

Management dimensions the therapy facilities and therapist work force based on the production agreements for the following years. This involves investing in facilities and hiring or dismissing therapists.

Policy for forming specialized teams

Therapists are organized in teams that are responsible for treating a number of diagnosis groups. Specialized teams can either be assigned to one diagnosis group, all diagnosis groups in a profit centre or to all diagnosis groups. The less diagnose groups a team treats, the more specialized the team is. Experts explain that therapists gain experience by attending courses and repeatedly treating the same diagnosis groups [Appendix H]. Management has stimulated therapists to specialize, because this is believed to lead to higher quality of care.

Specialized teams can be dedicated to either in- or outpatient's diagnosis groups or both. The benefit of dedicating teams to both is that patients can keep the same therapists when they change from inpatient to outpatient treatment. However, dedicating teams to either in- or outpatients makes it

possible to schedule in- and outpatient's appointments separately. Currently teams are dedicated to both in- and outpatients.

A team of generalists can be deployed in addition to the specialized teams. These generalists can intercept any surplus therapy that cannot be carried out by the generalists. all therapists are assigned to a specialized teams, because this makes coordination and team meetings easier to plan.

Basically there are three managerial decisions that describe a policy for the formation of teams:

1. Is a team of generalists formed in addition to the specialized teams?
2. How specialized should a specialized team be?
3. Are teams dedicated to either in- and outpatients or both?

The current policy is to form specialized teams, which treat all in- and outpatients that are assigned to a profit centre; however, there are also some highly specialized teams that treat only diagnosis group.

2.2.2 Tactical planning

Tactical planning is a level that is often overlooked. This planning has a much longer horizon than operational planning and therefore there is more flexibility. At this level decisions are made concerning the strategically agreed capacity and demand. Applied to the rehabilitation process this involves therapist staffing and admission control of new patients. There are two types of therapist staffing: the assignment of therapists to specialized teams and the assignment of therapists to weekly working shifts.

Allotment of therapists to specialized teams

Therapists are employed in specialized teams that are responsible for the therapy of a number of diagnosis groups. Therapists must be trained and allotted to the specialized teams that were formed on strategic level. In the current situation, the therapist allotment is based on the former experience of a therapist, e.g. if a therapist is experienced at treating spinal cord injury patients, the therapist is allotted to the spinal cord injury team.

Shift scheduling

The therapists' weekly working hours are recorded in *block schedules.* The block schedules are constructed by management in dialogue with therapists. Many therapists work part time. The block schedules are defined per half hour slot and therapists can indicate their availability per slot.

Therapists can schedule administration time in their block schedule: on these slots no therapy may be scheduled. This results in very complex schedules.

Admission control

The demand for therapies can be controlling the admission of new patients. Currently the admission policy is to admit inpatients immediately and to admit outpatients when capacity becomes available. For each specialized team there is a waiting list. Patients are admitted according to the first come first serve principle: the patient, who has been waiting the longest, is admitted first. This guarantees fairness among patients.

2.2.3 Offline operational planning

On offline operational level therapy appointments are scheduled and patients on the waiting list are admitted by planners of the central Scheduling Department. They receive all patients' therapy programs for following week after the weekly meetings of the physicians and specialized teams. The planners in the scheduling department make 30, 60 or 90 minute appointments between patients and therapists. The schedule is ready on Thursday and handed out to patients and therapists. Outpatients receive their schedules for next week by mail.

Patients are assigned to fixed therapists for their individual therapies. Newly admitted patients need to be assigned to a therapist. Patient can only be assigned to a therapist in the specialized team for their diagnosis group.

The planner must match the availability of the patient and therapist. Outpatients are allowed to block 5 day parts in the week and the availability of therapists is defined in the block schedules. Furthermore therapists currently announce their days off at a week's notice. Patients must be scheduled for group therapies that take place at fixed times in the week. Furthermore planners attempt to allow for adequate resting times and to avoid excessive waiting time between appointments.

2.2.4 Online operational planning

On operational level the therapy appointments are executed. Rescheduling of appointments is done by therapists themselves (decentral planning). Sometimes therapists will go to the clinic to try and find an extra inpatient they can give extra therapy or they have contact with outpatients and make extra appointments. When a therapist falls ill, other therapists will try to substitute if possible.

2.3 Performance measures

In this paragraph performance measures for the rehabilitation process are formulated. The importance of management by objectives has been explained by Peter Drucker in 1954 [3]. It is believed to lead to alignment of objectives across the organization and increase the understanding towards improvement of the performance. The criteria for good performance measures has been subject to intensive study and Doran published the SMART [4] criteria that are very famous and widely accepted guidelines that will be used in this study. Doran states that organizational objectives should be Specific, Measurable, Attainable, Relevant and Time-bound [3].

In paragraph 2.3.1 the objectives of the rehabilitation process will be described qualitatively by means of extensive interviews throughout the organization [Appendix H] and literature research. The broad involvement of employees and management in setting the performance indicators makes them Attainable and Agreed throughout the organization. In paragraph 2.3.2 the objectives that are Relevant for therapist capacity planning are selected. The criterion Time bound is less relevant in this case: the objective is to reorganize as quickly as possible. In paragraph 2.3.3 the objectives are quantified as key performance indicators (KPIs), such that they are Measurable. Finally a data analysis is carried out to measure the current performance in paragraph 2.3.4.

2.3.1 Qualitative definition of objectives

In this paragraph the objectives of the rehabilitation process will be explored. Many different stakeholders that can be distinguished in the rehabilitation process; internal stakeholder such as patients (and their caretakers), therapists, rehabilitation physicians and administrators, as well as external stakeholders such as the Dutch government and health care insurers [5]. There are roughly five different objectives for the rehabilitation process in the RRC: offering high quality of care, guaranteeing quick access to care for new patients, making economic use of resources, employee satisfaction and patient satisfaction.

Quality of care

The physician decides what therapies a patient should receive in order to successfully rehabilitate. The role of the physician is comparable to the role of a mechanical engineer in a production environment in the sense that they provide the technical restrictions for the process. The physician's first objective is to execute the patients' therapy programs as completely as possible. The degree to which programs are executed is called the realization level. The second objective is the simultaneous start of disciplines within the rehabilitation program: patients should start and undergo treatment in

all disciplines at the same time in order to successfully rehabilitate. The third important factor for high quality of care is the deployment of highly specialized and skilled staff. Fourthly continuity of care is considered important for successful rehabilitation programs, which means that patients should get a fixed therapist. These objectives for quality are comparable to the ones described by Braaksma, Kortbeek, Post & Nollet [6].

Access to care

The Dutch government has set norms for the access time to the therapy centre. These norms are called the Treeknormen and should ensure equal and quick access to care for all citizens.

Economic use of resources

The main concern of administrators is the continuity of the RRC [7]. The yearly budget is defined in the strategic production agreements with health care insurers. The production target is 5% growth compared to last year. The RRC has a strong incentive to meet the production agreements; otherwise the budget for next year will be revised downwards. There is no incentive to go over the production agreements, because the health care insurers will not compensate more than the agreed production.

The RRC must deploy its personnel efficiently to maintain financially stable. The RRC can invoice an hourly rate for therapy appointments; any activities other then therapy cannot be invoiced. The therapists' utilization describes how efficiently therapists are deployed; it is a measure of the realized therapies compared to the therapist work force. The load (described in paragraph 2.1.3) is often used a standard for therapist utilization.

Employee satisfaction

Therapists prefer their working hours to be well adjusted to their personal lives. There should be balanced distribution of the work load and sufficient time to complete their administrative tasks.

Patient and caretaker satisfaction

Caretakers play a very significant role in rehabilitation care as they take the care of patients when they are not in the RRC and they are responsible for transporting outpatients to and from the RRC. In- and outpatients differ in their preferences regarding the weekly appointment schedule. Inpatients like their therapies to be spread evenly over the days of the week. Outpatients on the other hand want to minimize their visits to the RRC and they want minimal waiting time between the appointments. Furthermore patients have preferences for resting time between appointments; especially when therapies are physically very demanding. Most patients and therapists like their

schedules to be similar in consecutive weeks. Furthermore there are restrictions in the density of the program for patients, e.g. patients should not get more than one physiotherapy appointment per morning of afternoon.

2.3.2 Selection of KPI's for therapist capacity planning

The focus of this research is the capacity planning of therapists, which is both a strategic and tactical decision. Therefore the list of objectives defined in the previous paragraph is narrowed down to a set of key performance measures relevant for this type of planning. Hulshof, Boucherie, Hans & Hurink [7] indicate that tactical planning in elective patient care has a crucial role in maximizing resource utilization, achieving agreed production targets, achieving minimized and equitable access time for all patient groups, maximized and equal quality of care for all patient groups, while balancing workload. Therefore four key performance indicators are selected:

- the realization level of rehabilitation programs
- the access time to the therapy centre
- the utilization of therapists
- achieving the agreed production

2.3.3 Quantitative definition of KPI's

In this paragraph the four selected KPI's are quantified to make them measurable and specific.

Realization level of rehabilitation programs

When therapy appointments cannot be scheduled or cancelled, a patient's rehabilitation program is not completely realized. The realization level, A_{idw}, of patient's, i, rehabilitation program in week, w, per discipline, d, can be expressed as follows:

$$A_{idw} = \frac{R_{idw}}{T_{idw}}$$

Where R_{idw} is the amount of therapy realized in discipline d for patient i in week w and T_{idw} is the amount of therapy that was prescribed in the rehabilitation program. The amount of therapy is measured in hours.

When all prescribed therapy is realized, the realization level is 100%. The scheduled realization level, A'_{ipw}, compares the amount of scheduled therapy to the amount of the therapy in the rehabilitation program.

$$\mathrm{A'_{idw}} = \frac{\mathrm{S_{idw}}}{\mathrm{T_{idw}}} = 1 - \frac{\mathrm{U_{idw}}}{\mathrm{T_{idw}}}$$

Where $\mathrm{S_{idw}}$ and $\mathrm{U_{idw}}$ are relatively the number of scheduled and unscheduled hours of therapy in discipline d in week w. In case all scheduled appointments are realized, the realization level is equal to the scheduled realization level. In this study we will assume all scheduled therapy is realized.

The realization level is comparable to the fill rate or β service level that is used in inventory management [8]. The fill rate is a service level that describes the proportion of total demand which can be delivered from stock on hand within a reference period.

At the moment there is no norm for the average realization level, but management and medical staff agree it should be maximized to ensure a high quality of care. The realization level should be same for each patient group to ensure equal treatment.

Access time to the therapy centre

The performance indicator(s) for the access time are the Treeknormen, which are defined by the Dutch government. The Treeknormen are twofold: 80% of all inpatients/outpatients should be admitted in 5/3 weeks, and the maximum waiting time for any inpatient/outpatient may not exceed 7/4 weeks. The access time, τ_i, for a patient, i, is defined as the difference between the week of referral and the week of admission.

The Treeknormen for outpatients can then formally be described as follows:

$$\text{(i) } \mathbb{P}(\tau_i \leq 3) = 0{,}8 \quad \text{and} \quad \text{(ii) } \mathbb{P}(\tau_i \leq 4) = 1$$

And for inpatients:

$$\text{(i) } \mathbb{P}(\tau_i \leq 5) = 0{,}8 \quad \text{and} \quad \text{(ii) } \mathbb{P}(\tau_i \leq 7) = 1$$

Therapists Utilization

The utilization, ρ_{hw}, of a therapist h in week w is defined as the fraction of time a therapist spends on treating patients. The utilization can found by comparing the realized amount of therapy, R_{hw}, to the number of hours the therapists is available. Note that we must take into account that in some disciplines can treat multiple patients at a time during groups sessions, this described by the factor φ_d.

$$\rho_{hw} = \frac{R_h}{n_h \cdot \varphi_d}$$

Where n_h is the number of hours per week a therapists is employed by the RRC. The load is used as a standard for the therapist utilization, see paragraph 2.1.3.

Production

The production target is defined as the amount of therapy that should be realized per discipline. The production target is 5% growth compared to last year. The target in split into monthly targets, so for example February this year is compared to February last year to cancel out the influence of seasonal trends in demand and supply. The KPI, κ_d, is defined per discipline d as the absolute difference between the realized production and last year's production plus 5%, because both under and over achieving is undesirable.

$$\kappa_d = |production\ of\ discpline\ d\ in\ month\ x - 1{,}05 \cdot production\ last\ year\ in\ month\ x|$$

2.3.4 Data analysis of current performance

In this paragraph a data analysis is carried out in order to evaluate the current performance in terms of the four formulated KPI's.

Realization level of rehabilitation programs

This KPI cannot be measured, because unscheduled appointments are not registered. Only the realized therapies are registered in the data warehouse. Experts believe that one average 90% of the therapies on the rehabilitation programs are scheduled and realized.

Access time to the therapy centre

Currently all inpatients are admitted straight away and therefore only outpatients experience an access time to the therapy centre. Currently the access times are not correctly logged. Therefore we

cannot test if the Treeknormen are obeyed. An analysis of the average access time can be found in Appendix D.

Therapists Utilization

Instead of analyzing each therapist's utilization individually, the average therapist utilization per discipline is analyzed. The realization of therapy hours is compared to the available capacity[3]. Note that therapists working in discipline d cannot spend all their time on therapies due to obligatory administrative tasks. Management has defined the load as the standard for the average utilization per discipline. Therefore it becomes apparent that the average utilization of therapists is structurally to low.

Discipline	Utilization	Load
Activity therapy	0,62	1,00
Movement teaching	0,57	0,95
Ergo therapy	0,79	0,80
Physiotherapy	0,86	0,90
Speech therapy	0,76	0,70
Social work	0,39	0,50
Psychotherapy	0,29	0,50

Table 6 Average therapist utilization per discipline

Currently many teams are highly specialized and treat only one diagnose group. As an example, we show the amount of physiotherapy per week for outpatients in the stroke diagnosis group (NCVA).

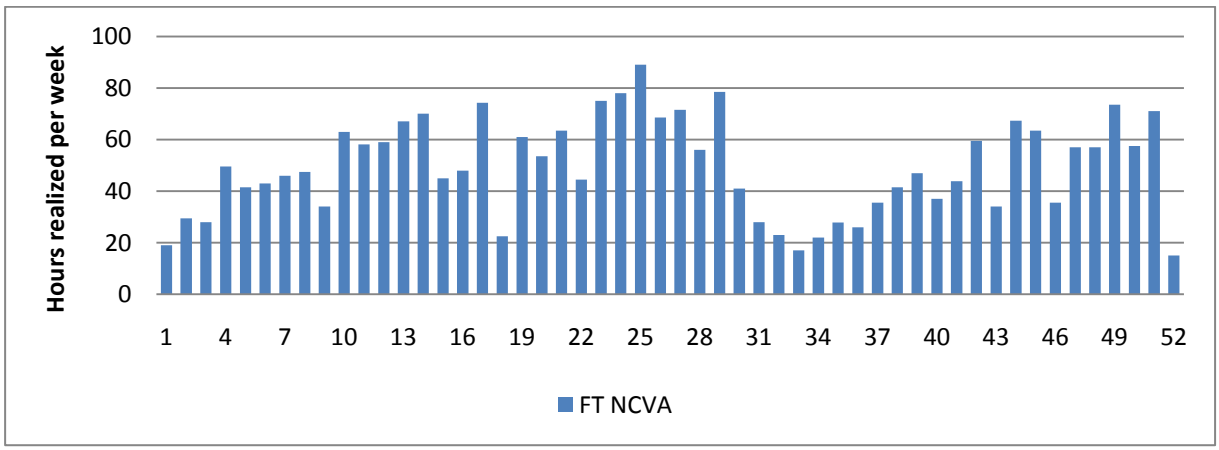

Figure 3 Realization per week in 2012, physiotherapy for stroke outpatients

[3] Time that is reserved on managerial tasks (voorwaarde scheppende tijd) is not taken into account in the available capacity.

The amount of therapies fluctuates heavily and there are clear seasonal trends: the production is lower in the school holidays: around the turn of the year and in the summer months. We will focus this research on the "normal" months.

When the amount of therapy of one diagnose groups is compared to the total amount of therapy per week, we see that the relative fluctuations are much smaller due to the phenomenon called risk pooling. This indicates sharing capacity among patient groups is a very interesting option to improve the therapist utilization.

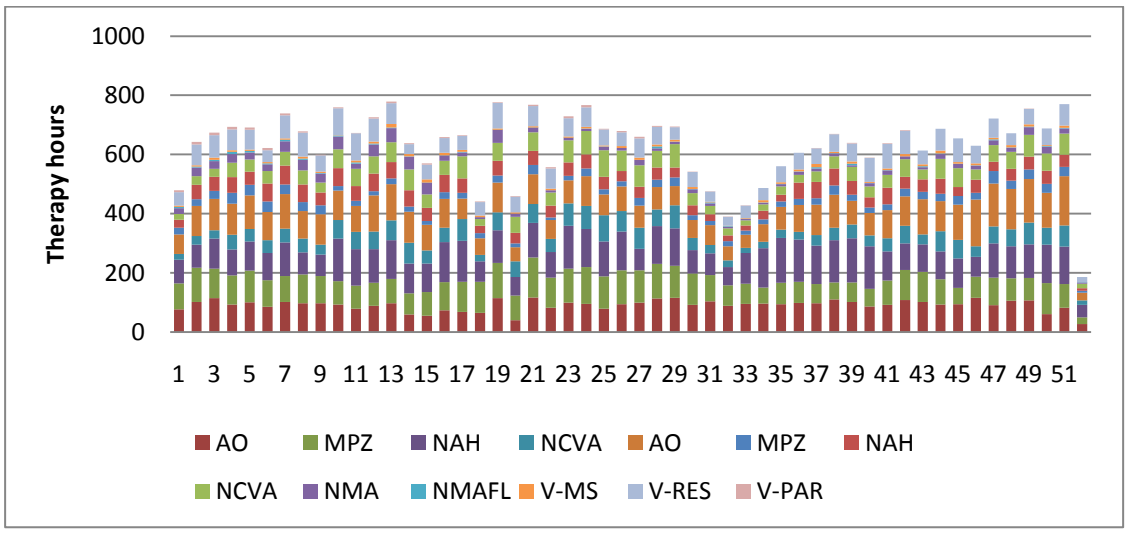

Figure 4 Realization of physiotherapies per week in 2012 (in hours) per diagnosis groups

Production

The average production per discipline is analysed per discipline; this is the average number of hours therapists work per week.

Discipline	Average production (hours per week)
Activity therapy	254,22
Movement teaching	323,99
Ergo therapy	467,34
Physiotherapy	754,29
Speech therapy	221,97
Social work	99,34
Psychotherapy	109,92

Table 7 Average weekly production per discipline

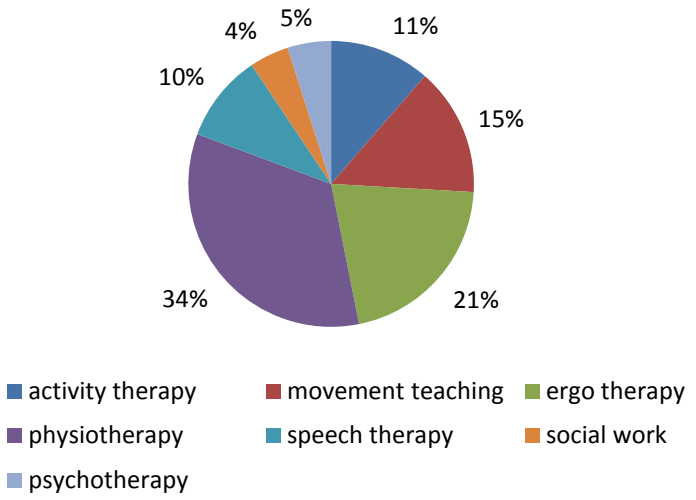

Figure 5 Pie diagram of the average production over the disciplines

We see that about 70% of the adult rehabilitation programs are physical therapies and the other 30% has more to do with mental rehabilitation. Over the recent years, the RRC has been successful in achieving its target production according to the financial department [Appendix H].

2.4 Bottlenecks

The scheduling department is currently struggling to adequately schedule the therapy programs. A bottleneck analysis of the current planning and control is carried out. All resource capacity planning decisions have been visualized and placed in hierarchical order in the figure below. The focus of this study is on tactical capacity planning of therapists; however, we will discuss all hierarchic levels of planning to give a complete picture of the current bottlenecks in the successful execution of rehabilitation programs.

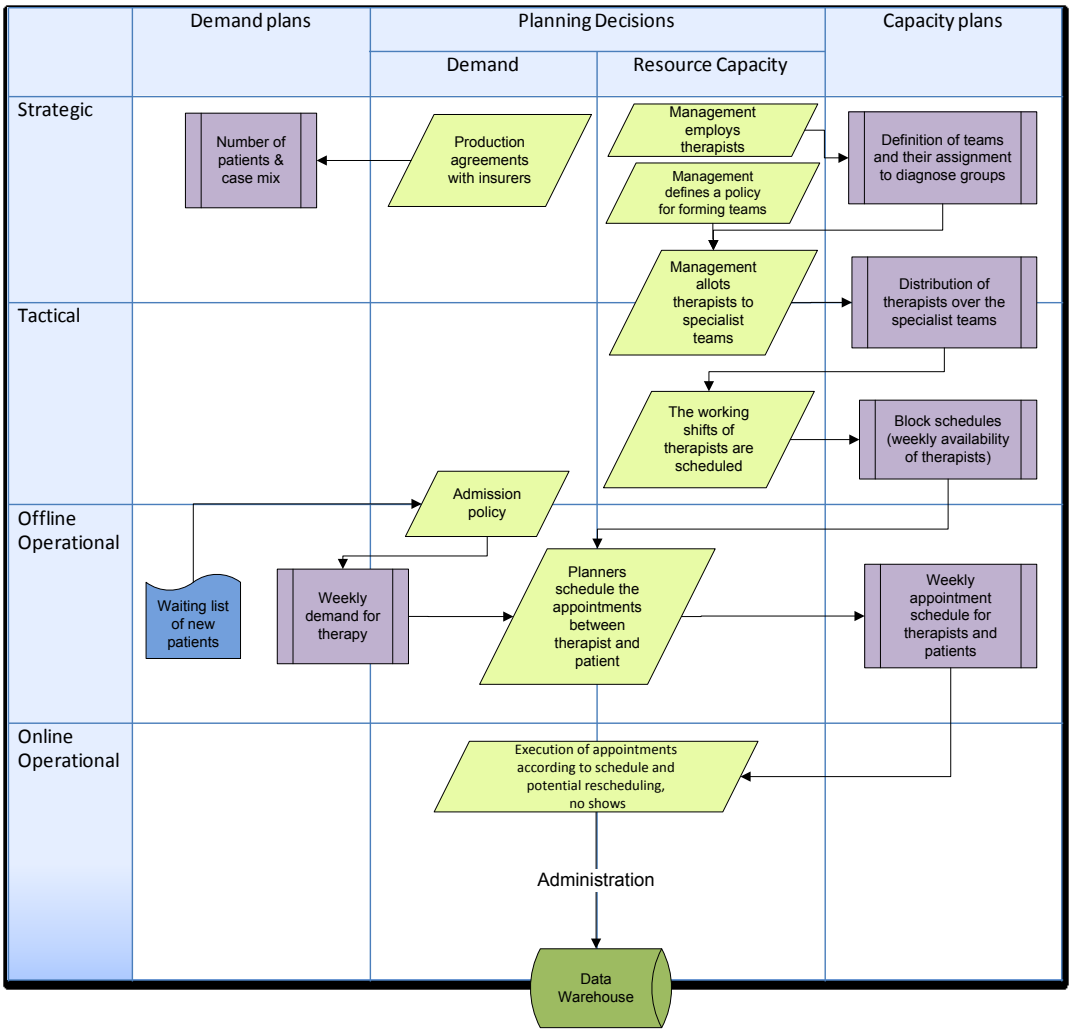

Figure 6 Overview of current planning and decisions making, for a legend of the used shapes, go to Appendix I

Policy for the formation of specialized teams & the allotment of therapists to specialized teams

The weekly demand for therapy fluctuates as a result of the uncertain arrival process of new patients and the fact that patients have a changing need for therapies during their rehabilitation program. When therapy demand exceeds that therapist capacity of a specialized team, therapy remains unscheduled, which leads to incomplete realization of therapy programs.

Currently the specialized teams are highly specialized and the work force is not well divided over the teams. Therefore the options for assignment of patients are very limited and therapy cannot be scheduled in one team, while therapists in another team have holes in their schedule. The admission process is also hindered, because new patients can only be assigned to a small number of therapists. This results in long access times to therapy.

Therapists' working shifts

Many inpatients complain that their therapy is very much concentrated on some days in the week, while they get almost now therapy on others. This is caused by the availability of therapists: most therapists work on Tuesday and Thursday and very little work on Friday. Outpatients prefer to receive their appointments on as little days as possible. Hthe availability of therapists is not well aligned across the disciplines and there are group therapies are given at fixed times in the week. Therefore appointments must be made on multiple days. Overall block schedules are not well tuned to the patients' preferences.

Appointment scheduling

The frequent alterations to the rehabilitation programs cause a large amount of administrative work and limit the horizon of appointment planning to one week. Outpatients receive their appointment schedules by mail on Friday, Saturday or even sometimes on Monday (in which case they might already have missed appointments). Therefore outpatients have very little time to adapt their personal schedule and make arrangements with their work, family to transport them etc.

Communication issues between medical staff and the scheduling department lead to incomplete knowledge of the rehabilitation programs. If therapy cannot be scheduled, this leads to the incompletely scheduled rehabilitation program. Very often, the treatment of a patient is elongated to make up for the missed therapy. This is very undesirable, because these patients block capacity for new patients and increase their waiting time. Furthermore, medical staff stresses that it is very important patients receive their therapy in time.

Therapists currently announce their days off at a week's notice. Very often, patients cannot be taken over by another therapist, because patients are assigned to fixed therapists or other therapists do not have any space in their schedules. This results in unscheduled appointments for patients.

Appointment scheduling is very complex: around 6000 appointments are made weekly and we noted they are subject to a large number of restrictions. Currently the planners use a heuristic to make the schedules: they copy the schedule of last week, adjust any changes in the frequency of therapies and then admit outpatients if there is capacity available. Due to the complexity, it is very likely that this heuristic leads to non-optimal schedules.

Execution of appointments and rescheduling

Many therapists have holes in their schedule that they cannot fill, this leads to unrest in the organization. Patient compliance is quite low: there are many cancellation and no shows, especially among outpatients. When a therapist falls ill, his appointments are very often cancelled, because patients cannot easily be assigned to another therapists. Cancellation by either the therapist or the patient leads to a lower realization of the rehabilitation program.

Therapists indicate that the actual duration of appointments are often much shorter than 30 minutes because other appointments finished late and/or patients needed time to move from one therapy facility to another.

2.5 Conclusion and delimitation

In this paragraph we will conclude the context analysis and delimit the scope of this study.

The core business of the RRC is to offer rehabilitation therapies. Patients are divided into groups according to their diagnosed condition; they will be referred to as diagnosis groups. Rehabilitation programs consist of weekly protocols stating type and duration of a therapy for the individual patient, who can be given individual or group appointments. The programs are defined by physicians and carried out by a multidisciplinary team of therapists who are employed for a fixed number of hours per week. Therapists normally spend a certain fraction of their working hours directly on treating patients and another fraction on administrative tasks that are directly related to the therapies. Management has set a standard for the maximum fraction of hours that therapists may be scheduled for therapies. This fraction will be referred to as the load. Therapists work for one of the disciplines and within a discipline they are allotted to a specialized team which is responsible for the treatment of a number of diagnose groups. The current policy is that therapists work in teams that treat all diagnosis groups that are assigned to in a profit centre. Management is however stimulating therapists to specialize even more, because this is believed to lead to higher quality of treatment. In consultation with therapists, management allots them to specialized teams and fixes their working shifts in the week. When appointments are cancelled by patients or therapists, rescheduling is done by therapists themselves.

In order to evaluate the current performance the objectives of the rehabilitation process were identified, ranked and quantified. Five different objectives are identified: quality of care, access to care, economic performance, employee satisfaction and patient satisfaction. The focus of this research lies on quality of care and economic deployment of staff. Access to care will not be taken into account, because it cannot be analyzed properly based on the available performance data[4]. The most important performance measure for quality of care is the realization level of rehabilitation programs. The realization level indicates which fraction of the therapy in the rehabilitation program can be realized by the available therapists. The economic deployment of staff is measured by the utilization of therapists, which is the fraction of their working hours they spend on treating patients.

[4] There is no information about the causal relations between admission and a patient's demand for therapy while the patient in therapy, so no analysis of the access time of new patients can be carried out. SRPs are a source of information about this causality. they are only defined for inpatients and not for outpatients and for inpatients they are very intensively altered. Therefore they are no reliable source of information.

The planning and control of the RRC is split into profit centres, each profit centre is responsible for the treatment of a number of diagnose groups. Therapy is scheduled by a central planning department that makes weekly appointment schedules and admits new patients for therapy. Unscheduled therapy occurs when therapy demand exceeds the capacity of a specialized team. The demand fluctuates as a result of the uncertain arrival process of new patients and due patients having a changing need for therapies during their rehabilitation program. The options to make appointments between patients and therapists are very limited, because a patient can only be assigned to therapists in one specialized team. This leads to many unscheduled appointments and increased waiting time for new patients. Furthermore we see a structural underutilization of therapists and a highly fluctuating workload. In the data analysis we found evidence that the performance can be improved by capacity sharing. This means that the amount of unscheduled therapy could be decreased by forming less specialized teams that treat more diagnosis groups. In this way, more capacity is shared amongst the diagnosis groups, which leads to risk pooling.

Therefore this study will be delimited to the allotment of therapists to specialized teams under different policies for the formation of specialized teams. Allotment of therapists to the teams should be done such that an equal realization of therapy program can be guaranteed to each diagnosis group. For recommendations on the other planning decisions we refer to paragraph 7.3.

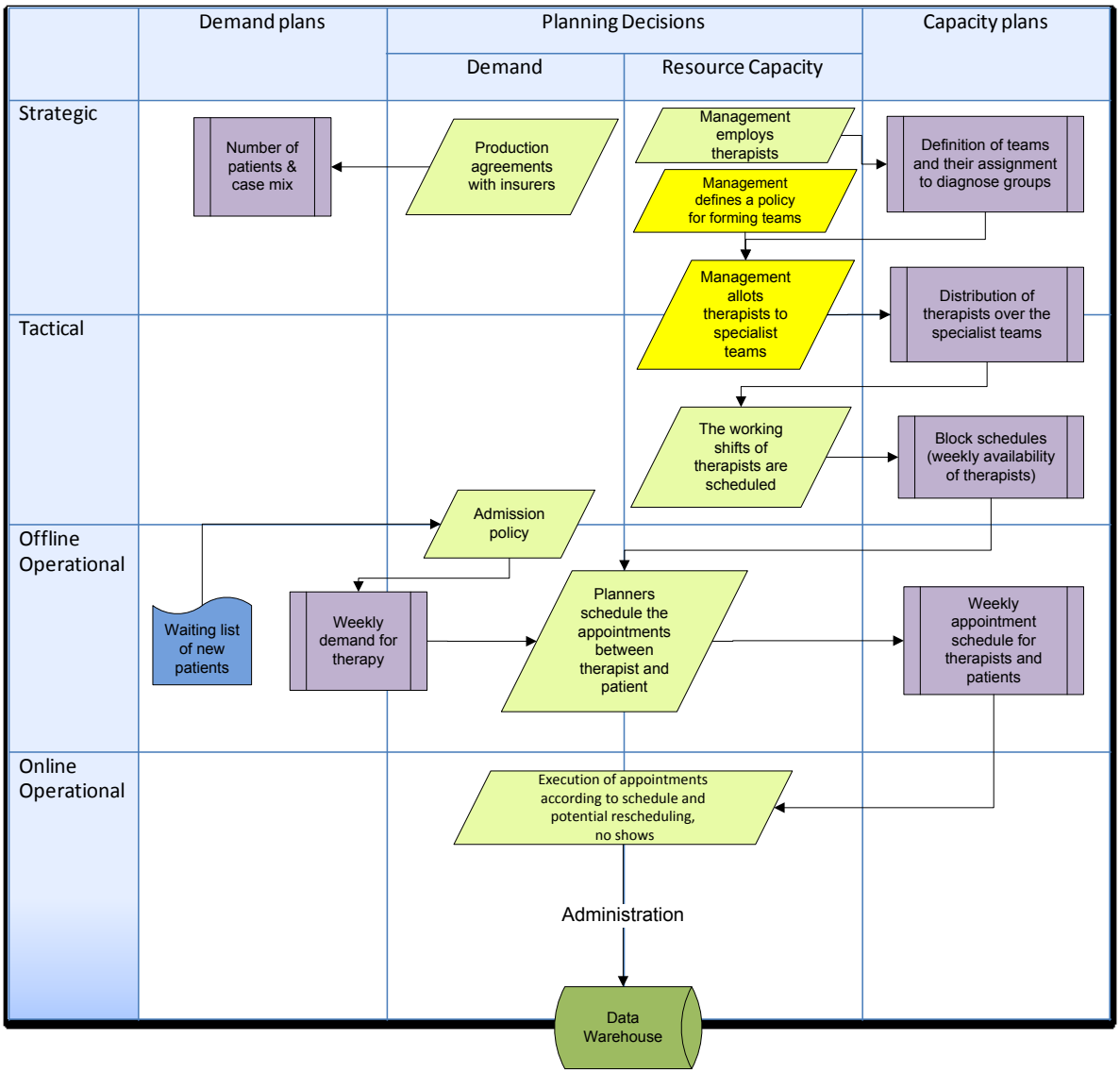

Figure 7 Hierarchic planning framework, the highlighted planning decisions are the focus of this study, for a legend of the used shapes go to Appendix I

3 Theoretic Framework

In this paragraph a theoretical framework is provided for strategic and tactical capacity allocation in rehabilitation care. The taxonomy by Hulshof and Kortbeek is used as the starting point for a literature review [9]. They classify rehabilitation care as a residential care service. We will give an overview all the theory and OR techniques for residential care services per hierarchic level in paragraph 3.1. In paragraph 3.2 we will review capacity allocation techniques that have been proposed for comparable health services.

3.1 Hierarchic planning in rehabilitation care

We notice that the majority of research in residential care services focuses on the operations in the clinic. However, our study concentrates on the operations in the therapy centre. This greatly narrows down the relevant literature.

3.1.1 Strategic level

On strategic level, literature engages in the placement policy of patients, the regional coverage, the case mix of patients and capacity dimensioning [10]. The placement policy describes which patients are eligible for rehabilitation care. These policies are agreements between regional hospitals and rehabilitation centres about the referral of patients. Regional coverage describes the geographic area a rehabilitation clinic serves. The case mix of patients describes which types and volumes of patients a centre will serve. The case mix is an agreement between health care insurers and rehabilitation centres. These three policies determine the arrival process of new patients and therefore the demand for therapy.

Literature states that the capacity dimensioning of the therapist disciplines in rehabilitation therapy are highly interrelated. The operations can only be improved when all disciplines are aligned [11]. Improperly balanced dimensioning can cause some disciplines to be bottlenecks, while others are underutilized [10]. Busby and Carter have shown the need for access capacity using basic queuing theory. When capacity dimensioning is based on average demand, this leads to long access times [11]. Desai, Penn, Brailsfort, and Chipulu researched a staff skill mix in order to optimize the performance: subtasks can be identified and executed by less qualified staff [12].

3.1.2 Tactical level

Admission control and capacity allocation are tactical planning decisions. Admission control consists of policies for the selection, admission and waiting time of new patients. The first step in admission

control is to group patients [13]. Then the patients groups must be prioritized by their medical urgency [14]. In practice, a new patient is often admitted, when capacity has become available [11]. Leff and Garg propose the use of admission plan that prescribes how many patients of each patients group should be taken into service during a certain planning horizon [13]. This policy was found to decrease the access time and increase resource utilization on the long run. Patrick proposes a dynamic admission rule that is based on the current state of the system and/or the forecasted state [14]. Such forecasted information could also be interesting to adapting the capacity to the demand[15].

Hhere is a strong interrelation between capacity allocation and admission control. Capacity allocation is classified by Kortbeek and Hulshof as a tactical decision in which the resource capacities that have been decided on strategic level are subdivided over the patient groups [9]. A special type of capacity allocation is shift scheduling. Shift scheduling is involved with assigning therapists to working shifts [16]. The assignment of therapists to working shifts is recorded in block schedules. These block schedules need created such that feasible appointment schedules can be generated on operational level [10]. In order to facilitate combination appointments (see next paragraph), the shifts of various disciplines should be aligned [17] to facilitate interdisciplinary team meetings [10].

3.1.3 Offline operational level

Therapy appointment scheduling has received a considerable amount of attention in literature. Several studies have developed decision support intelligence for therapy appointment scheduling with advanced planning and scheduling methods [18]. The tools proposed in these papers aim to increase the quality of the appointment schedules by increasing the utilization of therapists and more effectively meeting the patients' and staff's preferences, such as the number of appointments on a day, the waiting time between appointments etc. Some studied have been focussed on appointment scheduling in the outpatient clinic. The objective in these studies is to make combination appointments, where multiple appointments are made on one day to minimize the number of visits to a rehabilitation clinic [6].

3.2 Capacity allocation in comparable health services

When reviewing the body of research done in residential care services in the previous paragraph, we found that the amount of work done on strategic and tactical capacity allocation is negligible [9]. Therefore we will try and find relevant literature on capacity allocation by comparing the operations in the therapy centre to other types of health services. Capacity allocation is a tactical decision, which must be based on the forecasted demand. Lahrichi, Lapierre, Hertz, Talib and Bouvier explain that it

is very hard to estimate the true care demand on historical data, as this is often biased by the available capacity [19].

3.2.1 Capacity allocation in ambulatory health services

The first obvious comparison can be made between the therapy centre and an outpatient department. Operations in an outpatient department are categorized as ambulatory care services [9]. Kortbeek and Hulshof describe that the involved resources in ambulatory services are consultation rooms, waiting rooms, staff, consultation time capacity and equipment. Swisher, Jacobson, Jun and Balci describe that ambulatory care facilities dimension their resources with the objective to maximize the clinic profit, the patient satisfaction and the staff satisfaction [20].

Hulshof and Kortbeek distinguish two types of capacity allocation: the assignment of patient groups to resource types and secondly the division of available time over the patient groups. Smith, Mead Over, Hansen, Golladay and Davenport study the problem of optimal staffing to patient groups in an outpatient department in order to maximize the number of patients served [21]. In order to do so they described a mixed integer linear programming problem. They study the effects of scale and patient mix, but do not take into account uncertainty in the operations. In their review Smithdaniels, Schweikhart and Smithdaniels discuss the effect of uncertainty. They state that efficiency gains are possible in capacity allotment when certain tasks can be substituted between clinical staff, either horizontally (equally skilled staff) or vertically (lower skilled staff) [22].

3.2.2 Capacity allocation in home care services

The second comparison can be drawn with home care service. Home care is provided in multi disciplinary teams, because patients have needs in a mixture of disciplines. Home care professionals typically treat multiple patients per day. Coordination between the disciplines is required to ensure continuity of care [10]. The coordination between the disciplines makes the resource capacity planning in home care extremely complex [23]. Busby and Carter explain that the objectives for capacity allocation in home care services are to allocate the resources to patient groups and districts, such that workload for therapists , access times and quality of care for patients and equally divided [11]. Fairness among patient groups is a very important objective for the operations in health systems in Europe [24].

Benzarti, Evren, S. And Dallery describe in their literature review that fluctuations in demand arise from uncertainty in the arrival process of care requests and the different levels of care required per patient [10]. Busby and Carter created a decision tool that can evaluate the performance of the

capacity allocation of home care workers in terms of waiting time for patients, costs and quality of care. They define quality of care is defined as the number of visits. Their decision tool is based on queuing theory [11]. Lahrichine et al. study the dynamic assignment of a surplus team of home care nurses that can be flexibility deployed. They found that the organization can better react to any fluctuations in the demand or cancellations by personnel (because of illness or personal circumstances) and workload is better balanced [19].

3.3 Conclusion

In the literature, the effect of capacity allocation on the quality of service and the access time for new patients is described. W have not found a method that explicitly optimizes the quality of care by optimal allocation of resources. Therefore the problem of resource allocation will be further researched in this study. In particular we will look at the allotment of therapists to specialized teams.

4 Therapist Allotment Model

We found that the capacity planning of therapists greatly influences the realization of the rehabilitation programs. Each therapist is employed in one of therapy disciplines. Within their discipline, therapists are allotted to a specialized team. Each patient is classified into a diagnosis group. Specialized teams are dedicated to a number of these diagnosis groups. The therapy demand for the specialized teams fluctuates, which leads to unscheduled therapies when the demand exceeds the capacity of the team. We will research how we can alternatively allot therapists to the specialized teams using mathematical optimization. The objective of the allotment is to minimize the unscheduled therapy and therefore maximize the utilization of therapists and realization level of rehabilitation therapy programs.

The allotment is modelled as an integer programming problem. In paragraph 4.1 and 4.2 we will give a formal description of the entities and parameters involved in the allotment problem. There are two different allotment configurations: all therapists can be allotted to a specialized team or a part of therapists is allotted to specialized teams while the rest of the therapists are allotted to a team of generalists. These configurations are modelled and solved differently, which will we discussed respectively in paragraph 4.3 and 4.4.

Each discipline is analyzed independently; their interdependence is not taken into account. We assume a static allotment of therapists: a therapist is assigned to one team and is employed for a fixed amount of hours per week. The objective of this allotment is to minimize the unscheduled therapy and optimize the utilization of therapists. The total capacity that is assigned to each specialized team is compared to the stochastic demand. More detailed scheduling constraints such as the fixed assignment of therapists to patients, the availability and preferences of patients and therapist are not taken into account. Therefore the allotment planning is a type of rough cut capacity planning. The allotment of therapist to specialized teams will be based on statistical information about the historic demand.

4.1 Entities

In this paragraph we describe the involved entities in the allotment problem. The RRC has employed a number of therapists. Each therapist works for one of the therapy disciplines. Within a discipline, specialized teams are responsible for the rehabilitation programs for a number of diagnosis groups of patients. Therefore we have the following sets and elements:

Index	Description	Set	Description
h	Therapist	*H*	All therapists
d	Discipline	*D*	All disciplines
t	Team	*T*	All specialized teams
g	Diagnosis group	G	All disciplines

Table 8 Entities in the therapist allotment problem

There are 8 disciplines that will be evaluated in this study[5]: activity therapy, movement teaching, ergo therapy, physiotherapy, speech therapy, social work and psychology. There are 13 different in- and outpatient diagnosis groups, see paragraph 2.1.2.

4.2 Parameters

In this paragraph we will first division of therapists over disciplines and specialized teams. Then we discuss the assignment of diagnosis groups to specialized teams. Finally we will discuss the demand for therapy per diagnosis group and the therapy capacity.

4.2.1 Allotment of therapists to disciplines and teams

Therapists can be characterized by their discipline, d. A therapist works for only one discipline, e.g. a therapist is either trained as a physiotherapist or as a social worker. Therefore the total set of therapists can be split into set of therapists working for each discipline.

[5] There was insufficient data available about the other discipline in order to substantiate the analysis.

$$H = \bigcup_{d} H_d$$

Within a discipline each therapist is working for one of the teams. The total body of physiotherapists (therapists in discipline physiotherapy) is the combination of the teams within the discipline physiotherapy:

$$H_d = \bigcup_{t} H_{d,t}$$

Index	Description	Set	Description
h	Therapist	H_d	All therapists working for discipline *d*
h	Therapist	$H_{d,t}$	All therapists working for team *t* in discipline *d*

Table 9 Distribution of therapists over disciplines and specialized team

Therapist capacity

Many therapists are not available every day of the week and work part time. However, therapists have a fixed working schedule per week, which means they work for on fixed days for a fixed number of hours, n_h, per week. Therefore the capacity of therapist is defined per week.

The capacity of therapists can be defined in hours, e.g. a therapist that works 3 days a week, is employed for 24 hours (three times eight). this is not equal to the effective number of deployable hours, as we will clarify now. A therapist can treat a specific number of patients simultaneously, we describe that by the factor, ψ_d. Psychologists will typically only treat one patient, while movement teachers, d=M, can treat a maximum number of patients ω_M simultaneously. However, therapists that can treat more than one patient simultaneously will also treat patients individually when they require individual attention. Therefore a part of the therapists will do both individual and group appointments. When we take into account the percentage of individual appointments per discipline, π_d, ψ_d can be calculated as follows:

$$\psi_d = (1 - \pi_d) \cdot \omega_d + \pi_d$$

Furthermore each discipline has a maximum load, γ_d. This maximum load describes the maximum fraction of their time that they can spend directly on treating patients. The other part of their time they must spend on administrative tasks that are indirectly concerned with patient care. Therefore the total deployable hours of therapist, h, per week are:

$$c_h = n_h \cdot \varphi_d \cdot \gamma_d \; hours \quad \forall h \in H$$

The total number of hours per specialized team is:

$$c_{d,t} = \sum_{h \in H_{d,t}} n_h \cdot \varphi_d \cdot \gamma_d \; hours \quad \forall d, t$$

4.2.2 Policies for the formation of specialized teams

Each team is responsible for treating one or more diagnosis groups of patients according to the policy that is maintained. The division into teams is same in each discipline. Each diagnosis group is assigned to one of the specialized teams:

$$G = \bigcup_t G_t$$

Index	Description	Set	Description
g	Diagnosis group	G_t	All diagnosis groups treated by specialized team t

Table 10 The assignment of specialized teams to diagnosis groups

There are 10 different possible policies to form the specialized teams as discussed in paragraph 5.4.

Demand for therapy

Each week medical staff requests the therapy for all patients that are currently in treatment, according to their rehabilitation programs. The therapy is requested per discipline. For example a request for therapy can be 4 hours of physiotherapy, 2 hours of ergo therapy and 1,5 hours of logo therapy. All the patients' requests can be aggregated per diagnosis group to yield the aggregated therapy demand for in a discipline of the diagnosis group in a given week, v_{dg}. We know that a

specialized team is responsible for multiple diagnosis groups (depending on the policy that is maintained), therefore the demand per team, v_{td}, is the sum over all assigned diagnosis groups.

$$v_{dt} = \sum_{g \in G_t} v_{dg} \qquad \forall d, t$$

We assume that the aggregated demand to be normally distributed using the central limit theorem, $v_{dg} \sim N(\mu_{dg}, \sigma_{dg}^2)$. The central limit theorem stipulates that a large sum of independent stochastic variables with the same probability distribution will be normally distributed. The mean of v_{dg} is estimated by the sample mean, $\bar{v}_d$, and the variance is estimated with the sample variance, s_d^2, of the demand data sample with size *n*. Where the estimators are defined as follows:

$$\bar{v}_{dt} = \frac{1}{n} \qquad \forall d, t$$

$$s_{v_{dt}}^2 = \frac{1}{n-1} \sum_{i=1}^{n} (v_{dti} - \bar{v}_{dti}) \qquad \forall d, t$$

When we assume the demand in the different diagnosis groups to be independent, the therapy demand per teams is also normally distributed with the following parameters:

$$E(v_{dt}) = \sum_{g \in G_t} \mathrm{E}(v_{gd}) \qquad \forall d, t$$

$$var(v_{dt}) = \sum_{g \in G_t} var(v_{gd}) \qquad \forall d, t$$

4.3 Therapist allotment to specialized teams

In this paragraph we formulate the model for the allotment of therapists to specialized teams. Then we will discuss the computational problem is this problem and research and compare solving techniques.

4.3.1 Formal model description

Each therapist must be allotted to a specialized team within a discipline. Therefore the decision variable is formulated as follows:

$$X_{ht} = \begin{cases} 1 \; if \; therapist \; h \; is \; allotted \; to \; team \; t \\ 0 \; otherwise \end{cases}$$

Each therapist may only be assigned to one specialized team t:

$$X_{ht} <= 1 \qquad \forall h, t$$

The therapy capacity of team t in discipline, d, C, is the sum of the working hours of all allotted therapists:

$$C_{dt} = \sum_{h \in H_d} c_h \cdot X_{ht} \qquad \forall d, t$$

Notice that c_h is defined as the number of hours that therapists are employed per week. The weekly demand per team, V_{dt}, is stochastic and different per discipline: e.g. most stroke patients need more hours of physiotherapy than psychotherapy per week. With a certain probability the demand exceeds the therapy capacity of a team, in which case there will be unscheduled, thus unrealized therapy. These unscheduled hours of therapy, U_{dt}, lead to an incomplete realization of the rehabilitation programs. The probability that unscheduled appointments occur is defined as follows:

$$P_{dt}(U_{dt} > 0) = P(v_{dt} > C_{dt}) \qquad \forall d, t$$

This probability gives us an idea of how often unscheduled appointments occur, but it does not give an idea of degree to which rehabilitation programs have been scheduled and realized. The number of unscheduled appointments is a stochastic variable which is defined as follows:

$$U_{dt} = \max(v - C_{dt}, 0) \qquad \forall d, t$$

The resulting scheduled realization level[6] in team t in discipline d, A'_{dt}, is the fraction of the requested therapy that was scheduled:

$$A'_{dt} = 1 - \frac{U_{dt}}{v_{dt}} \qquad \forall d, t$$

We notice that in case of no unscheduled therapy, the scheduled realization level is 100%. v_{dt} is the demand for therapy for team, t, in discipline, d, which is the sum of all patients' individual demand that are treated by team, t. In this model it is a parameter. Patients' individual demands are specified in their rehabilitation programs. Therefore the scheduled realization level is a direct measure of the degree in which the patients rehabilitation programs have been scheduled for patients in team, t.

For this analysis we are interested in finding the expected value of the unscheduled appointments and the realization rate, respectively $E(U_{dt})$ and A_{dt}. They are related as follows:

$$A_{dt} = 1 - \frac{E(U_{dt})}{E(v_{dt})} \qquad \forall d, t$$

We start by defining $E(U_{dt})$.

$$E(U_{dt}) = E(\max(v_{dt} - C_{dt}, 0)) \qquad \forall d, t$$

We assumed the demand per team to be normally distributed, therefore we can find $E(U_{dt})$ in the following way:

$$E(U_{dt}) = \sigma_{v_{td}} \cdot L(z_{dt}) \qquad \forall d, t$$

Where $L(z_{d,t})$ is the standard normal loss function and $z_{d,t}$ is the standardized team capacity. These variables are the defined as follows:

$$z_{dt} = \frac{C_{dt} - E(v_{dt})}{\sigma_{v_{td}}} \qquad \forall d, t$$

$$L(z_{dt}) = \int_{z}^{\infty} (x - z_{dt}) \cdot \varphi(x) \; dx = \varphi(z_{dt}) - z_{dt} \cdot [1 - \Phi(z_{dt})] \qquad \forall d, t$$

[6] Notice that the actual realization level may be different from the scheduled realization level due to no shows and cancellations as explained in paragraph 2.4

$\boldsymbol{\varphi(x)}$	Standard normal density distribution function
$\boldsymbol{\Phi(x)}$	Standard normal distribution function

Table 11 Explanation of used functions

Therefore we can now determine $E(U_{dt})$ and $E(A_{dt})$ for team t in each discipline d.

We add two extra constraints to make sure the expected loss per team, $\mathrm{E}(\mathrm{U_{dt}})$, does not exceed the expected demand nor can it be negative. The expected loss can adopt these infeasible values, because we have assumed the demand to be normally distributed and a normal distribution allows for negative values.

$$E(U_{dt}) \geq 0 \qquad \forall d, t$$

$$E(U_{dt}) \leq E(v_{dt}) \qquad \forall d, t$$

The goal of this optimisation problem is to maximize the expected scheduled degree of realization of the therapy programs. This is analogous to minimizing the total number of unscheduled appointments. Therefore the objective is formulated as follows:

$$min \sum_{t} E(U_{dt}) \qquad \forall d$$

The demand for therapy is defined per discipline; therefore we have separate optimisation problems per discipline. By minimizing the unscheduled appointments, we simultaneously maximize the (scheduled) utilization of therapists, because we maximize the scheduled number of appointments per therapists. this objective might not be fair and lead to structural differences in degree of realization of therapy programs among the teams. In health care management we strive to achieve fairness for all patients: therefore we want to realize rehabilitation programs to the same degree in all specialized teams and therefore offer the realization level to all patient types. Therefore, an alternative objective is proposed that more fairly improves the realization level in the specialized teams:

$$\max(Y_d) \quad \forall d$$

For this maxmin objective we introduce an extra decision variable, Y_d, which is the minimal realization rate per discipline. Its constraints are defined as follows:

$$Y_d \leq A_{dt} \qquad \forall d, t$$

$$\mathrm{Y_d} \geq 0 \qquad \forall \mathrm{d}$$

A recap of the whole problem formulation can be found in Appendix E.

4.3.2 Solving method

The therapist allotment problem is classified as a mixed integer non linear problem (MINLP). It has binary and nonnegative decision variables. The objective function is not a linear function of the decision variables. This MINLP problem can be solved to optimality by complete enumeration of the solution space. Given H therapists and T is the number of teams, there are T^H different solutions in which all therapists are allotted to one of the teams: each therapist can be assigned to T different teams.

For the largest discipline, physiotherapy, there are 30 different therapists and if we choose the policy in which we have 13 teams, therefore there are 13^{30} ways to allot the therapists. For an elementary speed of 0.000001 seconds, it would take at least 50 milliard times the age of the universe to solve the problem.

We do not take into account the solutions in which therapists are not allotted to teams, because this would always yield more unscheduled therapy and therefore these solutions are not worth studying.

We do not take into account the solutions in which therapists are not allotted to teams, because this would always yield more unscheduled therapy and therefore these solutions are not worth studying. Therefore complete enumeration is not feasible and we will propose approximation methods that yield a feasible and near optimal solution within a reasonable computation time. We will research two constructive heuristics and then a local search technique and select the best one. The best heuristic is the one that yields the best solution within a day. Note that if we could prove that the objective of this problem is multi modular, local search yields an optimal solution [25].

Constructive Heuristics

In this paragraph two different constructive heuristics are discussed.

Random Sampling

In random sampling all therapists are considered and allotted to one of the teams randomly. The allotment probability is equal for each team. This yields a really quick, but poor solution. Each therapist is allotted once and therefore the solution is feasible.

Regret Based Sampling

Random sampling does not take into account difference in priority allotting therapists to teams. Therefore we propose a smarter sampling method. Regret based sampling takes the priority values into account and was proposed by Drexl for job scheduling in project management [26]. Before we allot the therapists, we sort them by non-increasing working hours: therapists that work the most will be allotted first and therapists that work little hours are allotted last. This longest processing time dispatching rule is often used online parallel machine scheduling problems. Therapists are allotted one at a time. The following steps are taken:

(1) Select therapist that is first in array
(2) Determine each team's regret factor
(3) Allot therapist to team with highest regret factor
(4) Delete therapist from array
(5) If therapist array is not empty, go back to step 1, else: stop.

The regret factor used is:

$$regret\ factor_{dt} = 1 - E(A_{dt})$$

Therapists are assigned to the team with the lowest expected realization rate, $E(A_{dt})$.

Local Search Heuristics

In addition to the constructive methods, a local search method was tested. We try to improve the solution by moving a therapist to another team. We start with feasible solution using the random sampling procedure that was explained previously. A neighbour solution is found by selected a random therapist and moving that therapist to a randomly selected team. This way any possible solution can be found. We do not consider solutions in which therapists are not all allotted, because these solutions will always cause a lower objective.

Simulated Annealing

Simulated annealing (SA) can be applied as a local search heuristic for combinatorial problems [27]. For an extensive description of the SA algorithm, we refer to the paper by Aarst and Korst [28]. For each objective (minimize the sum of expected loss or maximize the minimum realization level) a unique cooling scheme is used to make sure that the acceptance probability near the starting temperature is close to one and at the end temperature close to zero, for the cooling schemes, we refer to Appendix F.

Selection of best heuristic

For a randomly selected policy and a randomly selected discipline the three heuristics are compared. The first two heuristics solve the problem almost instantly; SA takes around 30 minutes to solve the allotment problem with the current cooling scheme. For longer cooling periods, the improvement in the objective was found negligible.

	Objective
Random Sampling	0.77
Regret Based Sampling	0.90
Simulated Annealing	0.91

Table 12 Comparing the performance of the heuristics for both objectives.

We see that the simulated annealing algorithm performs the best in minimizing the objective; therefore we well use SA to solve the allotment problem.

4.4 Therapist allotment to specialized teams with an additional team of generalists

In this paragraph we will formally describe the allotment problem of therapists to specialized teams and an additional team of generalists. The objective is to allot therapists such that a minimum fraction of therapy, q, is carried out by specialized teams. The computational complexity of this allotment problem is then discussed. The average number of unscheduled therapy cannot be described analytically and therefore a simple discrete event simulation will be carries out. The demand of the specialized teams is simulated by means of a Monte Carlo simulation.

When patients demand therapies, the appointments are made with therapists of the specialized teams. However, when these therapists do not have time in their schedule left, the therapies are scheduled to the team of generalists; in other words there is an overflow of demand from the specialized teams to the team of generalists. When the schedules of the generalists are full, therapy remains unscheduled.

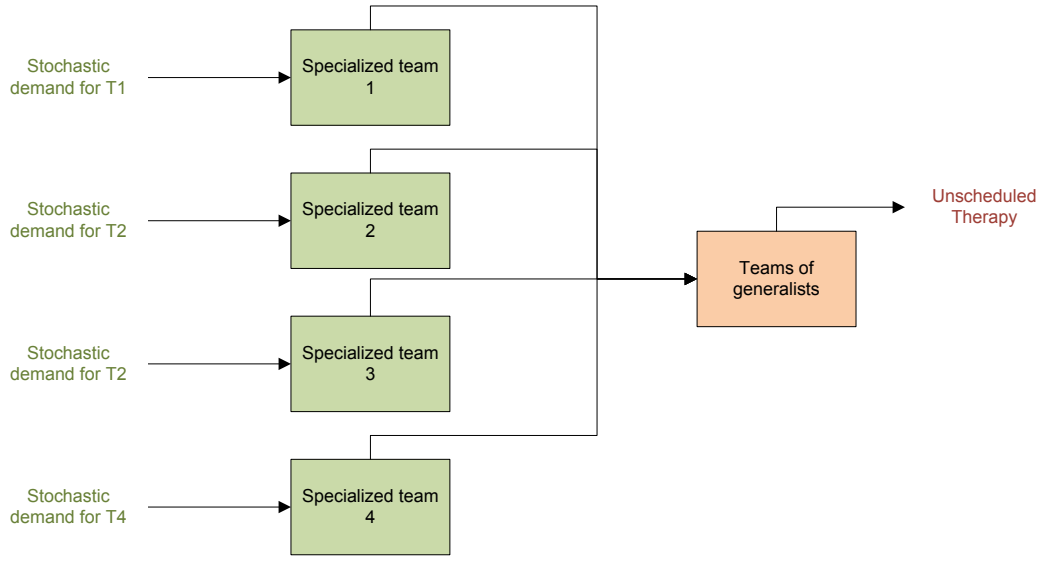

Figure 8 Visual representation of the overflow of demand from the specialized teams to the team of generalists

4.4.1 Formal model description

The therapists must be allotted to one of the specialized teams or the team of generalists. Allotting therapists to the team of generalists decreases the amount of unscheduled therapy. Therefore we want to maximize the number of therapists that are allotted to this team.

$$\min \sum_{h \in H_d, t \in T} (1 - X_{ht}) \qquad \forall d$$

Where:

$$X_{ht} = \begin{cases} 1 \; if \; therapist \; h \; is \; allotted \; to \; specialized \; team \; t \\ 0 \; otherwise; therapist \; is \; allotted \; to \; the \; team \; of \; generalists \end{cases}$$

To ensure the quality of care, we set a standard for the minimum fraction of therapy, q, which should be executed by specialists. The first allotment constraint is that a therapist may not be allotted to more than one specialized team. In case a therapist is not allotted to a specialized team, he is automatically allotted to the team of generalists.

$$X_{ht} \leq 1 \qquad \forall h, t$$

There is a minimum amount of hours, $C_{min,d,t}$, that needs to be allotted to each team to ensure that q*100% of the therapies are carried out by therapists in the specialized teams.

$$C_{min,d,t} = q \cdot E(V_{dt}) \qquad \forall d, t$$

Where $E(V_{dt})$ is the expected value of the therapy demand per specialized team. Therefore we can then formulate the following constraint:

$$\sum_{h \in H_d} c_h \cdot X_{ht} \geq C_{min,d,t} \qquad \forall d, t \in T$$

Therefore we have now made sure a minimum of $q \cdot 100\%$ of the expected therapy demand is carried out by the specialists, while a maximum amount of therapists is allotted to the team of generalists.

4.4.2 Solving method

This allotment problem can be classified as an ILP problem. Therefore it can effectively be solved to optimality with the CPLEX solver in AIMMS, this solver is based on the simplex algorithm.

4.4.3 Simulation of the unscheduled therapy

We are interested in the average number of unscheduled appointments with the current therapist allotment. Therefore we analyze the performance by simulating the therapy demand.

The weekly therapy demand for a specialized team is the sum over diagnosis group that the team is assigned to. The demand per diagnosis group is normally distributed with parameters that have been found by analysis of historic data. The weekly therapy demand for the team of generalists, $v_{wd,gen}$, is the sum of all demand that cannot be served by the specialized teams. The unscheduled demand of a specialized team is equal to the positive difference between its demand and capacity.

$$v_{wd,gen} = \sum_{t \in T_s} \max\left(0\,, v_{wdt} - \sum_{h \in H_d, t \in T_s} c_h \cdot X_{ht}\right) \qquad \forall w$$

Where $\sum_{h \in H_d} c_h \cdot X_{hdt}$ is equal to the capacity of a specialized team. Unscheduled therapy, u_{wd}, takes place when the demand exceeds the capacity of the team of generalist:

$$u_{wd} = \max\left(0\,, v_{wd,gen} - \sum_{h \in H_d} c_h \cdot X_{hd,gen}\right) \qquad \forall w$$

Where $\sum_{h \in H_d} c_h \cdot X_{hd,gen}$ is the capacity of the team of generalists. The overall fraction of scheduled demand, a_{wd}, is then defined as follows:

$$a_{wd} = 1 - \frac{u_{wdt}}{\sum_{t \in T_s} v_{wdt}} \qquad \forall w$$

Where $\sum_t \ v_{wdt}$ is the total therapy demand of all patients in week w.

The average utilization of therapists, ρ_{wd}, in discipline d is defined as follows:

$$\rho_{wd} = \frac{\sum_{t \in T_s} v_{wdt} \ - u_{wdt}}{\sum_{h \in H_d} c_h \cdot X_{ht}} \qquad \forall w$$

Number of replications

We must determine the number of replications, n, for our simulation. The goal of the simulation is to estimate the mean of the unscheduled therapy, $E(u_{wd})$. When we assume the mean of the unscheduled therapy has a normal distribution, the confidence interval of the mean is defined as follows:

$$\left[\bar{x}_d - 1.96 * \sqrt{\frac{{s_d}^2}{n}}, \bar{x}_d - 1.96 * \sqrt{\frac{{s_d}^2}{n}}\right]$$

Where $\bar{x}_d$ is the sample average of discipline d, which is an estimator for the mean and ${s_d}^2$ is the sample variation of discipline d, which is an estimator for the variance. We want to construct a 95% confidence interval for the mean that has a 10% error relative to the mean. However, the mean is unknown, and therefore we measure the error relative to the sample average. The relative error with respect to the sample average is 0.1 / (1-0.1) = 0.11 [29].

$$1.96 \cdot \sqrt{\frac{s^2}{n}} \leq 0.11$$

We have chosen to simulate 1400 weeks, n = 1400, such that the criterion above is true for each discipline.

4.5 Conclusion

In this chapter we have modelled the allotment of therapists to specialized teams as an integer non linear programming problem. We base the allotment decision on statistical information of the historic therapy demand. There are two different configurations of the allotment problem: in the first, all therapists are allotted to a specialized team and in the second an additional team of generalists is deployed. In the first configuration the objective of the allotment is to maximize the minimum realization rate amongst the specialized teams, to ensure the fair treatment of all patients. In the second configuration the objective is to minimize the number of unscheduled therapies in the team of generalists under the constraint that a minimum fraction of the care, q, is executed by therapists in the specialized teams.

We found that the instance of the first allotment problem (allotment to specialized teams) is so large that it takes too long to solve it by complete enumeration. Therefore heuristics are proposed to solve

the problem close to optimality. After testing, we have selected the Simulated Annealing algorithm as the best heuristic. The second allotment problem (allotment to one of the specialized teams or the team of generalists) can be solved with the CPEX solver in AIMMS in reasonable time. Furthermore we have described a discrete simulation model that can be used to predict the average amount of unscheduled therapy per week.

5 Experiments & Results

In this chapter, the allotment method defined in the previous chapter is used to generate alternative therapist allotment plans. First a data analysis is carried out to collect all necessary input data for the model in paragraph 5.1. The performance of our allotment method is validated against the current performance in paragraph 5.2. After validation, we will use the allotment heuristic to create an allotment plan for the current policy for the specialized teams. Then we compare different policies for the formation of therapist teams in paragraph 5.4. Finally we carry out a sensitivity analysis in paragraph 5.5 to investigate the robustness of this allotment method and we experiment with the current capacity to research possibilities to increase the utilization of therapists.

In order to evaluate the performance of the therapist allotment plans, the performance was measured in terms of the minimum realization level among the specialized teams, $min_t[E(A_{dt})]$, the expected amount of unscheduled therapy per week per discipline and the average utilization of therapists in the discipline. The average utilisation of therapists per discipline, ρ_d, is directly related to the amount of unscheduled therapy in the discipline, $E(U_d)$:

$$\rho_d = \frac{\sum_{g \in G} E(v_{dt}) - E(U_d)}{\sum_{h \in H_d} c_h \cdot X_{hdt}}$$

Where the denominator is the total effective working hours of all therapists in discipline *d* and $\sum_{g \in G} E(v_{dt})$ is the expected therapy demand of all patients in discipline *d*. We see that the maximum utilization of therapists is achieved when there is no unscheduled therapy.

5.1 Data analysis

In order to execute the capacity allotment planning, we need the right input data. Therapist allotment is a tactical decision that is based on aggregated data about on the uncertain demand. We will use statistical information about the historic demand of the last two years and we assume the demand to be normally distributed. The average and the sample variation of the aggregate demand per diagnosis group, per discipline were found by data analysis and can be found in [Appendix C].

In addition we need to describe the capacity: we need to know how many therapists are employed per discipline and how many hours per week are they contracted for [Appendix B]. To find the therapists' effective capacity we must take into account the so called load, γ_d, the maximum number of patients that can be treated by one therapist simultaneously in a group therapy, ω_d, and the

fraction of individual therapies, π_d [for a detailed description of the effective capacity, we refer to paragraph 2.1.3]. The values for γ_d and ω_d are based on expert opinions.

Discipline	Fraction Individual (A)	Maximum number of patients (B)	Simultaneous Factor (A+(1-A)*B)	Load
Activity Therapy	0.68	4	1.96	1
Movement Teaching	0.39	6	4.05	0.95
Ergo Therapy	0.96	3	1.08	0.8
Physiotherapy	0.93	4	1.21	0.9
Speech Therapy	0.89	3	1.22	0.7
Social Work	0.96	4	1.28	0.5
Psychotherapy	0.98	6	1.1	0.5

Table 13 Data of discipline characteristics

5.2 Validation

The average utilization is used to validate our model, because the other KPI's could not be measured. The (theoretic) utilization of therapists was calculated with our model and compared to the actual utilization found in the data analysis [paragraph 5.1]. For the calculation of the theoretic utilization we assume that therapists currently treat all in- and outpatient diagnosis groups in their profit centre (policy 4).

Discipline	Actual Performance	Theoretic Performance
Activity Therapy	0.62	0.62
Movement Teaching	0.57	0.56
Ergo Therapy	0.79	0.68
Physiotherapy	0.86	0.79
Speech Therapy	0.76	0.66
Social Work	0.39	0.36
Psychotherapy	0.29	0.32

Table 14 Comparison the average utilization of the actual performance compared to the theoretic performance

The theoretical utilization found for ergo therapy, physiotherapy and speech therapy is much lower than the actual utilization found by data analysis. In our model, therapy cannot be scheduled when there are not enough therapists. In practice, nurses carry out a part of the physio -, ergo - and speech therapies, when there are not sufficient therapists. Therefore there is a difference between the actual and theoretical utilization. However, the RRC prefers their therapists to carry out the therapies instead of the nurses. Experts indicate that on average only 90% of the therapy can be scheduled in the disciplines physiotherapy, which validates the findings of our model.

5.3 Generation of alternative therapist allotment plans

We have generated alternative therapist allotment plans using the allotment method. The specialized teams treat all in- and outpatient diagnosis groups in a profit centre (policy 4). An example of an alternative therapist allotment plan can be found in 0. In the table below the performance of the alternative and current planning are compared.

Discipline	Average amount of unscheduled therapy per week [hours]		Utilization therapists		Minimum realization level	
	Current	Alternative	Current	Alternative	Current	Alternative
Movement Teaching	2.95	1.30	0.56	0.57	0.99	0.99
Ergo Therapy	71.18	34.31	0.68	0.73	0.71	0.93
Physiotherapy	49.80	43.76	0.79	0.81	0.90	0.94
Speech Therapy	29.07	36.28	0.66	0.64	0.69	0.83
Social Work	9.62	5.15	0.36	0.37	0.77	0.95
Psychotherapy	5.19	0.45	0.32	0.29	0.91	1.00

Table 15 Comparison of the performance of the current allotment of the alternative allotment plans

The alternative therapist allotment plans leads to less unscheduled therapy in all disciplines except speech therapy. With less unscheduled therapy the utilization of therapists improves. Furthermore we see that new allotment method divides the capacity of therapists better over the teams, such that the minimum realization level across the teams is increases. In other words, therefore there is more equal treatment of all diagnosis groups. Therefore we conclude that the alternative allotment plans successfully improve the performance.

5.4 Comparison of policies for forming therapist teams

There are different policies for forming teams; these are determined by the following three managerial decisions. For a detailed explanation of the consideration in forming teams we refer to paragraph 2.2.1.

1. Is a team of generalists formed in addition to the specialized teams?
    a. Yes, form a team of generalists in addition to the specialized teams
    b. No, form only specialized teams
2. How specialized should a specialized team be?
    a. Highly specialized, assign team to just one diagnosis group
    b. Moderately specialized, assign team to all diagnosis groups in a profit centre
    c. Not specialized (generalists), assign team to all diagnosis groups
3. Are teams dedicated to either in- and outpatients or both?
    a. Yes, they either in- or outpatients
    b. No, they treat both in- and outpatients

This results in 10 policies for the formation of therapist teams, which are shown in the table below. Policy 4 is currently maintained.

Policy Nr	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Decision 1	No	No	No	***No***	No	No	Yes	Yes	Yes	Yes
Decision 2	One	One	Profit centre	***Profit centre***	All	All	One	One	Profit centre	Profit centre
Decision 3	Either	Both	Either	***Both***	Either	Both	Either	Both	Either	Both

Table 16 Overview of all possible policies for the formation of therapist teams

In the first 6 policies all therapists are assigned to a specialized team and in policy 7 to 10 and additional team of generalists is formed.

5.4.1 Forming only specialized teams (policy 1 to 6)

Each therapist is allotted to one of the specialized teams and the minimum realization level across the teams is maximized. The performance of allotment plans for each policy is compared in the table below.

	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5	Policy 6
	Average Amount of Unscheduled Therapy (hours per week)					
Activity Therapy	N.A.	10.07	2.36	0.57	0.00	0.00
Movement Teaching	N.A.	54.78	3.28	1.30	0.66	0.07
Ergo Therapy	82.62	66.58	45.27	34.31	27.41	20.61
Physiotherapy	149.71	129.58	65.51	43.76	36.91	20.63
Speech Therapy	N.A.	118.42	65.12	36.28	31.14	25.48
Social Work	N.A.	25.23	10.23	5.15	3.59	1.43
Psychotherapy	N.A.	7.78	1.84	0.45	0.10	0.00
	Minimum Realization Level					
Activity Therapy	N.A.	0.92	0.99	1.00	1.00	1.00
Movement Teaching	N.A.	0.64	0.98	0.99	1.00	1.00
Ergo Therapy	0.75	0.84	0.89	0.93	0.94	0.96
Physiotherapy	0.72	0.79	0.90	0.94	0.95	0.97
Speech Therapy	N.A.	0.43	0.68	0.83	0.86	0.89
Social Work	N.A.	0.27	0.85	0.95	0.96	1.00
Psychotherapy	N.A.	0.88	0.98	1.00	1.00	0.99
	Average utilization					
Activity Therapy	N.A.	0.60	0.62	0.62	0.62	0.62
Movement Teaching	N.A.	0.47	0.56	0.57	0.57	0.57
Ergo Therapy	0.65	0.67	0.71	0.73	0.74	0.75
Physiotherapy	0.69	0.71	0.78	0.81	0.81	0.83
Speech Therapy	N.A.	0.35	0.54	0.64	0.65	0.67
Social Work	N.A.	0.29	0.35	0.37	0.38	0.39
Psychotherapy	N.A.	0.27	0.29	0.29	0.29	0.29

Table 17 Performance of therapist allotment plans in different policies.7

[7] When the number of therapist is smaller than the number of teams, the discipline no allotment plan is evaluated and N.A. is displayed in the table

From policy 1 to 6 therapist teams become less specialized; thus teams are assigned to more diagnosis groups. The best performance is achieved when all therapists are allotted to one large team of generalists (policy 6). The deployment of highly specialized teams leads to more unscheduled therapy. This leads to a lower utilization of therapists and a lower realization level of the therapy programs. Furthermore, dedicating teams to either in- or outpatients instead of both has a negative influence on the performance. The reason that the formation of less specialized therapist leads to the improved performance is that diagnosis groups share capacity. By sharing capacity the variability of the demand is reduced, this effect is called risk pooling.

5.4.2 Forming specialized teams with an additional team of generalists (policy 7 to 10)

A team of generalists can be formed in addition to the specialized teams. This team intercepts the demand that cannot be served by the specialized teams. Forming a team of generalists is possible in physical therapy disciplines such as physiotherapy, ergo therapy and movement teaching. We take the allotment of physiotherapists as example in our experiments. The allotment plans are formed such that therapists in specialized teams will execute a fraction of the therapies, q. In case q equals 1, all therapists will be allotted to a specialized team and when q= 0, all therapists are allotted to the team of generalists. We will evaluate the performance that can be achieved for various values of q between 0 and 1. Furthermore, the various policies for the formation of forming specialized teams are compared. Teams become less specialized from policy 7 to 10.

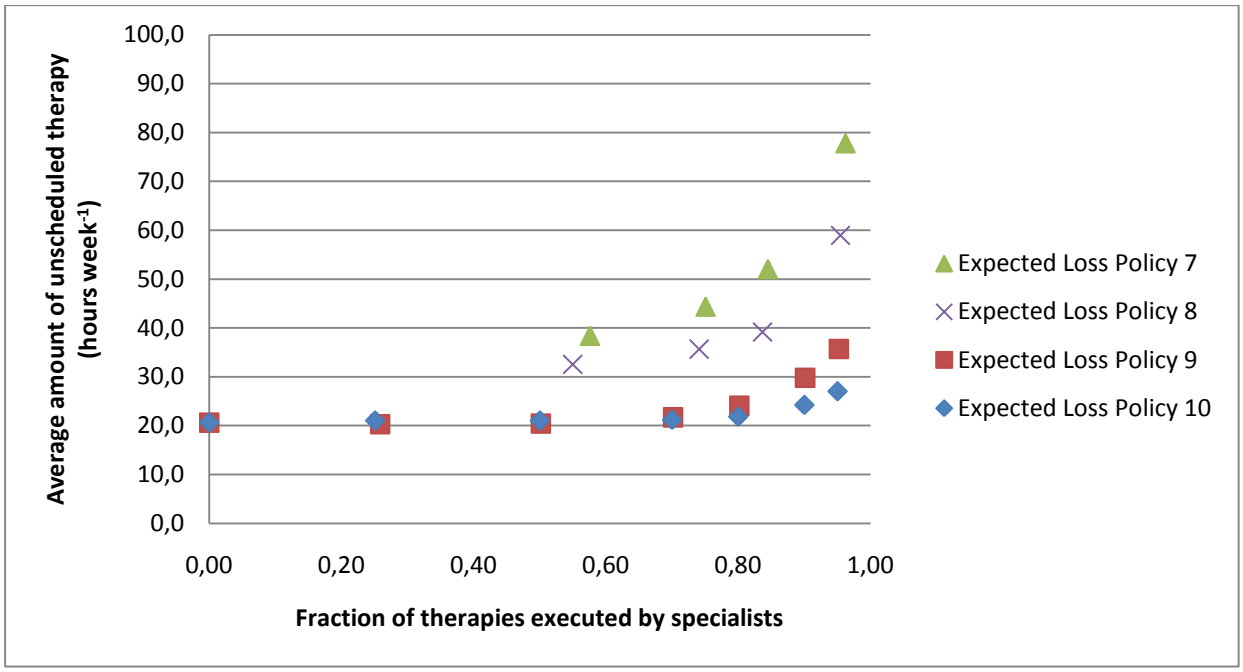

Figure 9 The average number of unscheduled therapies (in hours per week)

The average amount of unscheduled therapy increases when a larger fraction of the therapies is carried out by the specialized teams. The largest improvement of the performance takes place when at least 20% of the therapies are carried out the by the teams of generalists, $q \geq 0.8$ (see figure above).

We will now compare policies that have the same type of specialized teams, but in one policy there is an additional team of generalists and in the other policy there isn't. We allot the therapists such that a maximum of 20% is executed by the team of generalists, q = 0.8.

	Only specialized teams	Specialized teams plus a team of generalists
	Policy 1	**Policy 7**
Unscheduled therapy Per week [hours]	149.71	52.0
Realization level	0.72	0.93
Utilization of therapists	0.69	0.80
	Policy 2	**Policy 8**
Unscheduled therapy Per week [hours]	129.58	39.18
Realization level	0.79	0.95
Utilization of therapists	0.71	0.81
	Policy 3	**Policy 9**
Unscheduled therapy Per week [hours]	65.51	24.06
Realization level	0.90	0.97
Utilization of therapists	0.78	0.83
	Policy 4	**Policy 10**
Unscheduled therapy Per week [hours]	43.76	21.85
Realization level	0.94	0.97
Utilization of therapists	0.81	0.83

Table 18 Comparison of the performance in physiotherapy for the policies with and without a team of generalists

The amount of unscheduled therapy is greatly reduced by 50 to 70% by employing a team of generalists that carries out 20% of the therapies. Therefore we see the utilization of therapists and realization level improves as well.

5.5 Sensitivity Analysis

A sensitivity analysis is executed to investigate the influence of variations in the demand and/or the capacity of therapists.

5.5.1 Increased demand fluctuations

The unscheduled appointments are currently not registered. Therefore the variability of the demand is structurally underestimated. To correct for this the variation in the demand is increased by 10 and 20%.

	Average amount of unscheduled therapy per week [hours]		
Discipline	No extra variation	+ 10 % variation	+ 20 % variation
Activity Therapy	2.36	3.21	4.00
Movement Teaching	3.28	4.62	4.39
Ergo Therapy	45.27	47.23	49.58
Physiotherapy	65.51	67.28	71.88
Speech Therapy	65.12	65.57	68.69
Social Work	10.23	11.04	11.55
Psychotherapy	1.84	2.20	2.55

Table 19 Sensitivity analysis with respect to the demand variability

We see that the under higher variation, the amount of unscheduled appointments increases. When the allotment plans for physiotherapists were compared, we saw in a randomly picked policy that 22 of the 29 therapists were assigned differently. Therefore the solutions of our allotment tool are not robust to change. This is actually very undesirable; because this means that many therapists must be re-allotted and retrained.

5.5.2 Experiments with the current capacity

In the experiments we found that the utilization of therapists is structurally lower than the load. The load is currently used as a standard for the utilization of therapists; however, the load is currently used as the maximum fraction of the capacity that can be scheduled. Therefore we will experiment with increasing the (schedulable) load with 10% and 20%, while making sure the load does not exceed 100%. Furthermore we found that the current therapist work force too large for the current demand; therefore we have also experimented with decreasing the workforce by cutting down the working hours of therapists by 20% and 40%. We have carried out the experiments for policy 6:

assigning all therapists to one large team of generalists. Experiments are only feasible if the average utilization does not exceed the load and the realization level should not fall below 90%.

Experiment	1	2	3	4	5	
Increase in load	10%	20%	10%	20%	20%	
Decrease in work force	0%	0%	20%	20%	40%	
	Realization level					
Activity Therapy	1.00	1.00	0.99	0.99	0.91	
Movement Teaching	1.00	1.00	0.99	0.99	0.91	
Ergo Therapy	0.99	1.00	0.89	0.95	0.76	
Physiotherapy	0.99	0.99	0.91	0.91	0.70	
Speech Therapy	0.95	0.99	0.82	0.90	0.71	
Social Work	1.00	1.00	0.98	1.00	0.93	
Psychotherapy	1.00	1.00	1.00	1.00	1.00	
	Utilization					**Load**
Activity Therapy	0.62	0.62	0.77	0.77	0.94	1
Movement Teaching	0.57	0.57	0.70	0.70	0.86	0.95
Ergo Therapy	0.78	0.78	0.88	0.94	1.00	0.8
Physiotherapy	0.85	0.85	0.97	0.97	1.00	0.9
Speech Therapy	0.72	0.75	0.78	0.85	0.89	0.7
Social Work	0.39	0.39	0.48	0.49	0.61	0.5
Psychotherapy	0.29	0.29	0.37	0.37	0.49	0.5

Table 20 Results of experiments, the red values are not within the acceptable standards

Increasing the schedulable load is a very effective tool in increasing the average utilization of therapists. However, the efficiency can only be improved to a certain limit. In order to improve the utilization even further, the work force of the disciplines activity therapy, social work and movement therapy must be cut down. We see that this leads to improved performance when the work force is decreased slightly; however, when the work force is cut down too drastically the realization level drops below the acceptable standard.

5.6 Conclusion

The allotment method has been validated and generates feasible plans for the allotment of therapists to specialized teams. The current policy is to form specialized teams that treat all diagnose groups in a profit centre. We generated alternative allotment plans for all disciplines and found that they lead to more equal treatment of patients. The capacity is divided more fairly over the teams and the minimum realization level among the teams improved in all disciplines; 90% of all therapies are realized in all disciplines except speech therapy. Furthermore, experiments show that the average amount of unscheduled therapy is decreased by 50% for most disciplines, which leads to a better utilization of therapists. In the remainder of this paragraph the experiments for physiotherapy will be used as typical examples for all disciplines.

The different policies for forming specialized teams have been investigated. It was found that forming highly specialized teams and dedicating teams to either in- or outpatients increase the amount of unscheduled therapy. Unscheduled therapies cause a poor utilization of therapists and a poor realization level of therapy programs. The most therapy can be scheduled and realized when all therapists are allotted to one large team of generalists that treat any type of patient. E.g. in physiotherapy forming a team of generalists leads to 86% less unscheduled therapy compared to forming the most highly specialized teams[8]. This results in a realization level of 97% and a utilization of 83%.

Furthermore we have experimented with forming a team of generalists in addition to the specialized teams. When 80% of the therapies are carried out by the specialized teams, the amount of unscheduled physiotherapies can be decreased by 50 to 70%. Therefore a realization level of more than 93% can be achieved and the utilization of physiotherapists of 80%.

Finally, experiments have been carried out concerning the economic deployment of therapists, because currently they are structurally underutilized. The first intervention is to increase the therapists' schedulable load. A second intervention is to cut down the current work force. Experiment showed that the average utilization is improved by both interventions and cutting down is possible in activity therapy, movement teaching, social work and psychology. With these proposed interventions the average utilization of therapists can meet the standards set by management.

[8] Comparing policy 1 and 6

6 Implementation of alternative capacity planning

This chapter described a proposal of the implementation of the new therapist capacity planning. Management needs to make therapist allotment plans using the mathematical model described in chapter 4. Therefore the mathematical model has been implemented into a modelling system called AIMMS. The allotment tool has been developed as a prototype and its application by management is discussed in paragraph 6.1. The allotment tool requires performance data; therefore the current performance measurement must be improved. Furthermore, active and routine performance measuring could be the key a cultural change and improved performance. Performance measurement will be discussed in paragraph 6.2. Finally, the considerations in re-allotting therapists are discussed in paragraph 6.3.

6.1 Prototype of allotment tool

In this study a prototype for an allotment tool has been build. The allotment method developed in this study has been implemented in a prototype tool that can be utilized by management to create a new allotment plan.

The allotment tool can evaluate a range of policies for the formation of specialized teams. Management can determine the level of speciality of a specialized team, by assigning teams to one diagnosis group, all diagnosis groups in a profit centre or all diagnosis groups. Specialized teams can be dedicated to just in or outpatients or teams can treat both in- and outpatients in the diagnosis group. Furthermore management can decide if they want to deploy a generic team in addition to the specialized teams.

The tool has a user friendly interface that can be operated by a manager. Historic demand data and the current therapist capacity data can be easily loaded into the program by the user. In the selection menu the user can decide what types of teams need to be formed (select a policy).

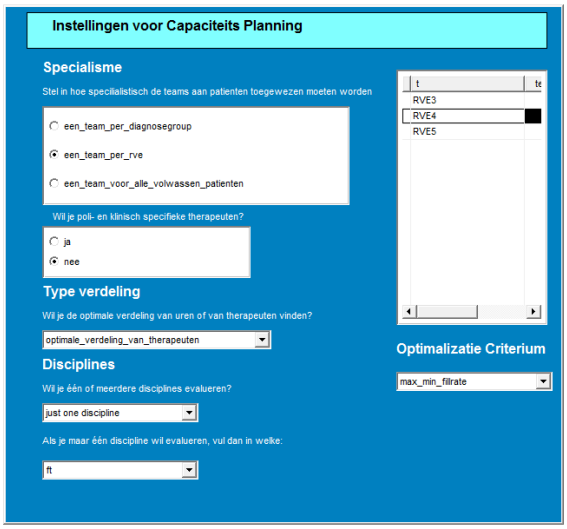

Figure 10 Screenshot of selection menu

In the results window the solution for the therapist allotment is shown, as well as the values for the utilization, realization rate and the expected number of unscheduled appointments.

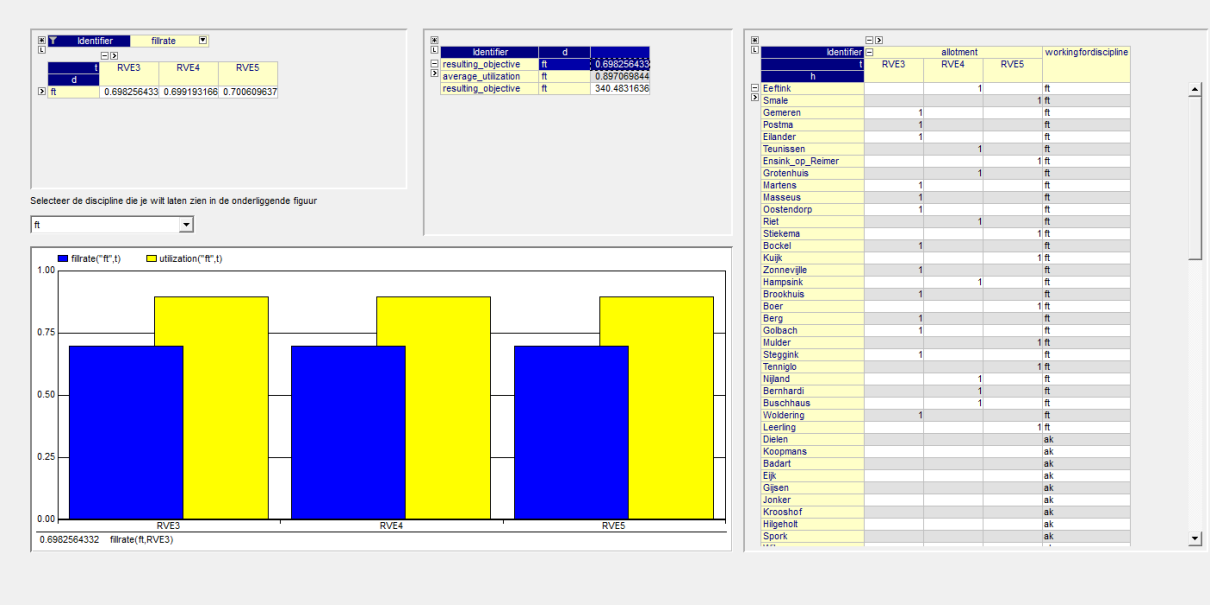

Figure 11 Results window

6.2 Performance Measurement

At this moment a structural lack of data hinders substantiated planning and decision making. Therefore we propose the RRC starts to measure the following list of performance data:

- The arrival rate of new patients
- The characteristics of patients:
    - Diagnosis group
    - In/Out patient
    - Assignment to an SRP
- The therapy program per progressive week per discipline (e.g. 5 hours physiotherapy in the first week, 4 hours physiotherapy in the second week, 3 hours of ergo therapy in the second week, 2 hours of social work in the second week, etc ...)
    - N.B. this is NOT the realization; this is the demand that is requested! And must be registered in the scheduling department before the appointments are made.
    - From this data the realization level can be deduced.
- The deviations from the standard rehabilitation programs: how much longer or shorter are patients in therapy and how much more or less do they need than indicated in the SRP?
- The actual length of a therapy appointments (versus the scheduled length)

6.3 Re-allotting therapist to specialized teams

This therapist allotment could be evaluated yearly and/or when new therapists are employed. However, we warn that re-allotting therapists on a regular basis would cause a lot of unrest in the organization and is therefore undesirable. The user of this tool can load all statistical demand information and capacity information into the tool. Instead of finding a whole new allotment of therapists, the optimal allotment of hours be also be benchmarked to the current allotment of hours.

An alternative assignment of therapists to specialist teams means that therapists will treat different types of patients or therefore re-specialize. This requires appropriate training and hence a considerable investment by management. Forming a team of generalists in addition to the specialized teams is a very interesting option, because we found this greatly improves the operational performance. The RRC could employ all newly employed therapists as generalists and leave the current therapists working in their own specialism; such that they do not have to be retrained. Therefore we see that the investment in training is much lower when a team a generalists is formed.

6.4 Conclusion

In order to improve the capacity planning of therapists, the allotment tool can be used as decision support by management. The tool can be easily operated and can evaluate a large range of policies. The tool needs historic demand as input to optimize the allotment, this requires improved performance measurement. The most important performance measure that needs to be logged is the amount of unscheduled therapy per week. Performance measurement can also play a vital role in motivating therapists to adopt the new way of working.

Re-allotting therapists to teams requires an investment in the form of retraining of therapists. The amount of retraining required can be reduced by forming a team of generalists instead of making therapists re-specialize.

7 Conclusions & Recommendations

In this chapter we present the findings of this study and give recommendations to management. We start by recapping the main conclusion of this research in paragraph 7.1. Then the limitations of this study are discussed in paragraph 7.2. Finally, we will do other recommendations for the RRC and further research concerning the improvement of the execution of therapy programs in paragraph 7.3.

7.1 Conclusions & Recommendations

Management wants to improve the execution of the therapy programs by tactical capacity planning of their therapists and therefore the following research question was defined:

How can therapist capacity planning improve the execution of the adult therapy programs?

In the context analysis we found that patients are treated according to their rehabilitation program. Rehabilitation programs consist of weekly protocols stating type and duration of a therapy for the individual patient. The therapies are carried out by a multidisciplinary team of therapists. Therapists are employed for a fixed number of hours per week and work for a specialized team which is responsible for the treatment of one or more diagnosis groups. The current policy is to form specialized teams per profit centre. When the therapy demand exceeds the capacity of a specialized team, therapy remains unscheduled.

The objectives for capacity planning are to deliver high quality of care, while guaranteeing quick access for new patients, making economic use of the resources and meeting the production target that was agreed with health care insurers. In order to measure performance four KPI were established: the production target, the utilization of therapists, the access time to the therapy centre and the realization level. The realization level is defined as the fraction of the therapy program that has been realized; it is a measure for the quality of care. The utilization of therapists and the realization level do not meet the standards set by management and the improvement of these KPIs is therefore the focus of this research. The access time cannot be evaluated based on the available performance data.

Based on this analysis we developed a method to improve the allotment of therapists to specialized teams and we researched different policies for the formation of specialized teams. In our allotment method the problem is modelled as non linear integer programming problem and solved with a

simulated annealing heuristic.

First the improved allotment of therapists to specialized teams is regarded. Experiments showed that the method developed in this study generates an alternative allotment of therapists that leads to more equal treatment of patients and decrease the current amount of unscheduled therapies by 50% for most disciplines. Furthermore a realization level of 90% of the therapy programs can be achieved for all disciplines except for speech therapy.

Secondly we compared policies for the formation of specialized teams. Experiments showed that forming highly specialized teams and assigning teams to either in- or outpatients increases the amount of unscheduled therapy. We found that unscheduled therapies have a negative effect on the realization level of the therapy programs as well as the therapists' utilization. The best performance is achieved when all therapists work in one large team of generalists; for physiotherapy the amount of unscheduled therapy can be reduced as much as 86%. This results in a realization level of 97% and a utilization of 83%.

However, forming specialized teams is beneficial for the quality of the therapies. Therefore a further option is to form a team of generalists in addition to the specialized teams. If 80% of the therapies are carried out by highly specialized teams, a realization level of 93% can be achieved with a physiotherapists' utilization of 80%. We see that these values are only slightly lower than the possible performance (policy of forming one large team of generalists). The quality of the care is high, because a large part of the program can be carried out by the specialized teams and a high realization of the therapy programs is achieved and efficient deployment of therapists is guaranteed by their high utilization. Therefore we recommend the RRC to form highly specialized teams plus an additional team of generalists, because we believe this is the best suited policy with the best trade off between quality of care and efficient deployment of therapists. Furthermore the amount of retraining required is smaller by forming a team of generalists compared to re-allotting therapists to specialized teams.

The load is currently used as the standard for the utilization; however, experiments show that actual utilization will always lower, even with the improved capacity planning. We showed that the utilization of therapists can be increased by increasing the schedulable load. However, the utilization can only be improved to a certain limit, because we found the current workforce is too large the current workload. In order to improve the economic deployment of therapists further, management must make a choice: either increase the current workload by attracting more patients to the RRC or cutting down the current workforce.

The access time for therapy has not been studied in detail; however, based on the data analysis presented in Chapter 2 and 5 it follows that forming less specialized teams will reduce workload variability, which will in turn decrease the access time to the therapy centre. This is yet another reason why we recommend the RRC to make its therapist capacity planning more flexible by forming an additional team of generalists and/or forming less specialized teams.

Furthermore we recommend executing as many group appointments as possible. This is an interesting option to increase therapists' productivity, because therapists can treat multiple patients during group appointments. This way the therapist capacity becomes even more flexible.

7.2 Discussion & Limitations

This study has several limitations.

- The quality of the alternative capacity planning that is proposed in this report is limited by the availability of reliable performance data; therefore the results of for the alternative capacity planning should be interpreted with care. The most pressing issue is that unscheduled appointments are currently not documented and the current performance data is biased. However, the results of this study show clear trends that provide valuable insights for the RRC.
- We found that the allotment is not robust to changes in the variation of the therapy demand; the allotment of therapists changes drastically. This is a problem for implementation, because this means many therapists have to be re-allotted and their specialist knowledge is wasted. Therefore we believe that further development of the tool should focus on proposing allotments that are as similar to the current allotment as possible.
- In our model we assume that patients are treated by any therapist in a specialized team. However, in practice we see that many patients are assigned to fixed therapists; therefore we suspect that the actual performance will be lower than predicted by our model.
- Furthermore, our model does not take into account the interdependence between the disciplines. In practice we see that therapies need to be executed simultaneously in all disciplines, therefore therapy is only planned when there is capacity available in all disciplines. This will lead to a lower utilization of therapists and an increased access time for new patients.
- We did not take operational restriction such as the availability of therapists and patients into account.
- Further research may be invested into improving the fairness of the allotment, by formulating the current objective differently. Fairness is very important, because we want to guarantee equal treatment to patients.
- We assume a normal distribution of the demand. However, this theoretic distribution allows for negative values and is therefore not a good assumption in case the demand in a diagnosis group is very small.
- Due to time restrictions, we were not able to generate allotment plans with an additional team of generalists for all discipline. Therefore we have taken physiotherapy as an example.
- In this study the focus has been on capacity planning of therapists; however, further research should also take into account other resources such as rooms and therapy devices.

7.3 Other recommendations

In order to improve the execution of therapy programs, the RRC must optimize its recourse capacity planning and control on each hierarchic level (strategic, tactical, operational offline and online). Furthermore a culture of continuous improvement must be created throughout the whole organization and we strongly advice the RRC to execute routine performance measurement in order to facilitate better informed decision making. A lack of clearly defined and selected KPIs prevents this. Management must define goals for the operations; such as access times, utilization of therapists etc, and translate these into standards for the KPIs. These can be used to control processes and achieve cultural change by comparing the current performance to the standards. Employees must be rewarded for detecting operational problems and all employees should be actively involved in improvement and innovation. After detection of the problem its causes should be researched carefully and as a result thereof, a solution can be devised and selected.

In the remainder of this report, recommendations are done for the planning and control of the therapy programs per hierarchic level, N.B. no recommendations are done on strategic planning.

7.3.1 Tactical Decision Making

Shift scheduling of therapists is very important in creating feasible and well balanced appointment schedules for patients. The shift scheduling must be optimized to minimize the number of weekly visits for outpatients and to spread the inpatient's therapy as equally over the week as possible. Aligning the shifts of outpatient-dedicated-therapists across the disciplines increases the possibility of planning combination appointments and thus decreases the number of visits to the RRC. Inpatient-therapists' shifts should be assigned evenly over the week in order to spread the therapy programs of inpatients. Not only the individual appointments, as well as the group sessions should be well positioned in the week schedule. A practical recommendation is to start therapists' shifts after 10 o'clock in the morning, because physicians and nurses are taking care of patients before that time.

In an attempt to align patient demand and therapist capacity, therapists could be deployed more flexibly; therapists weekly working hours are adapted to the current demand. When therapy programs are planned further ahead and uncertain demand is forecasted, therapists' shifts can be scheduled dynamically a few weeks ahead. Currently the therapy demand is communicated to the scheduling department one week in advance and this is at too short notice to alter the therapists working hours.

Admission control is a very important tool in managing and decreasing the variation in therapy demand. Fluctuations in the demand are caused by a fluctuating the number of patients as well as fluctuations in patients' individual demand over the course of their treatment. It would be very interesting to test alternative admission strategies. A good admission policy should balances the waiting time for new patients, the realization of therapy programs for the present patients and the workload of therapists. A dynamic admission rule could be based on forecasted data. We believe that dynamic shift scheduling, dynamic admission rules and forecasting demand deserve more attention in further research.

Furthermore we encourage medical staff to think of more flexible definition of the therapy programs. Currently, the therapy programs are defined per week and if therapy is cannot be scheduled, it is cancelled. Instead of cancelling the appointments, a further option would be to schedule therapy a week later or earlier.

7.3.2 Offline operational planning and scheduling

Therapy scheduling is a very complex procedure, because it is subject to a large number of restrictions: assignment restrictions, availability of patients and therapists and preferences of patients and therapists. To conquer the complexity, we recommend that planners use a decision support tool based on advanced planning and scheduling principles to improve the appointment schedules with respect to the scheduled therapy that can be scheduled and meet the patient's preferences more effectively. The planners could then focus more on spotting structural capacity problems and gain information on the demand.

Furthermore, we recommend the RRC to invest in IT support and cooperation between therapists and planners[9] to prevent communication problems between work floor and scheduling department and increase the feasibility of the schedules. By standardizing the policies for assignment of patients to therapists, the rehabilitation programs and the working schedules of therapists, the alignment between work floor and scheduling department will become much more efficient and less susceptible to communication errors. This requires all therapists to be scheduled to standardized shifts, fixed agreements about the assignment of therapists to diagnosis groups and the development of standard rehabilitation programs for all diagnosis groups (in and outpatient) in each discipline. Therapists' and physicians' agendas should be coordinated, to avoid unnecessary double

[9] Some initiatives already exist in which therapists think along with planners to assign patients to therapist, these initiatives should be stimulated.

appointments. We recommend increasing the planning horizon of outpatient appointments to avoid the high number of cancellations by outpatients. This requires medical staff to plan outpatient's rehabilitation programs further ahead. We also believe it is not necessary for outpatients to block day-parts (currently they are allowed to block 5 per week), when appointments are planned further ahead. The off times of therapists must be coordinated by their process manager and there should be a strong focus on substituting for one another to make sure all patients receive their therapies. To increase the realization of therapy programs, we believe they should be scheduled more flexible: physicians should indicate which therapy can be scheduled a week earlier or later to improve the overall realization of the program.

Appointments should be as flexible as possible to avoid unnecessary and excessive scheduling efforts and allow for flexible rescheduling of the appointment schedule in case appointments run out or are being called off. Many of the therapy sessions are carried out as group therapies and could possibly be organized as walk in appointments. The high rate of no shows among outpatients makes it interesting to overbook appointments in order to increase the utilization of therapists and increase the realization of therapy appointments. However, an overbooking rule should take into account the waiting time for patients and the workload for therapists. Furthermore cyclic appointment for outpatients should be made: such that they always have to visit the RRC on the same weekday(s). This provides certainty to the outpatient and it simplifies the scheduling effort. Instead of scheduling 30 minute slots, outpatient could be assigned to morning or afternoon sessions, in which they receive all their different therapies. Further research should investigate the feasibility of these appointment methods.

7.3.3 Online operational

In order to increase the number of patients that can be treated per therapist, the RRC should focus on decreasing the therapists' secondary activities such as administration and meetings. This could be achieved by clever use of IT and active involvement of therapists in finding more efficient solution. The therapists' individual utilization should be closely monitored by process managers. Furthermore we found that therapists are capable of treating multiple patients simultaneously during group sessions, therefore we would suggest that the RRC organizes as much of the therapy in group sessions as possible.

Furthermore we believe more attention should be paid to rescheduling appointments due to the large number of cancellations and no shows. We believe that the planning department and therapists should stay actively involvement in rescheduling cancelled appointments after making

finishing the appointment schedules. Right now many communication problems hinder efficient rescheduling. To fill up no shows, a physical or virtual waiting room could be arranged, from which therapists can select another patient when a patient does not show up for an appointment.

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This study marks the end of a great journey called "my study time". My studies have led me through a bachelor in chemical Engineering and in minor in education, a year in Art School and finally a master in Industrial Engineering and Management. My bachelor taught me a great deal of independence and always challenged my analytic skills. On paper, my results were fine, but unfortunately there was no "chemistry" between me and this field of research. After a bachelor research project on micro membranes, I switched university for a foundation year in Art School. Being permanently covered in paint stains and armed with my glue gun, I started to miss analytic puzzles after a while. So back to university I went!

My master has been full of wonderful OR puzzles and interesting subjects. I clearly remember a lecture of "Introduction to IE&M" that was given by an enthusiastic professor who told us about the application of OR in health care. This professor was of course Erwin and he immediately drew my attention. Throughout my master I met Erwin now and again which resulted in some very interesting discussions. Almost a year ago he told me he had an assignment for me in the Roessingh that would perfectly fit me, the rest is history... I want to thank Erwin for our pleasant talks and keeping me focused on the big picture during my research project, which definitely elevated the quality of my work. Thanks go to Maartje for her super quick answers and even inviting me to her place once (in time of crisis). I always found your comments extremely helpful and I even learned a thing or two about mathematical notations. So Erwin and Maartje, thank you both so much for your enthusiastic supervision.

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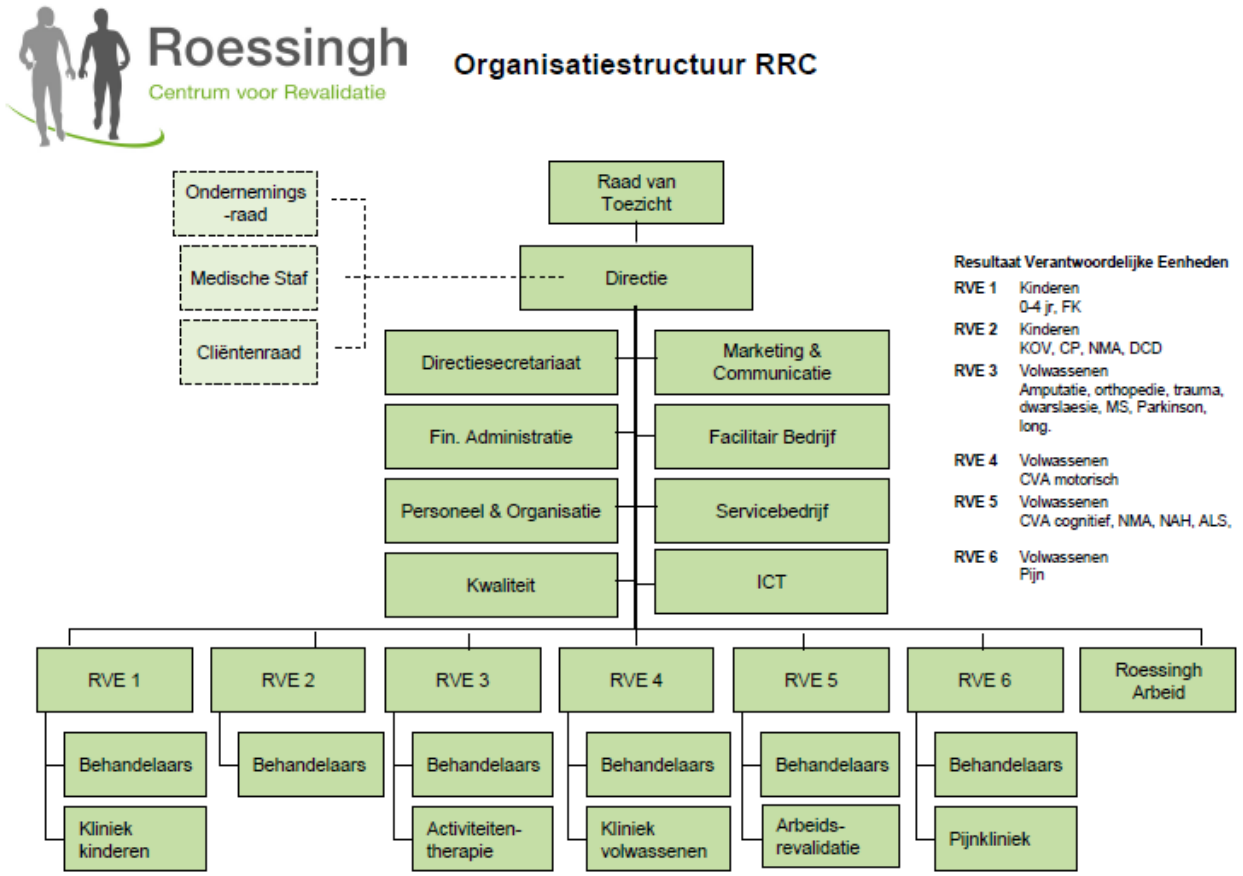
Signed by,

Annemarie Nijsbert Dedden

Appendix A. Organization Chart of the Roessingh Rehabilitation Centre (RRC)



Appendix B. Overview of work force

Staff Type	Fraction of total work force	Medical compared to administrative
Physicians	7,16%	66,47%
Nurses	24,17%	
Therapists	32,60%	
Other *	2,54%	
Supporting & Administrative Staff	33,53%	33,53%

* (Vocational training, driving school, dietics, creative therapy, therapeutic computer therapy)

	# FTE's therapists employed per discipline
Activity Therapy	5.79
Movement Teaching	3.92
Ergo Therapy	15.31
Physiotherapy	20.24
Speech Therapy	6.65
Social Work	6.26
Psychotherapy	9.50

Appendix C. Statistical information of the historic demand for therapies

	Average of Aggregated Demand (hours per week)												
Diagnosis Group	AO	MPZ	NAH	NVCA	AO	MPZ	NAH	NCVA	NMA	NMAFL	V-MS	V-RES	V-PAR
Profit Centre	3	3	5	4	3	3	5	4	5	5	3	3	3
In/Outpatient	In	In	In	In	Out	Out	Out	Out	Out	Out	Out	Out	Out
Activity Therapy	51.48	43.11	43.82	69.76	14.16	1.88	19.83	7.89	0.89	0.01	1.29	0.00	0.09
Movement Teaching	26.47	28.27	14.89	26.66	42.69	7.85	40.58	33.34	10.51	0.53	3.06	86.71	2.44
Ergo Therapy	24.75	48.73	84.37	184.21	22.07	10.04	31.73	39.27	11.11	4.15	3.39	0.88	2.62
Physiotherapy	88.32	91.09	107.39	169.92	86.19	22.39	41.76	49.36	20.49	2.46	6.78	64.96	3.18
Speech Therapy	1.14	1.35	16.16	108.92	0.13	0.13	4.53	85.96	1.20	1.12	0.74	0.03	0.58
Social Work	6.51	9.70	9.63	10.96	3.79	1.10	14.31	7.79	6.73	9.56	2.22	16.68	0.35
Psychotherapy	2.16	6.17	11.11	16.85	9.57	3.55	29.78	17.62	5.87	0.45	5.21	0.95	0.62

This is based on historical data 2012 and 2013 up till week 44.

	Sample Variation of Aggregated Demand (hours per week)												
Diagnosis Group	AO	MPZ	NAH	NVCA	AO	MPZ	NAH	NCVA	NMA	NMAFL	V-MS	V-RES	V-PAR
Profit Centre	3	3	5	4	3	3	5	4	5	5	3	3	3
In/Outpatient	In	In	In	In	Out	Out	Out	Out	Out	Out	Out	Out	Out
Activity Therapy	653.04	389.41	238.72	579.23	60.30	4.89	52.85	43.99	4.59	0.00	4.27	0.83	0.18
Movement Teaching	65.70	62.79	30.10	63.59	122.21	13.99	94.82	119.08	33.43	0.45	4.72	3804.94	3113.55
Ergo Therapy	76.26	171.59	308.32	2867.72	67.03	17.03	112.15	150.98	64.82	9.87	3.99	2.34	3.85
Physiotherapy	446.70	419.60	747.60	1882.86	688.72	77.01	139.58	244.41	111.64	5.27	5.84	2055.71	1768.13
Speech Therapy	2.27	1.26	53.53	825.35	0.20	0.19	10.33	533.51	1.21	1.36	0.38	0.09	0.49
Social Work	15.76	68.09	20.65	13.62	13.86	1.20	37.46	17.81	22.41	31.20	1.95	164.08	133.41
Psychotherapy	2.89	10.53	19.13	170.46	12.61	23.23	139.02	51.66	59.63	0.65	6.27	72.39	0.89

This is based on historical data 2012 and 2013 up till week 44.

Appendix D. Analysis of average access time

The RRC doesn't properly log the access time to the therapy centre, because they defined it as the average access times for patients that are currently waiting for therapy, of course this is an unreliable measure and it paints a picture of the average access time that is far to positive.

We can do a better analysis of the average access time based on the monthly samples on the number of patients on the waiting list, L_g, per diagnosis group, g. By using Little's Law the average access time can be deduced from the average number of patients on the waiting list, by the following formula:

$$E(W_g) = \frac{E(L_g)}{\lambda_g}$$

We assume the arrival process of outpatients is Poisson with parameter λ and therefore the arrival process of an outpatient diagnosis group is:

$$\lambda_g = \mathbb{P}(G = g) \cdot \lambda$$

Where $\mathbb{P}(G = g)$ is the probability an arbitrary outpatient belongs to diagnosis group g. Therefore we get the following waiting line analysis per diagnose group:

Diagnosis group	Fraction of outpatients	Average access time [days]
AO	23.16%	23.34
MPZ	8.26%	38.70
NAH	23.53%	4.59
NCVA	20.30%	8.66
NMA	9.58%	14.31
NMA FL	5.05%	2.46
V-MS	3.77%	31.23
V-PAR	1.26%	18.65
V-RES	5.09%	20.68

Appendix E. Mathematical Problem Formulation

The problem formulation of the allotment of therapists to specialized teams:

Allotment of therapists to specialized teams

Objective function is to maximize the minimum realization level among the specialized teams:

$$\max(Y_d) \quad \forall d$$

s.t.

$$Y_d \leq A_{dt} \qquad \forall d, t \qquad \text{(maxmin constraint)}$$

$$X_{ht} <= 1 \qquad \forall h, t$$

$$C_{dt} = \sum_{h \in H_d} c_h \cdot X_{ht} \qquad \forall d, t$$

$$P_{dt}(U_{dt} > 0) = P(v_{dt} > C_{dt}) \qquad \forall d, t$$

$$U_{dt} = \max(v - C_{dt}, 0) \qquad \forall d, t$$

$$A_{dt} = 1 - \frac{E(U_{dt})}{E(v_{dt})} \qquad \forall d, t$$

$$E(U_{dt}) = E(\max(v_{dt} - C_{dt}, 0)) \qquad \forall d, t$$

$$E(U_{dt}) = \sigma_{v_{td}} \cdot L(z_{dt}) \qquad \forall d, t$$

$$z_{dt} = \frac{C_{dt} - E(v_{dt})}{\sigma_{v_{td}}} \qquad \forall d, t$$

$$L(z_{dt}) = \int_z^{\infty} (x - z_{dt}) \cdot \varphi(x) \; dx = \varphi(z_{dt}) - z_{dt} \cdot [1 - \Phi(z_{dt})] \qquad \forall d, t$$

Range of decision variables:

$$X_{ht} = \{0,1\} \qquad \forall h, t$$

$$C_{dt} \geq 0 \qquad \forall d, t$$

$$z_{dt} \in \mathbb{R} \qquad \forall d, t$$

$$0 \leq E(U_{dt}) \leq E(v_{dt}) \qquad \forall d, t$$

$$0 \leq A_{dt} \leq 1 \qquad \forall d, t$$

$$\mathrm{Y_d} \geq 0 \qquad \forall \mathrm{d}$$

Allotment of therapists to specialized teams with an additional team of generalists

Objective function is to allot as many therapists to the team of generalists as possible:

$$\min \sum_{h \in H_d, t \in T} (1 - X_{ht}) \qquad \forall d$$

S.t.

$$X_{ht} \leq 1 \qquad \forall h, t$$

$$C_{min,d,t} = q \cdot E(V_{dt}) \qquad \forall d, t$$

$$\sum_{h \in H_d} c_h \cdot X_{ht} \geq C_{min,d,t} \qquad \forall d, t \in T$$

$$X_{ht} = \{0,1\} \quad \forall h, t$$

Range of decision variables:

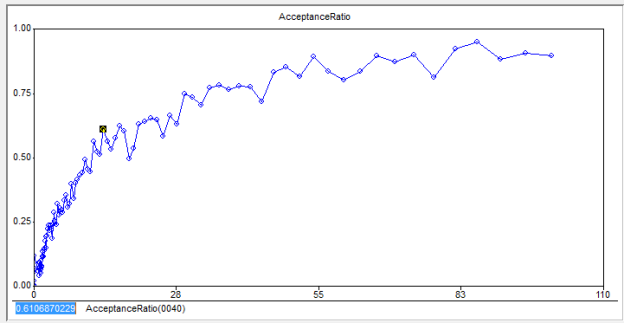
$$X_{ht} = \{0,1\} \qquad \forall h, t$$

$$C_{min,d,t} \geq 0 \qquad \forall d, t$$

Appendix F. Simulated annealing cooling parameters

Parameter	Value
Cooling Parameter	0.975
Start Temperature	1.5
End Temperature	0.01
MarkovChainLenght	200

With these parameters, the following algorithm cooling scheme was obtained.



Appendix G. Example of an allotment plan

Example of an allotment plan for policy 3 of forming specialized teams.

Profit centre	RVE 3	RVE 3	RVE 4	RVE 4	RVE 5	RVE 5
Assigned to	inpatients	outpatients	inpatients	outpatients	inpatients	outpatients
Hemmink						1
Endeman					1	
Schulten						1
Hultink			1			
Schipper					1	
Lenferink			1			
Krabbe				1		
Fleerkotte			1			
Fleerkotte 2				1		
Vegt	1					
Aa	1					
Kahlman			1			
Stege		1				
Lohuis			1			
Oosterhoff			1			
Ebner	1					
Bijvank				1		
Donkersloot			1			
Engele					1	
Huttenhuis			1			
Olde Klieverik		1				
Walter					1	

Appendix H. List of interviewed personnel

Position	Name
Management	Carrol Terleth (medical director)
	Ronald Groen (head of service department)
	J. Jillings (project manager)
	P. Theeuwen (project manager)
	H. Franken (project manager)
Secretaries	S. Mekenkamp
	L. Perik
	N. Melenhorst
	J. Boerman
	M. Wolters
Project Manager	O. Roukens
Medical staff	E. Maas (physician)
	J. Nijlant (physican)
	A. de Kort (physician)
	D. Brouwer (head nurse)
	J. Oostendorp (physio therapist)
	A. Engele (ergo therapist)
	E. Donkersloot (ergo therapist)
	J. Rinket (career counselling)
	P. de Haan (ergo therapist)
Patient matters, complaint officer	N. Bongers
Planners	A. de Vries (head of department)
	R. Geerdink
	S. Peeters
	A. Mast
Controllers	M. Weegerink
	J. Cloostermans
ICT department	J. Tibben
	J. Nederhoff
Patients	All inpatients that attended the “klankboordgroep”

Appendix I. Legend of used shapes

Appendix J. Glossary English - Dutch

Roessingh Rehabilitation Clinic	Roessingh Revalidatie Centrum
The service department	Het service bedrijf
Inpatients	Klinische patienten
Outpatient	Poliklinische patienten
Inpatient department	De kliniek
Outpatient department	De polikliniek
Therapy Centre	Alle behandelfaciliteiten
Physicians	Revalidatie artsen
Nurses	Verpleging
Therapists	De behandelaars
The scheduling department	De afdeling planning
Block schedules	Structuuragenda's
Activity Therapy	Activiteitentherapeut
Career Counseling	Arbeidsrevalidatie
Movement Teaching	Bewegingsagoog
Dietetics	Dieethiek
Cognitive therapy	Cognitieve therapie
Ergo Therapy	Ergotherapeut
Physiotherapists	Fysiotherapeut
Speech Therapy	Logopedist
Social Workers	Maatschappelijk werker
Psychology	Psycholoog
Profit Centres	Resultaat Verantwoordelijke Eenheden, afgekort RVE's
Patient Progress Review	Patiënt Bespreking, wordt veel afgekort als "PB"

Weekly Meeting	Ochtend overleg met behandelteam
Spinal cord injury	Dwarlesie
Orthopaedics	Orthopedie
Stroke	CVA
Non congenital brain damage	Niet aangeboren hersenletsel
Neuromuscular disorders	Neuromusculaire aandoeningen
Parkinson's disease	De ziekte van Parkinson
Lungs and respiratory system	Longen en luchtwegen
Multiple Sclerosis	MS
Off times	Spertijden
Appointment Compliance	Het nakomen van afspraken
Allotment of therapists to specialized teams	Het toewijzen van therapeuten aan specialistische teams