MASTER THESIS INDUSTRIAL ENGINEERING AND MANAGEMENT
FACULTY OF BEHAVIOURAL, MANAGEMENT AND SOCIAL SCIENCES

A FORECASTING MODEL OF MULTIDISCIPLINARY REHABILITATION THERAPY DEMAND

A case study in the Sint Maartenskliniek

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MANAGEMENT SUMMARY

Introduction

Recently, initiatives have been started to improve the therapist capacity planning and the scheduling of patients at the rehabilitation department of the Sint Maartenskliniek with support of the Department of healthcare logistics. Management of the rehabilitation department has the impression that it is possible to align the therapist capacity with the demand for care in a better way, such that it is possible to decrease access times and to increase the efficiency of resource use. Another important aspect for the quality of care, is that patients receive the right number of therapy sessions at the right moment. To give the right number of therapy sessions to a patient, it is important that there is balance between the deployment of therapists and the demand for care. Therefore, the research objective of this research is the following:

The research objective is to design a prototype decision support model to support the staffing of therapists on a tactical level for the Spinal Injury Rehabilitation care unit of the SMK.

Problem description

During the context analysis we performed it became clear that therapist capacity is determined long before execution of the care process while it is not clear what the demand for care is for the coming period. As a result, it is difficult to balance the deployment of therapists with the demand for care. Currently, decisions about the deployment of therapists capacity are based on the preferences of therapists, since the demand for care is not known for the coming period. Therefore, we identify a shortage of insight in the demand for care for the coming period as the core problem in this research. Since care pathways are a guideline according to which patients are treated, we assume that the demand for care equals the need for treatment following from the care pathways. Figure 1 shows the inpatient demand for care and the available capacity of the physiotherapists for in- and outpatient care in hours per week at the Spinal Injury Rehabilitation care unit in 2015. Figure 1 shows that the fluctuations in the inpatient demand for care are currently not in synchronisation with the available therapist capacity for care.

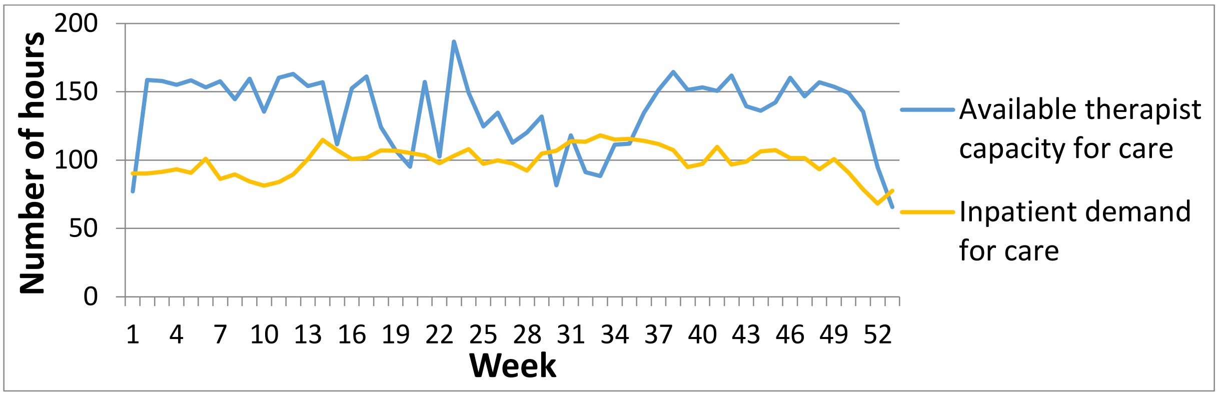

Figure 1; Balance between the inpatient demand for care and the therapist capacity for in- and outpatient care for the discipline Physiotherapy in 2015 at the Spinal Injury Rehabilitation care unit of the Sint Maartenskliniek

Solution approach

There are several possible methods to align the therapist capacity with the demand for care. However, before deciding about the number of therapists to deploy or the number of patients to admit, a demand forecast is needed. We developed a model to forecast the demand for care from inpatients based on the working of a forecasting model of Vanberkel et al. [1]. We forecast the demand for care based on the care pathways of patients currently in treatment and based on a forecast of the care pathways of yet to arrive patients. We first computed the probability that a patient with a certain care pathway occupies a bed and, subsequently, we computed the distribution of the workload following from the care pathways of the patients for all beds in a care unit. This results in a forecast of the probability distribution of the inpatient demand for care in hours per week per discipline. Figure 2 shows a result for the discipline Physiotherapy. As a result of the heavy case mix of current patients, the predicted workload distribution is in the first weeks higher than on average as Figure 2 shows.

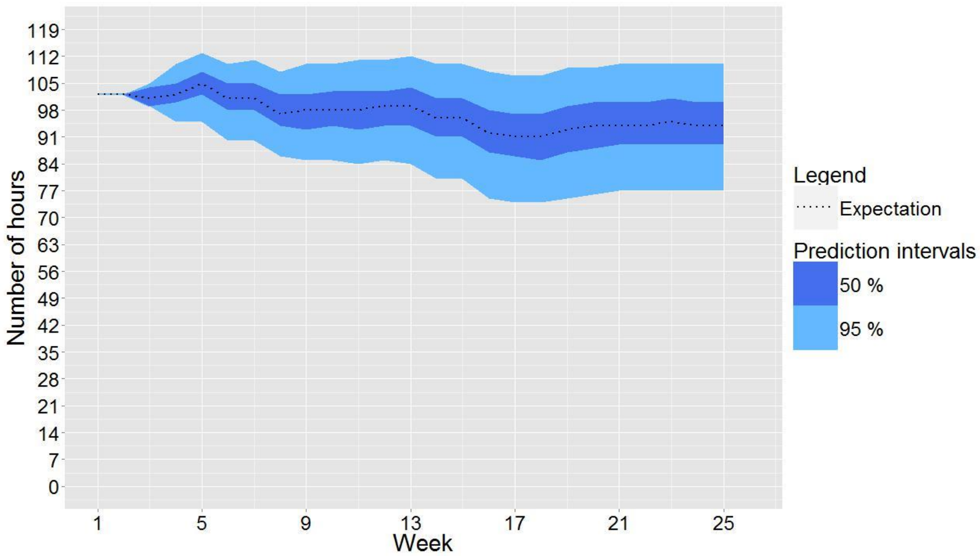

Figure 2; A forecast of the inpatient demand for care for the discipline Physiotherapy based on scenario 5

Conclusion: main findings

With the developed forecasting model it is possible to forecast for the different disciplines the probability distribution of the workload following from the inpatients that are treated in a care unit. When data registration is improved, a quantitative validation can be performed. Thereafter, it is possible to use the model in practice. One of the findings from the experiments performed with the model is that the more information is known, the more the probability distribution concentrates to specific values for the workload and the more certainty there is about the future workload. An increase in the number of known care pathways for which patients need treatment, an increase in the duration of care pathways, and a lower variation in workload between care pathways increase the information known about possible future workloads or decrease the uncertainty about possible future workloads. The forecast gives information about the expected workload in the coming period, and thus it can be used to support in making medium-term decisions about the admissions of (out)patients, the use of the annual hour system for deployment of therapist capacity and the division of therapist capacity over patient-related time and other activities in a certain period. It is important to take the forecast for all disciplines into account when deciding about the admissions of new patients and it is important to take the period for which the workload is lower into account when admitting new patients.

What's next?

The developed forecasting model forecasts the workload following from inpatients. Since therapists also treat outpatients, a direction for further research is to forecast the outpatient demand for care. The developed model forecasts demand on a weekly basis, but for operational scheduling of therapists a forecast on daily or even hourly basis can be useful. Therefore, forecasting demand in more detail is also a direction for further research. Next to gaining full insight in the demand for care, other directions for further research are the automated support of the scheduling of therapists [2], the use of admission planning to balance demand and the deployment of resource capacity and the development and implementation of scheduling algorithms to find appointment scheduling proposals that are efficient for both patients and therapists [2].

Care pathways and treatment plans are used to combine medical planning, resource capacity planning and financial planning. Registering the care pathways and the treatment plans of patients is essential for calculating the capacity required to serve the case mix in resource capacity planning. Therefore, the most important recommendation for the Spinal Injury Rehabilitation care unit in the Sint Maartenskliniek is to improve the registration of care pathways and treatment plans. When data registration is improved it is also possible to perform a quantitative validation of the forecasting model.

PREFACE

After a period of hard work, this report is the result of the graduation project I performed to complete the master Industrial Engineering and Management, at the University of Twente. After completing my bachelor in Biomedical Engineering, I chose to switch studies and I never regretted this choice. During my master I enjoyed studying in a way I never did during my bachelor studies.

I would like to thank my supervisors. It would not have been possible to reach this result without them. Erwin, thanks for guiding me throughout my graduation project and even more for showing the possibilities for Industrial Engineering and Management students in health care. Your lectures were exciting. Also, your ability of giving students the personal feedback they need to get the best out of them is admirable. Ingeborg, thank you for your supervision. The discussions we had about my project were valuable. Moreover, your positive feedback on this report was more thorough than I ever encountered during my studies. Thank you, Wieteke, for your supervision, for the discussions we had about my graduation project and for providing me with the information that was needed to fullfill my graduation assignment.

After learning the theoretical knowledge during the courses I followed in my master, it was an interesting challenge to combine the learned knowledge with practice. I cannot think of any better environment to do this than the department of healthcare logistics in the Sint Maartenskliniek. It was interesting to get an impression of the development of health care optimisation techniques and the steps that are involved in the implementation of these techniques. Moreover, the knowledge and experience at the department of healthcare logistics were helpful for me. Rob, Dianne, Nikky, Annemarie, Bregje and Anne, thank you for your help, feedback and inspiration, and thank you for the times you brought a smile on my face. Further, I would like to thank Ted, Brigitte, Rik and everyone else who was somehow involved in my project and provided me with feedback, information or a smile on my face.

Heit and mama, thank you for supporting me during my studies and thank you for supporting me without any hesitation in making the decisions of which I thought that they were the right decisions for me. Finally, I would like to thank my sister Lian. Thank you for listening to all my probably not very interesting stories about my graduation assignment and thank you for cheering me up in the tougher parts of it. You owe me one.

August 2016, Nijmegen

CONTENTS

1 INTRODUCTION

This report is a description of research on aligning therapist deployment with the demand for care at the Spinal Injury Rehabilitation (SIR) care unit of the Sint Maartenskliniek (SMK) in Nijmegen. This introductory chapter consists of a broad introduction into the research and the associated report. Paragraph 1.1 describes the context of the research. Paragraph 1.2 describes the motivation for this research and the associated core problem that this research tackles. Paragraph 1.3 describes the research objective and paragraph 1.4 describes the research questions with an outline of the report.

1.1 CONTEXT

Demand for rehabilitation care is increasing. Also, there are possibilities to deliver more complex care because of technological innovations and increasing medical knowledge. Because of this, health care costs are rising and the health care market changes. Competition between different care providers grows, the expectations of patients become higher and there are changes in the case mix of patients. The SMK faces these challenges and therefore strives to obtain efficient care processes. Because of this, the SMK has founded a department of healthcare logistics to support in solving logistic problems. Recently, initiatives have been started to improve the therapist capacity planning and the scheduling of patients in the rehabilitation department with support of the department of healthcare logistics. The SMK consists of three main care departments. This research takes place at one of these departments, namely the rehabilitation department. The rehabilitation department consists of 4 different care units as Figure 3 shows. This research focuses on the SIR care unit that treats in- and outpatients. In the calendar years 2013 until 2015 approximately 115 inpatients per year are treated.

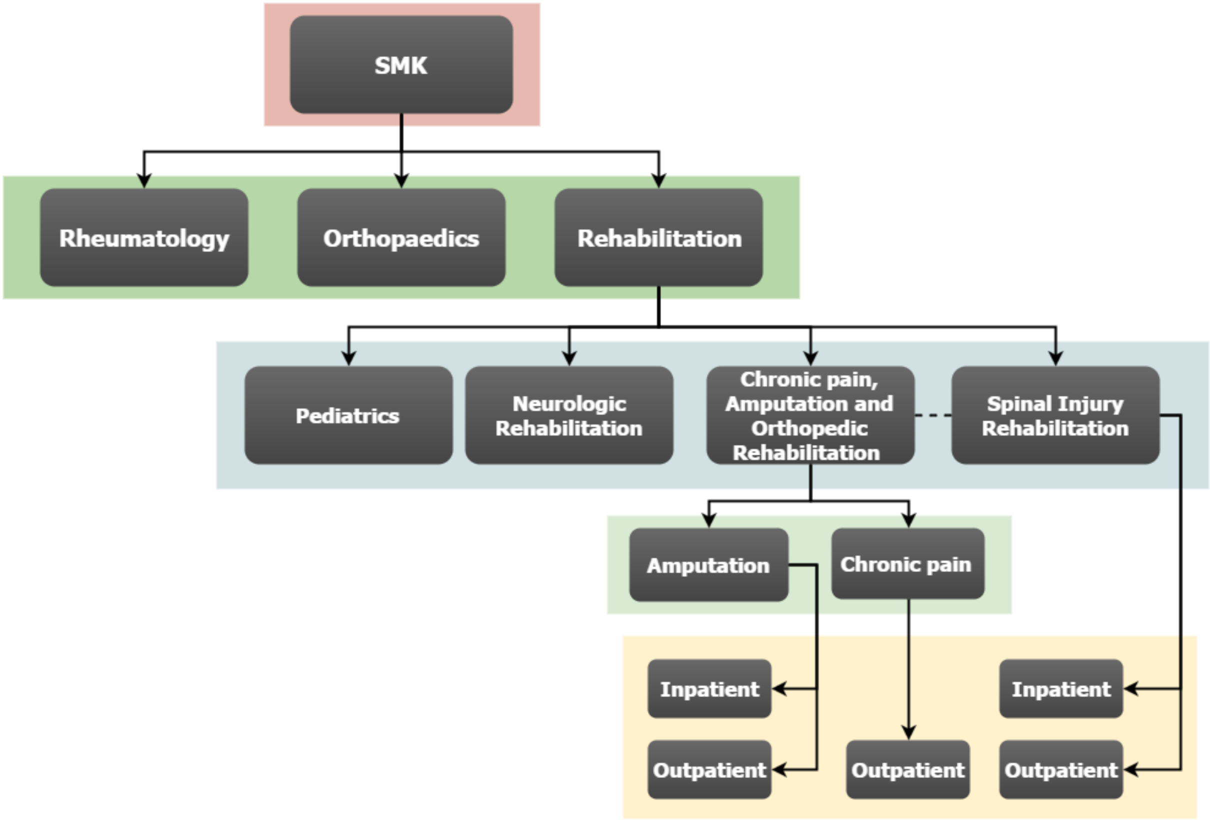

Figure 3; Rehabilitation care units in the SMK

1.2 PROBLEM DESCRIPTION

1.2.1 MOTIVATION FOR RESEARCH

Currently, access times for patients do not always meet the internal and external norms for the SIR care unit [3]. Management of the rehabilitation department has the impression that it is possible to align the capacity of therapists with the required therapist capacity in a better way, such that it is possible to decrease access times and to increase the efficiency of resource use. Another important aspect for the quality of care is that patients receive the right number of therapy sessions at the right moment. To give the right number of therapy sessions to a patient, it is important that there is a balance between deployment of therapists and the demand for care by patients. Scheduling all patients according to their care pathways becomes difficult when the demand for care is higher than the availability of therapists, whereas it is difficult to maintain high utilisation of therapists when demand for care is low compared with the availability of therapists. Imbalance between the therapist capacity and the demand for care complicates the patient scheduling. The balance between deployment of therapists and demand for care has, next to influence on the quality of care, also influence on the work satisfaction of therapists. As a result of differences between demand and available capacity, periods with high workloads for therapists alternate with calm periods.

1.2.2 PROBLEM DESCRIPTION

This research focuses on resource capacity planning. The goal of resource capacity planning is to align the available capacity of resources with the demand for care. Specifically, this research focuses on aligning deployment of therapists with the demand for care on a tactical level. Aligning deployment of therapists with the demand for care is a complex task in the SMK. One reasons for this complexity is that there is a gap between the period for which it is possible to forecast demand and the period for which therapist rosters are determined. Currently, therapist rosters are fixed and thus the available therapist capacity is fixed a long time before execution of treatment. Management should communicate therapist rosters to therapists several weeks in advance (28 days according to collective labour agreements [4]). The demand for care is known short before the execution of treatment. Aligning deployment of therapists with the demand for care is difficult in this way.

It is possible to align deployment of therapists with varying demand when demand for care is known at the moment of determining therapist rosters. The demand for care, which is the amount of therapist capacity required per discipline, fluctuates, because the number of patients in treatment varies over time. Besides, the demand for therapy varies between therapists from the different disciplines because of the specific care pathways of the patients. Also, the availability of therapists of a specific discipline varies over time, because of for instance holidays or sickness. Challenges in aligning the demand for care with the resource capacity lie in forecasting demand for the next period, which is required to determine the required therapist capacity.

The core problems of this research are the difference between the length of the period for which there is insight in the demand for care and the length of the period for which the therapist capacity is determined, and the resulting imbalance between the need for therapists based on the demand for care and the deployment of therapist capacity.

1.3 RESEARCH OBJECTIVE AND SCOPE

The strategic direction of the SMK focuses on five overall objectives, namely safe and efficient health care, performance and growth, patient satisfaction, staff satisfaction, and guiding on quality, service and flow. The research objective of this research relates to the overall SMK objectives of improving patient and staff satisfaction and improving the efficiency of health care.

The research objective is to design a prototype decision support model to support the staffing of therapists on a tactical level for the Spinal Injury Rehabilitation care unit of the SMK.

The objective to develop a model for the tactical level implies here that the objective of the model is not to support the making of therapist rosters for specific therapists on a short-term, but rather supporting the number of therapists to deploy on a somewhat longer term. Moreover, it aims at combining information of patients under treatment with forecasts of yet to arrive patients. For a broader description of the different hierarchical levels in health care planning and control we refer to Hans et al. [5].

1.4 RESEARCH QUESTIONS AND OUTLINE OF REPORT

We formulate the following research questions based on the research objective:

- *How is the care process and the planning and control process for therapist resource allocation currently organised and what are the main bottlenecks in these processes?*

Chapter 2 describes the current resource capacity scheduling process and the appointment scheduling process in the form of a context analysis.

- *What are the key performance measures for therapist resource allocation and what is the current performance on these measures at the SIR care unit of the SMK?*

Chapter 3 describes the zero-measurement of the therapist resource allocation and the main problems faced during the measurements.

- *What models are there in the literature that support in therapist resource allocation on a tactical level?*

Chapter 4 gives an outline of the literature on resource capacity planning in rehabilitation centres to show what is already investigated in the field of research.

- *What is the design of a model to support resource allocation of therapists applicable to the SIR care unit in the SMK?*

Chapter 5 describes a forecasting model of multidisciplinary rehabilitation therapy demand for inpatients and the assumptions behind the model.

- *What are the potential benefits of using the designed model for resource allocation compared with the current situation?*

Chapter 6 describes verification and validation of the forecasting model and the experimentation performed with the model. It describes the different scenarios analysed and the results of these scenarios. Chapter 7 contains a conclusion and discussion of the research and it describes recommendations for further research and recommendations for the SMK.

2 CONTEXT ANALYSIS

This chapter describes the context of this research. Paragraph 2.1 describes the care process for the different patient groups and the admission policy. Paragraph 2.2 describes the medical planning at the SIR care unit in the SMK. Paragraph 2.3 describes existing resource capacity planning and control decisions at the SIR care unit in the SMK. Paragraph 2.4 gives a conclusion of this chapter and describes the main bottlenecks.

2.1 PROCESS DESCRIPTION

2.1.1 CARE PROCESS

This paragraph describes the care process for the different patient groups of the SIR care unit. A division is made into inpatients and outpatients. Figure 4 shows the diagnosis groups of the SIR care unit. For the different diagnosis groups there consist care pathways containing guidelines for treatment. Part of the inpatients continues after inpatient rehabilitation with outpatient treatment. Inpatients have a multidisciplinary treatment team consisting of the rehabilitation specialist, ward physicians, nurse practitioners and nurses. Patients are treated by allied health professionals from multiple disciplines. Namely, physiotherapists, occupational therapists, movement therapist, social workers, psychologists and sometimes by a sexologist, dietician or a speech therapist [3]. This research focuses on this paramedical personnel. In the rest of this report the term therapists is used as collective term for the different types of allied health professionals. During their treatment, patients receive individual treatment and several types of group therapy. During group therapy one or more therapists treat multiple patients, whereas during individual treatment one or more therapists treat one patient.

Figure 5 shows the care process for inpatients starting with an incoming order and ending with the end of the care process for a patient. First, the rehabilitation specialist decides based on the referral whether the SMK admits a patient. The SMK admits most inpatients with a fresh spinal injury within a few days, because of an admission policy. This policy states that referring hospitals can refer patients with a fresh spinal injury to another rehabilitation clinic when a clinic does not admit patients within five working days. Most patients with a fresh spinal injury start with a diagnostic phase for two weeks. After the diagnostics phase, patients start with treatment based on a treatment plan. There are separate care pathways for the diagnosis phase and the treatment phase. Once every six weeks, patients have a meeting with their multidisciplinary treatment team to discuss progression of their treatment. During the first meeting the team determines the duration of treatment. Two weeks before the discharge date the multidisciplinary treatment team decides whether it extends or finishes the inpatient treatment. When the patient is discharged, the patient continues with outpatient treatment or stops with treatment in the SMK. Next to the multidisciplinary treatment team meetings, there is a weekly meeting without patients to discuss possible mutations in the treatment plans of all inpatients. Inpatients receive individual treatment during their diagnostic phase and start with group therapy in their treatment phase.

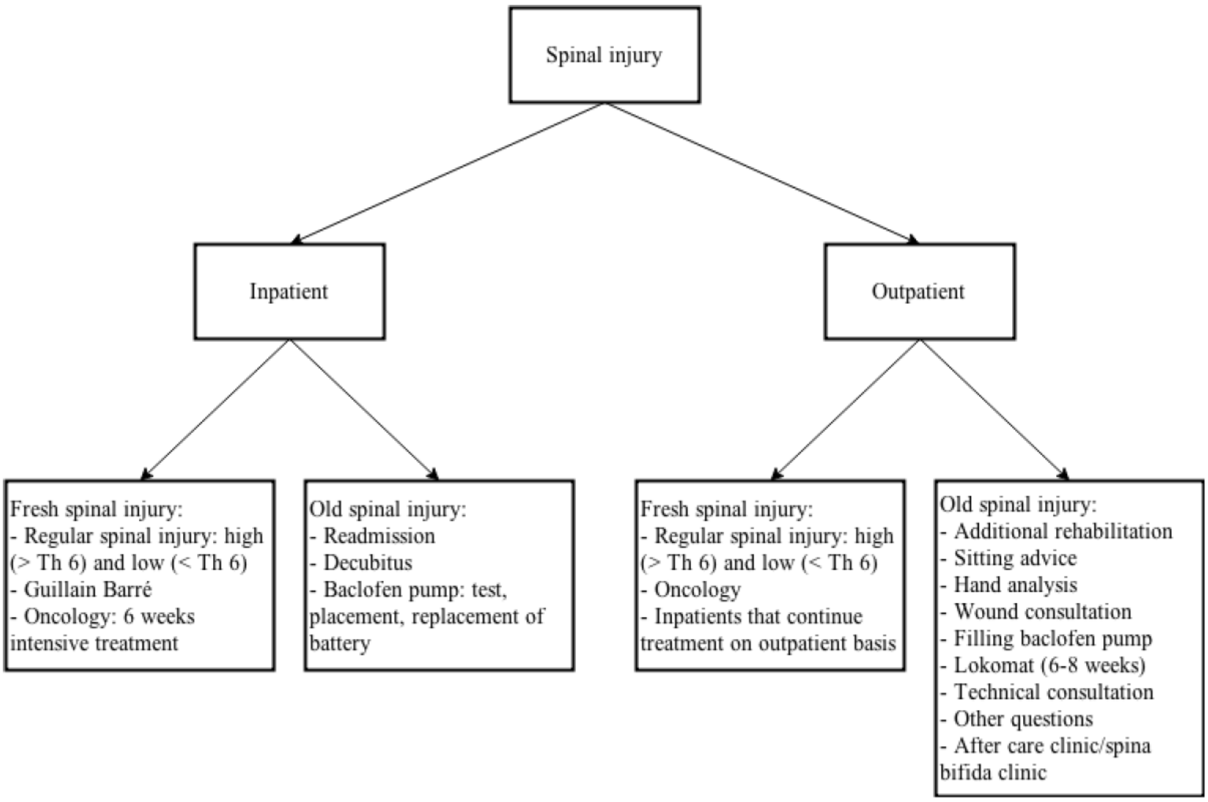

Figure 4; Diagnosis groups of SIR care unit [3]

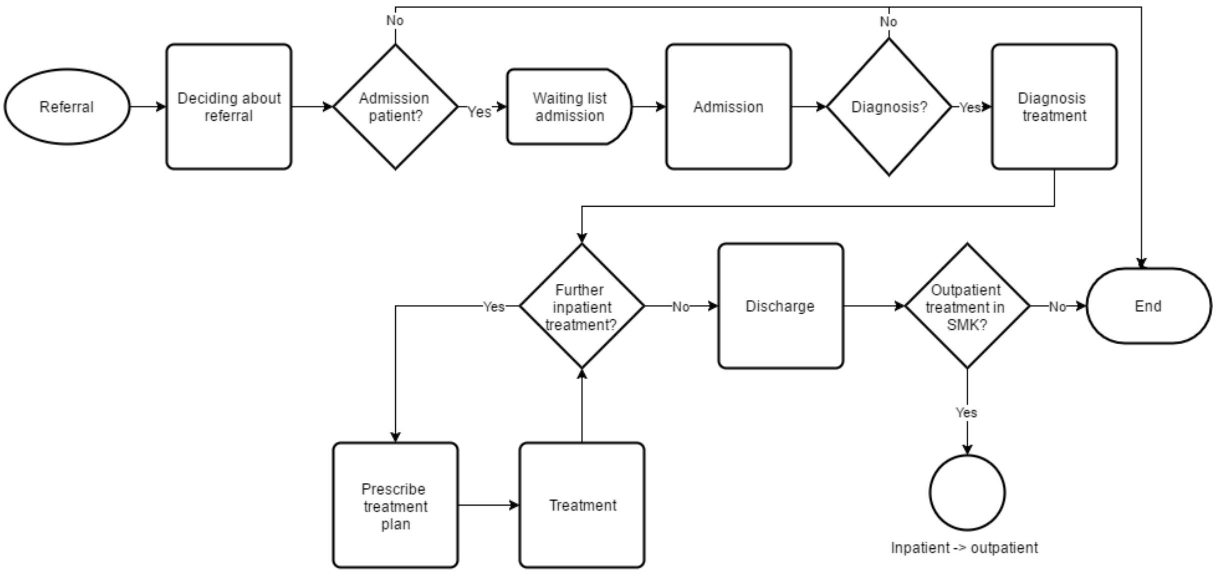

Figure 5; Care process of inpatients in the SIR care unit of the SMK

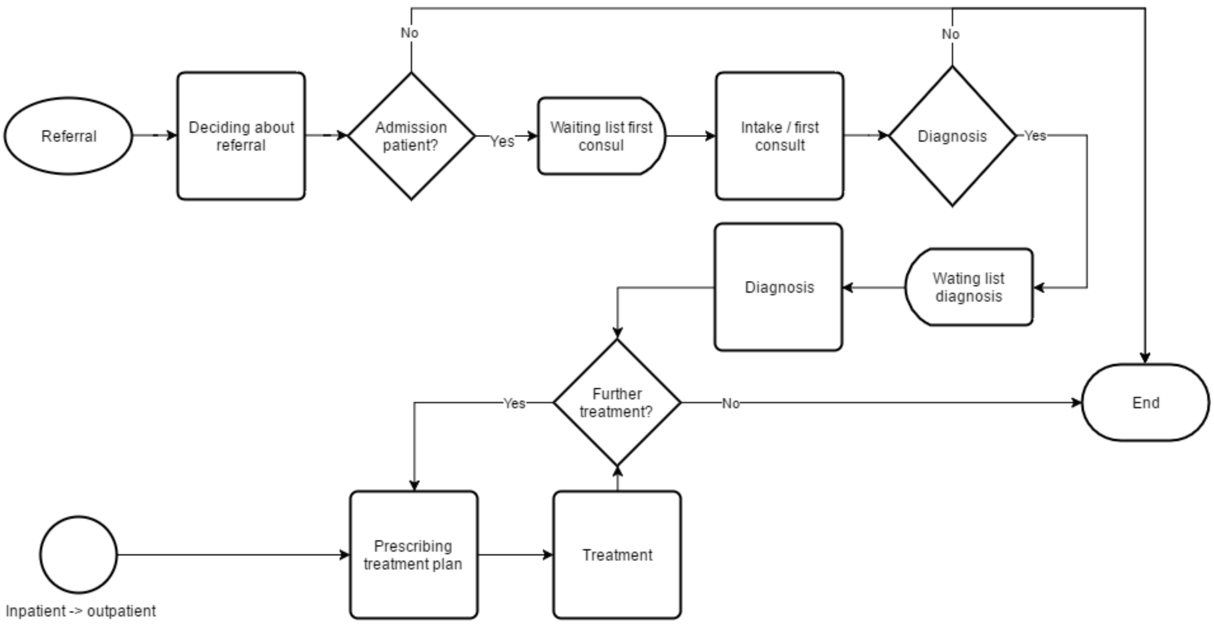

Figure 6; Care process of outpatients in the SIR care unit of the SMK

Figure 6 shows the care process for outpatients. Outpatients have a first consultation with the rehabilitation specialist before diagnostics or treatment starts. The planner plans the first consultation with the rehabilitation specialist based on a referral. Based on this consultation and the referral, the rehabilitation specialist decides whether the patient is eligible for treatment and according to which care pathway a patient is treated. When a patient receives treatment in the SMK, it places the patient on a waiting lists for diagnostics and treatment. Treatment takes place in the same way as for inpatients, namely the rehabilitation specialist prescribes a treatment plan and patients are treated according to this treatment plan. Every six weeks the treatment team decides whether the treatment stops or continues. The multidisciplinary treatment team reconsiders the treatment plan if the treatment continues. Inpatients who continue with outpatient treatment do not need any diagnostics. These patients start with outpatient treatment based on a treatment plan without any delay, where other new outpatients are placed on a waiting list first. Reasons to reject patients could have medical grounds or organisational reasons such as the travelling distance for outpatients, availability of beds for inpatients or availability in time of patients for treatment.

2.1.2 ADMISSION PLANNING

There is a weekly meeting to discuss admissions of new patients. The rehabilitation specialists discuss with physician assistants, the head of the care unit, a member of the nursing staff and the scheduler for the care unit which inpatients are admitted in the coming weeks. The rehabilitation specialists rank the patients based on medical urgency. If the medical urgency is the same for patients on the waiting list, then the decision on which patient is admitted first is based on the length of the waiting time. Other aspects considered in deciding to admit new patients are the availability of patients and the availability of beds. During the meeting the team does not consider the availability of therapists when deciding about the admissions of new inpatients. For most (in)patients it is important that they are admitted as soon as possible because of their health status, thus the largest part of the inpatients are not admitted on a moment that there are enough therapists available for their treatment. These patients are admitted directly after the moment a bed comes or is available. The SMK admits new outpatients when there is room to treat additional patients in the rosters of therapists after scheduling all appointments for inpatients. Outpatients are prioritised based on urgency, waiting time and the complexity and size of their treatment plan.

2.2 MEDICAL PLANNING

The rehabilitation department uses different terms regarding the planning and execution of treatment. These different terms interfere with the different hierarchical levels in medical planning that Hans et al. use in their theoretical framework for planning and control [5]. Figure 7 shows a schematic representation of the terms and the hierarchical relation between these terms. The rest of the paragraph describes the different terms shortly. Buil gives an extensive description of the terms [6].

Care pathway/ Treatment protocol

The care pathways are a guideline for treatment of patients from a certain care profile. The care profile is a division into a certain patient group within a care unit. Table 1 gives an overview of the different care profiles in the SIR care unit. The care pathways that the SIR care unit uses contain a guideline for the duration of treatment. Besides this, the pathways are used as guideline for the frequency and duration of treatments patients should receive. The care pathway divides treatment time in direct individual treatment time, treatment time for treatment in groups and indirect treatment time. The care pathway describes treatments per discipline. There are different care pathways for the different treatment phases of patients. There are pathways for diagnosis, pathways for inpatient treatment and pathways for outpatient treatment. Appendix B and Appendix C give examples of currently used care pathways for diagnosis and treatment. Care pathways exist to combine medical planning, resource capacity planning and financial planning on the long term. It is important that patients receive the right amount of care, but care given to patients should also be cost-efficient. Besides, care pathways are guidelines for calculating the capacity required to serve the case mix in resource capacity planning.

Treatment plan

Where the care pathway is a description of the treatments for all patients of a certain care profile, the treatment plan is a description of treatment for an individual patient. Care pathways are the basis for treatment plans. A treatment plan describes overall objectives for a patient and goals for the coming period and the treatment required to reach this. Care pathways do not adapt to the individual desires of a patient, where it is possible to adapt a treatment plan to the individual desires of a patient. The initial treatment plan is the first version of the treatment plan, and after that it is possible to use several mutated treatment plans if the progress of a patient requires this. Therapists and rehabilitation specialists communicate mutations in the treatment plans via several ways. Therapists communicate mutations by mail, during meetings or in the hallway. Rehabilitation specialists communicate mutations also using the hospital information system (HIS). The rehabilitation specialist register the initial treatment plan including the care pathway a patient follows in the HIS using a request form. Appendix D gives an example of the registration method of care pathways and treatment plans in the HIS.

Treatment schedule

The treatment schedule contains information about the treatment appointments for a patient. Based on the treatment plan the schedulers schedule appointments for patients. The schedule contains information about the timing of treatment. The schedule defines which patients sees which therapist on what moment. The planner makes every week a final version of the treatment schedule for the next week. The SIR care unit uses the treatment schedule on an operational level to plan execution of the care process.

Realised treatment schedule

The realised treatment schedule contains all appointments, from the treatment schedule, that are realised. As a result of unexpected events, such as for instance therapist absenteeism, part of the appointments from the treatment schedule may not take place. These appointments are no part of the realised treatment schedule.

Table 1; Overview of the different care pathways used in the SIR care unit

	Care pathway
Outpatient care pathways	Sitting advice
	Baclofen pump outpatient
	Arm/hand function screening
	Standard outpatient
Other / inpatient and outpatient	Sports desk
	Lokomat
	'Other'
	After care
	Not found
Inpatient care pathways	Spinal injury other
	Baclofen pump
	Bolus baclofen
	Decubitus
	Spinal injury T7 and lower
	Spinal injury T6 and higher
	Guillain Barré
	Oncology

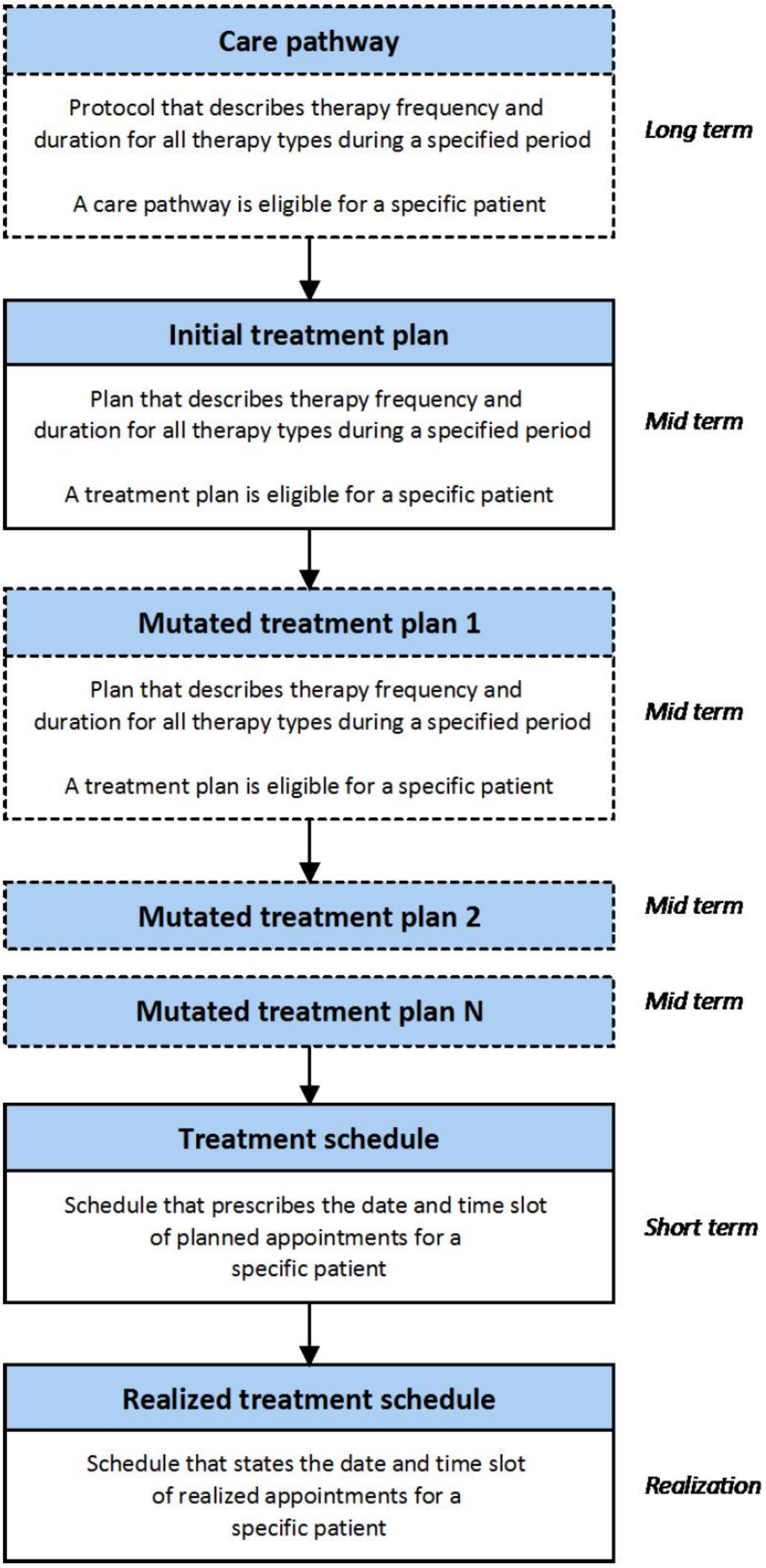

Figure 7; Schematic representation of interlinked terms used in rehabilitation department

2.3 RESOURCE CAPACITY PLANNING AND CONTROL

Paragraph 2.3 describes existing resource capacity planning and control decisions in the SIR care unit of the SMK. A division in subparagraphs is made based on the different hierarchical levels that Hans et al. use in their theoretical framework for healthcare planning and control [5]. In Figure 8, an example application of the framework is shown for a general hospital.

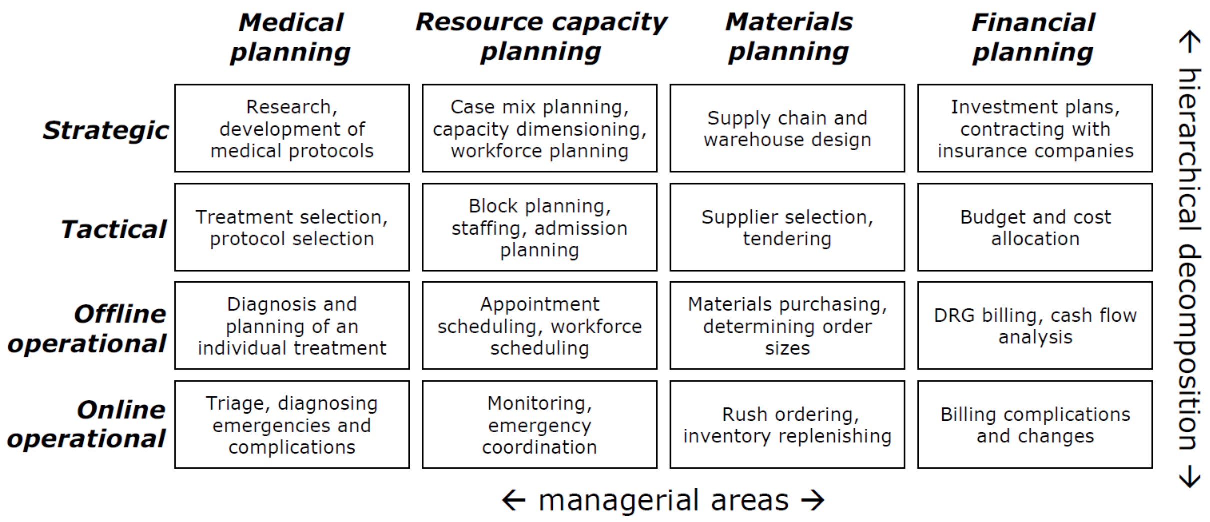

Figure 8; Example application of the framework for health care planning and control to a general hospital[5]

2.3.1 STRATEGIC RESOURCE CAPACITY PLANNING PROCESS

The head of the care unit estimates the required number of therapists for the next year based on the number of treated patients in previous years and a possibly perceived capacity surplus or shortage. The head of the care unit estimates how many patients the care unit serves in the next year per Diagnosis Treatment Combination (DTC, in Dutch DBC). A DTC is defined as the whole of activities and services of hospital and medical specialists stemming from the demand for care for which the patient consults the specialist. It covers the complete process of care: from the first consultation of the medical specialist until the completion of treatment[7]. For every DTC there are several categories with varying intensities. The head of the care unit estimates the number of patients it treats for every category and uses this to calculate the required workforce capacity. Care pathways give information on the required number of therapy hours per discipline in more detail than the DTCs, for example information about the timing of treatments. On this moment, the head of the care unit uses DTCs to calculate how many therapist capacity is required.

2.3.2 TACTICAL RESOURCE CAPACITY PLANNING PROCESS

On the tactical resource capacity planning level, the head of the care unit and the team coordinator base most of the therapist planning decisions on the preferences of therapists. The head of the care unit and the team coordinator do not consider the demand for care in detail. The head of the care unit uses the assumption that demand is reasonably homogenous divided over the year. Team coordinators support the head of the care unit operationally and executes part of the staffing policies. Two times a year, therapists consult their vacation leave planning with the head of the care unit or the team coordinator. Before the first of September, therapists discuss their vacation leave planning from the first of November until the first of June. Before the first of December, therapists discuss their vacation leave planning from the first of June until the first of November. Currently, during the summer and Christmas holidays the available capacity needs to be at least 60 per cent of the normal available capacity for a specific day. During other school holidays the availability has to be at least 70 per cent. During non-holiday periods the availability of therapists has to be at least 80 per cent. Possible last minute changes, as a result of for instance sickness, are not considered when determining whether the minimal availabilities are met. Team coordinators compare the availability of therapists with a percentage of the available capacity for a specific day. This means that if the normal availability of therapists on Fridays is lower than the availability on other days of the week, then the requirements are also lower for Fridays, independent of the demand for care on that day.

There are several flexible capacity instruments to align deployment of therapists with the required therapist capacity. The annual hour system is an instrument that can be used to adapt the working pattern of therapists to their private lives and to align the working patterns with the required capacity. The annual hour system regulates the work and rest pattern for individual employees. The head of the care unit decides with the employee what his working pattern is. The annual hour system regulates that an employee with an 36 hour contract can work 40 hours per week during five weeks, 32 hours per week during five weeks and the rest of the weeks 36 hours. The collective agreement states that the employer communicates the work pattern at least 28 days in advance to an employee. Currently, the SIR care unit does not use the annual hour system actively. A temporary staff increase is another temporary capacity change to align the available capacity and demand. There is no floating pool of therapists currently and therefore, it is not possible to use this as a temporary staff increases on a tactical level.

2.3.3 OPERATIONAL RESOURCE CAPACITY PLANNING PROCESS

The first step in operational planning, making the rosters of therapists, is currently performed on the long term. The head of the department determines the working times of therapists with the therapists at the beginning of their contract. Currently, changes in the long-term working patterns of therapists are rare. If there are changes in the working patterns, then therapists induce changes. Personal circumstances are the reason for changes in the working patterns of therapists and the head of department does not change the working patterns because of variation in demand currently. Therapists can ask permission from the head of the department or from their team coordinator to change their availability temporarily on the short term. After receiving permission, the therapists are responsible for informing the schedulers about changes in their availability. Knowing the availability of therapists is inevitable for schedulers, however because of delays in communications schedulers receive information about the final working times of therapists sometimes in the last week before treatment. The team coordinator allows changes when the total availability of therapists for that specific day is at least equal to the minimal requirements that the team coordinator also uses for the vacation leave planning. The minimal requirement is 80 per cent of available capacity according to the fixed rosters of therapists on that day. During the summer and Christmas holidays the available capacity needs to be at least 60 per cent of the normal available capacity. During other school holidays the availability has to be at least 70 per cent. Currently, the team coordinator does not consider demand for care when deciding about the short-term changes in therapists availability. The head of the department rarely uses temporary capacity changes on operational level, such as using overtime.

2.3.4 PATIENT SCHEDULING PROCESS

Schedulers schedule appointments for all patients who are in treatment, based on the treatment plans of patients. Schedulers use the HIS to register all appointments. Schedulers schedule appointments in a repetitive manner. Schedulers try to schedule patients every week on the same time with the same therapists by scheduling appointments for an infinite horizon. However, treatment schedules change frequently, because of treatment plans mutations and because of changes in therapists or patients availability. The schedulers use most of their time to make the final schedules for the next week, because the availability for therapists and the treatments required by patients in the next week are known. The schedulers finish the schedules every Thursday for the next week, in order to inform outpatients about their appointments in time. Schedulers have meetings with discipline planners on Thursday to solve conflicts for the next week. The discipline planner is a therapist who has an extra task besides his normal tasks. If there is a difference between the required therapist capacity and availability of therapists for the next week, then the discipline planner decides with the planner which patients receive more or less therapy. Discipline planners have more knowledge about the patients and the therapy they require than the schedulers. Therefore, they support schedulers in deciding about changes in the number of treatments for patients. These discipline planners exist for the larger disciplines, namely AT, FT and ET.

2.4 CONCLUSIONS

Capacity is fixed long before execution of the care process while it is not clear what the demand for care is for the coming period. As a result, it is difficult to balance deployment of therapists with the demand for care. There are many last-minute changes in the rosters of therapists, which could attenuate the incentive for appointment schedulers to plan appointments on a long time horizon. Knowing the available therapist capacity for a longer time horizon is useful for deciding about admissions of new patients to the hospital. The current registration method of treatment plans does not enable automated analysis of demand for care on a patient specific level. Therapists communicate information about treatment plans by mail, using oral communication or in text fields via a registration form in the HIS. As a result, it is difficult to estimate demand for the coming period. Also, it is not possible to compare the congruence of treatment plans of individual patients with their realised care. Because of the registration method of treatment plans, it is not possible to compare the average treatment plan for all patients with a certain care profile with the corresponding existing care pathway. Currently, decisions about the deployment of therapists capacity are based on the preferences of therapists, since demand is not known for the coming period. As a result of the shortage of insight in the demand for care in the coming period, it is difficult to balance deployment of therapists with the demand for care, which is needed to provide the patients with the treatments that they need and to use the available resources efficient. Therefore, we identified a shortage of insight in the demand for care for the coming period as the main bottleneck at the SIR care unit in the SMK. The next chapter gives a quantitative description of the current performance regarding the balance between deployment of therapists and demand for care.

3 PERFORMANCE ANALYSIS OF CURRENT SITUATION

The research objective of this research is to support the staffing of therapists on a tactical level in the Spinal Injury Rehabilitation care unit of the SMK. It is possible to determine the current staffing performance by comparing demand for care with the availability of therapists for care. Currently, schedulers and the management perceive that demand for care is not always in balance with the capacity of therapists for care. However, quantitative decision making requires measurable performance indicators by which the quality of health care delivery can be expressed [8]. This chapter describes how to measure the balance between demand for care and the capacity of therapists for care, which assumptions we made to do this and what problems we encountered in performing this measurement. Paragraph 3.1 describes the definitions for measuring performance. Paragraph 3.2 describes the measurement of the therapist capacity available for care. Paragraph 3.3 describes the results of the measurement of the demand for care. Paragraph 3.4 describes the measurements of balance between therapist capacity and demand for care and other measures. Paragraph 3.5 describes recommendations and paragraph 3.6 describes the conclusions of the chapter that follow from the measurements and the effects on the rest of the research.

3.1 DEFINITIONS OF PERFORMANCE MEASURES

To measure performance, it is essential to first define performance. After defining performance it is possible to measure performance using key performance indicators (KPIs). Therefore, KPIs have to be defined and it has to be decided how to measure these KPIs. The SMK uses three main categories when measuring performance, namely quality of care, quality of work and quality of business. In Appendix F, an overview is given of the main goals for the different categories in the SIR care unit. The most important performance measures for this research are identified together with the management of the SIR care unit based on these goals. We use the definitions that are used at another department of the SMK. This paragraph describes the definitions to measure the balance between demand for care and the therapist capacity for care. Therefore, we first define demand for care and the availability of therapists for care.

3.1.1 DEFINITION AVAILABILITY OF THERAPISTS FOR CARE

There are different definitions of the available capacity of therapists. Figure 9 shows a division of the available capacity in different terms. Since the objective of the zero measurement is to compare supply and demand we use the availability of therapists for care as a definition for supply. The availability of therapists capacity for care depends on the gross availability of therapists. We define gross availability as the total available capacity in number of hours of therapists based on their contracts. Since therapists are part of the gross availability not available for their function as therapist, the net availability per year is in the SMK defined by subtracting leave, absenteeism, training and secondment from the gross availability. There is also a difference between the net availability of therapists and the availability of therapists for care. Part of their presence therapists use for projects, mentoring, pausing, meetings or administration. These activities are combined in the VWS time (Dutch: voorwaarden-scheppende tijd) and is in contrast with the availability of therapists for care not directly patient-related time. The availability of therapists for care is in the SMK defined by subtracting the VWS time from the net availability of therapists. Figure 9 shows an overview of the different terms.

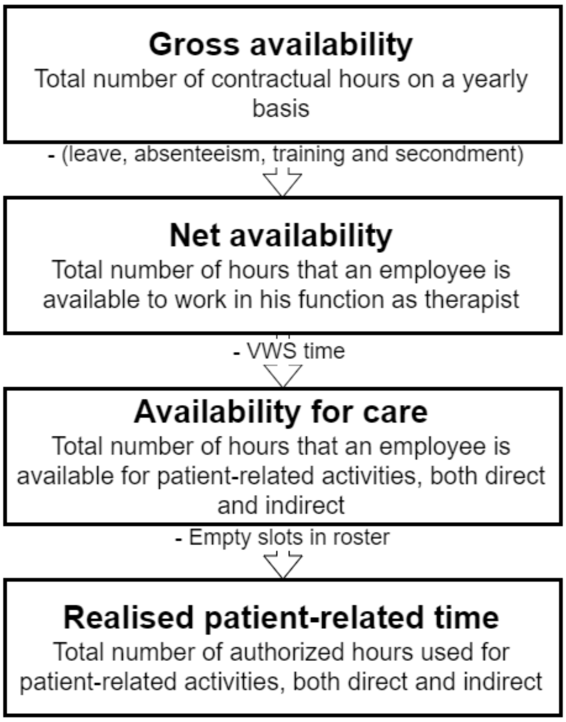

Figure 9; Definitions available capacity of therapists

3.1.2 DEFINITION OF THE DEMAND FOR CARE

There are several possible definitions of the demand for care. Figure 10 gives an overview of possible methods to define the demand for care. Since treatment plans contain patient specific information about their need for therapy we define the demand for care as the total number of therapists hours that are needed to provide the direct and indirect time according to the treatment plans of all patients who are in treatment in a certain week. We define the demand for care from a therapist perspective as Example 3.1 shows.

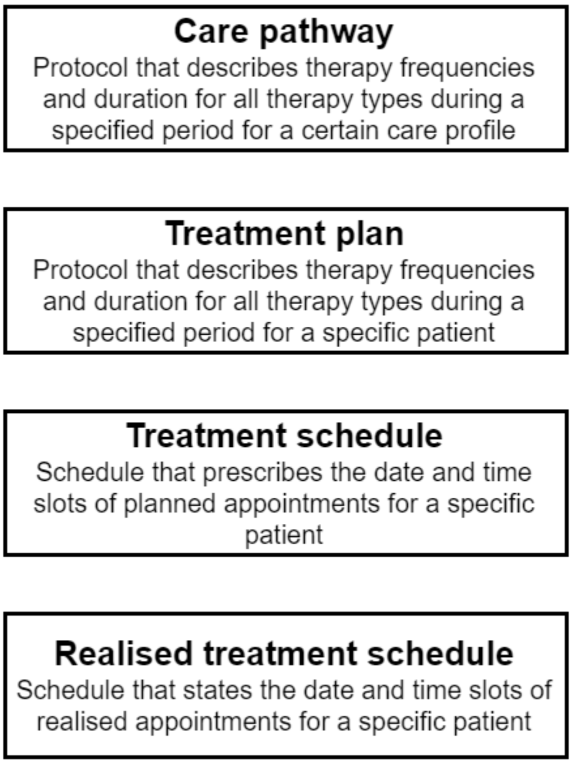

Figure 10; Definitions for the demand for care

Example 3.1: The demand for care

When 2 therapists treat 6 patient for 0.5 hours, then the treatment plan of every patient contains 0.5 hour treatment time in a group. The total number of hours following from the treatment plans for these 6 patients is equal to 3 hours. However, the number of therapist hours needed in this example is equal to 1 hour, namely the number of hours following from the treatment plans multiplied with the ratio between therapists and patients in group treatment. Since we define the demand for care as the number of therapist hours needed the demand for care is equal to 1 hour in this example. When 2 therapists treat 1 patient at the same time for 0.5 hours, then the treatment plan of this patient contains 1 hour individual treatment time. The demand for care is equal to 1 hour in this case.

3.1.3 DEFINITION OF BALANCE AND OTHER MEASURES

Balance is the situation where the demand for care in a certain week is equal to the therapist capacity for care in that week. Since it is difficult to reach a situation where the therapist capacity for care is exactly equal to the demand for care we define the following three situations:

a) Understaffed: a week is understaffed when with 10 percent more availability of therapists for care the demand for care still would be higher than the availability of therapists for care

b) Over manned: a week is over manned when with 10 percent less availability of therapists for care the demand for care still would be lower than the availability of therapists for care

c) Balance: the availability of therapists for care and the demand for care are in balance if the cases understaffed and over manned do not apply.

Other measures that give information about the quality of resource capacity planning and control are congruence, access time and productivity. Buil defines and measures congruence in earlier research at the SIR care unit of the SMK [6]. Buil defines congruence as the extent to which plans or protocols are in accordance with realised care. It is important to remark that incongruence not necessarily a bad thing is. If realised care is incongruent with the care pathway because of specific patient characteristics, then this may be beneficial for the patient and the SMK [6]. Trentelman defines and measures access time in earlier research at the SIR care unit of the SMK [3]. Trentelman defines access time for outpatients, as the time in weeks between the moment the rehabilitation specialist decides that the patient is eligible for treatment and writes an order for the treatment plan, until the first therapy session [3]. Trentelman defines access times for inpatients as the time in weeks between the order for admission and the actual admission [3]. The definition that the SMK uses for productivity is:

$$\frac{realised\ patient\ related\ time}{net\ availability} * 100\ \%.$$

Figure 11 gives an overview of the different measures.

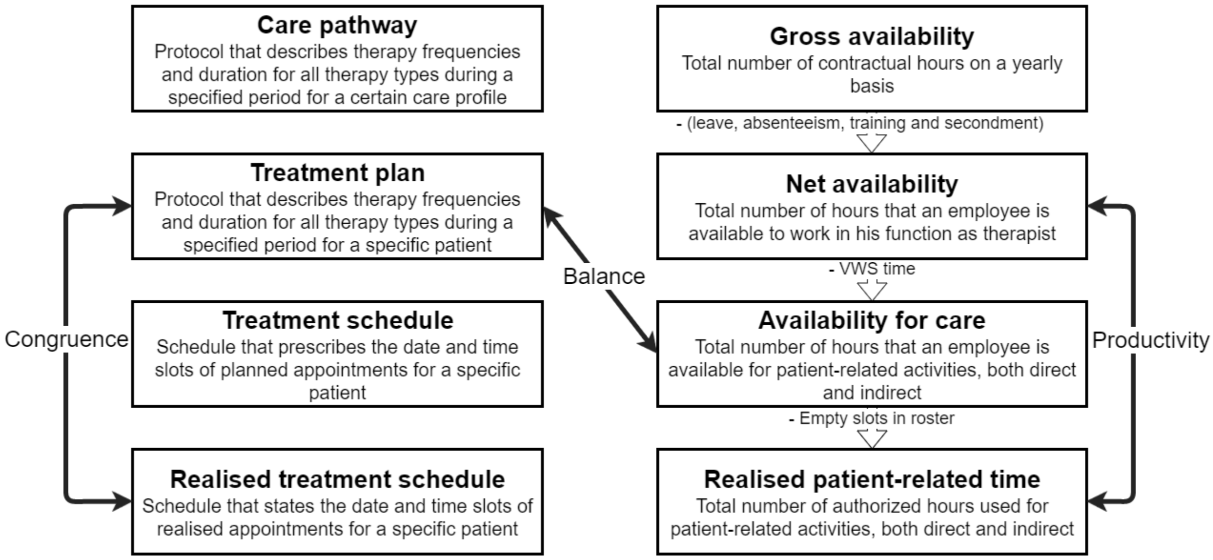

Figure 11; Overview of resource capacity planning measures

3.2 AVAILABLE THERAPISTS CAPACITY FOR CARE

3.2.1 MEASUREMENT METHOD AND DATA GATHERING

It is possible to measure the different terms for the capacity of therapists in different ways. There are multiple registration systems in use in the SMK. The net availability of therapists is most correctly registered in the personnel administration software. Schedulers register the VWS time and the patient-related time in the HIS and not in the personnel administration software. Since schedulers schedule appointments in the rosters of therapists the fixed working times of therapists are also registered in the HIS, however temporarily changes in the rosters are not registered in the HIS. We perform all measurements using weeks as a unit of time. We show the results for measurements for the discipline physiotherapy, since this is the largest discipline.

3.2.2 MEASUREMENT OF THE THERAPIST CAPACITY FOR CARE

Table 2 shows the calculations that the SIR care unit currently uses for the different terms. As a result of for instance differences in timing of presence of patients and the presence of therapists it is not always possible to plan appointments during all time slots that therapists are available. Therefore, part of the availability of therapists for care is not used. This is currently not taken into account when determining the number of therapist to deploy in a certain period.

Table 3 shows the measurement of the net availability of therapists using the personnel administration software, which is not directly connected with the HIS. We use the net availability for both care units for the therapists that works for two care units. When we subtract the 362.5 hours that the therapist should have worked for the other care unit the resulting net availability is 89 percent of the gross availability. Reasons for the difference with the theoretical 81 percent are the same as for the measurement using the management dashboard Maartensspiegel. Table 3 shows that the realised net availability is 87 percent of the gross availability. The fact that one of the therapists works for 2 care units causes part of the difference between the realised net availability and the calculations in Table 2. At the moment of measuring it was not possible to separate the measurements in the management dashboard Maartensspiegel per care unit. The therapist in question should work 362.5 hours of his gross availability for the other care unit. When subtracting these hours of the net availability the resulting percentage is 84 percent. Other possible reasons for the difference with the theoretical 81 percent are the use of overtime or there is less time spent on leave, absenteeism, training and secondment than expected. The registered VWS time in the HIS was in 2015 equal to 19.6 percent of the rosters for the physiotherapists (based on measurements in the management dashboard Maartensspiegel), however it is not known whether VWS time is always registered correctly. We found a difference of 9.5 percent between the availability for care and the realised patient-related time based on measurements in management dashboard Maartensspiegel. Possible reasons for this difference are: that there is no demand for care, that there are differences in timing of availability of therapists and availability of patients or that patients do not show up for therapy.

Table 2; Capacity of physiotherapists in 2015 based on calculations of the care unit

	% of gross availability	In hours	Remarks
Gross availability	100 %	11602	Based on contracts of therapists, use of overtime not considered
Net availability	81 %	9397	Used calculations for 36 hour workweek
Availability for care	59 %	6813	27.5 % of net availability is reserved for VWS time
Realised time for care	59 %	6813	Not used in calculations

Table 3; Capacity of physiotherapists in 2015 based on measurements in management dashboard Maartensspiegel

	% of gross availability	In hours	Remarks
Gross availability	100 %	11602	Based on contracts of therapists, use of overtime not considered
Net availability	87 %	10125	Patient-related time + Blocked + VWS + project + empty slots
Availability for care	74 %	8554	Patient-related time + empty slots
Realised time for care	65 %	7545	Patient-related time

Table 4 shows the measurement of the net availability of therapists using the personnel administration software, which is not directly connected with the HIS. We use the net availability for both care units for the therapists that works for two care units. When we subtract the 362.5 hours that the therapist should have worked for the other care unit the resulting net availability is 89 percent of the gross availability. Reasons for the difference with the theoretical 81 percent are the same as for the measurement using the management dashboard Maartensspiegel.

Table 4; Measurements using the personnel administration software

	% of gross availability	In hours	Remarks
Gross availability	100 %	11602	Based on contracts of therapists, use of overtime not considered
Net availability	92 %	10723	Net availability of SIR therapists for all care units, includes overtime

Since registrations of VWS time is not always correct, we use the theoretical 27.5 percent of VWS time to measure the availability of therapists for care that we also use to measure the balance between the therapist capacity for care and the demand for care. Figure 12 shows the availability of physiotherapists for care in 2015 together with the gross availability, the net availability and the minimal availability requirements that the SIR care unit currently uses. Figure 12 shows that the net availability is sometimes higher than the gross availability. This could be the result of the use of overtime. Several times per year there are aftercare clinics. These clinics take place outside of the normal working hours of therapists, therefore these clinics could induce some peaks in the net availability of therapists.

The net availability is sometimes lower than the minimal requirement. A possible reason for this is absenteeism. When the deployed capacity is equal to the minimal requirement then it is possible that the realised availability of therapists becomes lower than the minimal requirement because of sickness. Currently, the management compares the minimal requirements with the net availability throughout the year, except for the summer vacation, when the management compares the minimal requirements with the availability of therapists for care. The reason for this is that during vacations therapists use only the strictly necessary VWS time and use the rest of their time for patient-related activities.

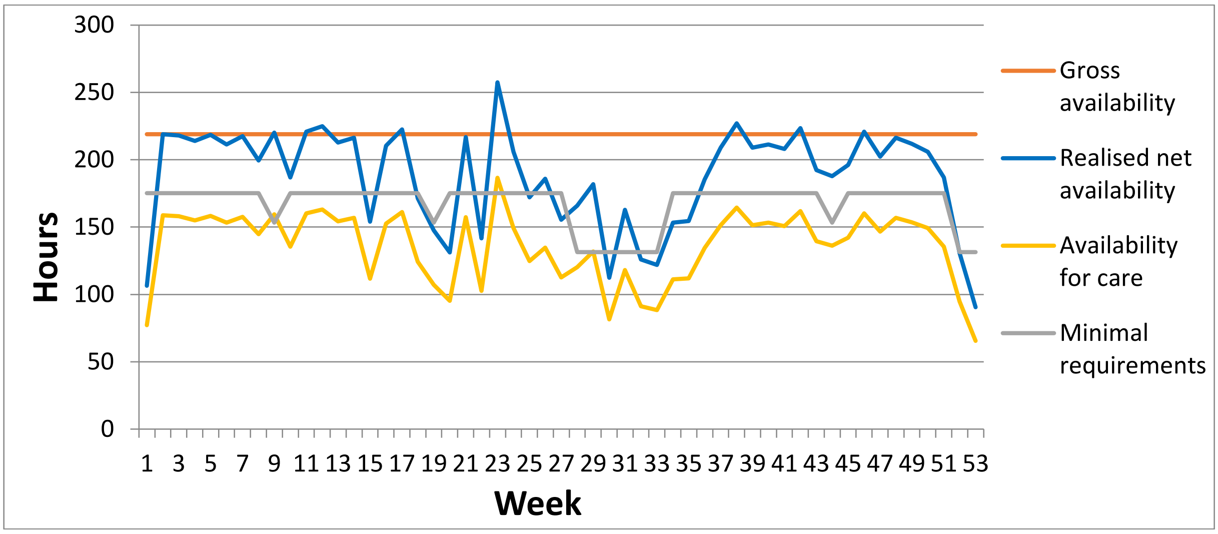

Figure 12; Capacity of physiotherapists in 2015

3.3 THE DEMAND FOR CARE

3.3.1 MEASUREMENT METHOD OF THE DEMAND FOR CARE

This paragraph discusses which method we use to measure the demand for care by describing advantages and disadvantages of different methods. The definition of the demand for care makes use of treatment plans to determine the demand for care. However, currently it is not possible to use the treatment plans for measuring the demand for care because of the registration method of treatment plans in the HIS. The treatment plans are registered in free-text fields, which makes automatic analysis difficult. Another option to measure the demand for care is to use realised treatment schedules of patients. However, the realised treatment schedules are dependent on the availability of patients and therapists. Therefore, the use of the realised treatment schedules to measure the demand for care is questionable. Currently, the SIR care unit does not use overtime frequently and the planner decides with the discipline planner which patients receive less treatment when the demand for care is higher than the available therapists capacity. The demand for care will never be higher than the supply of therapists when the realised treatment schedules are used. Since the objective of the measurement is to measure the performance of staffing, we do not use this option. The third alternative to measure the demand for care is to use the care pathways of patients. The care pathways are not adapted to individual patients, however rehabilitation specialist base the treatment plans of patients on the care pathways and therefore they should give a good estimation of the demand for care. Measurements of Buil at the SIR care unit show that differences between the number of treatments in care pathways and realised treatments are large [6]. It is not known whether differences between the care pathways and the treatment plans are also large. One of the objectives of using care pathways, next to the objective of improving the quality of care, is to increase the efficiency of resource use [9]. Therefore, we use the care pathways to measure the demand for care. Also, the objective of the research to support staffing on a longer term is a reason to use the care pathways to measure the demand for care.

We measure the demand for care using the care pathways, which only contain information about the direct and indirect time required for the treatment of a patient. Using the availability of therapists for care makes it possible to compare the therapist capacity with the demand for care. We assume based on expert opinions that for group therapy the average ratio between patients and therapists is equal to three patients per therapist. This implies that for every hour of group therapy in a care pathway 20 minutes of therapist capacity is required as is explained in paragraph 3.1.2.

3.3.2 DATA GATHERING FOR THE DEMAND FOR CARE

Currently, rehabilitation specialists register the care pathways of patients in a request form for a treatment plan in the HIS. Appendix D contains an example of the request form. There are several limitations in the registration of care pathways. Appendix E gives an overview of the registered care pathways in all submitted request forms for the period 2013 until 2015. This paragraph describes the main findings.

Table 5 shows the new requests for treatment that are submitted between the beginning of 2013 and the end of 2015. Table 5 shows that in more than 50 percent of all outpatient treatment request the care pathway ‘other’ is requested. For the care pathway ‘other’ there is no description of therapy frequencies and durations. Table 5 also shows that for approximately 10 percent of the outpatient treatment requests an inpatient care pathway is requested. These inpatient care pathways have higher treatment intensities than the outpatient care pathways.

Table 6 shows the request forms for inpatients in more detail. There are different care pathways for the different phases of treatment. Patients start with a diagnostic phase, then most patients continue with inpatient treatment phase and part of the inpatients continues after the treatment phase with an outpatient continuation phase. Table 6 shows that rehabilitation specialists do not register the transition from the diagnostic phase to the treatment phase frequently, since almost all patients who are admitted to the hospital receive a treatment according to the management. One of the possible reasons for this is that there is no incentive to request the treatment phase. Treatment of patients start already in the diagnostic phase and it is possible to communicate changes in the treatment plan of patients to the schedulers via e-mail or in person.

Table 5; New treatment traject requests in the period 2013 until 2015

	Care pathway \ requested treatment	Outpatient treatment	Inpatient treatment
Outpatient care pathway	Sitting advice	51	
	Baclofen pump outpatient	1	
	Arm/hand function screening	6	1
	Standard outpatient	38	1
Other / inpatient and outpatient	Sports desk	3	
	Lokomat	5	
	'Other'	367	34
	After care	93	
	Not found	19	7
Inpatient care pathway	Spinal injury other	9	10
	Baclofen pump		39
	Bolus baclofen		14
	Decubitus	5	61
	Spinal injury T7 and lower	23	110
	Spinal injury T6 and higher	23	146
	Guillain Barré	1	10
	Oncology	1	17
	Total	**645**	**450**

Table 6; Differentation in requests between treatment phase and diagnostic phase for the period 2013 until 2015

Care pathway	New traject request	Continuation traject request	Mutation traject request
Spinal injury T7 and lower			
Treatment phase	6	7	15
Diagnostic phase	104		1
Spinal injury T6 and higher			
Treatment phase	7	4	17
Diagnostic phase	139	1	1
Guillain Barré			
Treatment phase	1		2
Diagnostic phase	9		2
Oncology			
Treatment phase	1		
Diagnostic phase	16		

Table 7 shows the requests for continuation trajectories for the period 2013 until 2015. There is a care pathway for outpatient continuation. However, as Table 7 shows, this outpatient continuation care pathway is requested in only 19 of the 88 cases. Since transitions from outpatient to inpatient rarely occur, the numbers in Table 7 are remarkable.

Table 7; All requests for continuation trajects for the period 2013 until 2015

Care pathway	Outpatient treatment	Inpatient treatment	Total
Sitting advice	1		**1**
Outpatient continuation	10	9	**19**
Other	13	1	**14**
Not found	6	22	**28**
Spinal injury other	2	2	**4**
Decubitus		2	**2**
Spinal injury T7 and lower	3	7	**10**
Spinal injury T6 and higher	4	5	**9**
Guillain Barré	1		**1**
Total	**40**	**48**	***88***

A request form does not always ensure that a patient is treated for that care pathway. There can be organisational cancellation reasons, such as a shortage of available beds, or the patient can have reasons to cancel treatment. Currently, the SMK does not register the reasons for cancellation and thus it is not known whether cancelled request are demand (organisational reasons) or not (patient cancels treatment). Table 8 shows the number of inpatients who are admitted to the SMK in the period 2013 until 2015. In this period there were 450 new trajectories requests for inpatients. Part of the difference between these 450 requests and the 339 admissions could be the result of the different requests for different phases. Since it is not possible to link treatments to a certain care pathway for outpatients, it is not known how many of the requests for outpatient care pathways are performed.

Table 8; Division of requests of admitted inpatients over the year for the period 2013 until 2015

Month / Care Pathway	1	2	3	4	5	6	7	8	9	10	11	12	Total
Baclofen pump	3	3	3	3	1	3	3	3		6	3	5	**36**
Bolus baclofen		3	3	2	2	2	1					1	**14**
Decubitus	2	4	7	4	9	5	4	4	3	4	3	4	**53**
Spinal injury other		2	3	1			1		1				**8**
Spinal injury T6 and higher	15	10	9	7	6	10	17	10	9	10	10	7	**120**
Spinal injury T7 and lower	6	6	11	9	8	3	10	4	12	9	4	5	**87**
Guillain Barré	1	1			2				1	1	1	1	**8**
Oncology		3		3			3	1				3	**13**
Total	**27**	**32**	**36**	**29**	**28**	**23**	**39**	**22**	**26**	**30**	**21**	**26**	**339**

3.3.3 MEASUREMENT OF THE DEMAND FOR CARE

This paragraph describes the measurements of the demand for care. We measure the demand for care using the request forms for the care pathways. We sum up the frequencies of treatments in care pathways to determine the demand for care. We use all requests in the period between the 1st of January of 2013 and the 31st of December of 2015. Due to the registration of admission information in the HIS it is possible to link request forms, and thus care pathways, to the length of stay of inpatients. We assume that patients receive treatment for the care pathway in their request form during their stay. According to their length of stay we determine whether patients receive care for the diagnostic phase and for the treatment phase or not, and if they receive care for their treatment phase then for how long they receive care.

Figure 13 shows a measurement of the demand for care for the discipline physiotherapy for all inpatients in the period 2013 until 2015 based on the length of stay of these patients. The demand for care builds up during the warm-up period, because the measurement starts with no patients. Figure 13 shows a warm-up effect in the first 20 weeks of the measurement. In theory the duration of the warm-up period is equal to 24 weeks, since the duration of the longest care pathway is equal to 24 weeks. For the rest of the measurements in this paragraph we only use the data for 2015.

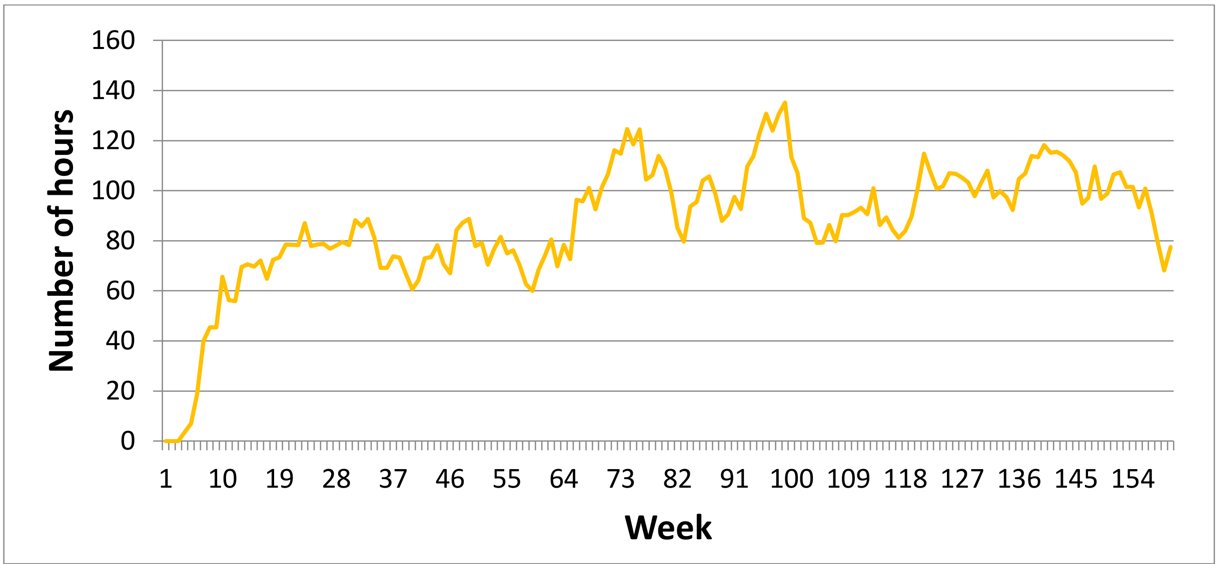

Figure 13; The inpatient demand for care for Physiotherapy based on their length of stay for the period 2013 until 2015

Figure 14 shows the demand for care for the physiotherapy discipline in 2015 using three different measurement methods. For outpatients 367 of the 650 requests were requests for the care pathway 'other'. Since there is no description for the care pathway 'other' these patients are not used in the measurements shown in Figure 14. The care pathway After care is not always requested via a request form, therefore this care pathway is also not taken into account. If the care pathway is not found in the request, then the request is also not used in the measurement. We only know the length of treatment duration for inpatients, therefore Figure 14 shows a measurement of the demand for care for inpatients based on this duration. Figure 14 also shows measurements of the in- and outpatient demand for care. Since we do not know the length of treatment durations for outpatients, we use the theoretical duration of the care pathways of all patients in the measurements for both inpatients and outpatients. Table 9 shows the difference between the theoretical duration of care pathways and the realised duration of treatments between 2013 and 2015. Table 9 shows that there are large differences between the treatment duration in practice and the theoretical treatment duration of care pathways. This is the reason for the large differences between the measurement based on the theoretical treatment duration and the measurement based on the practical duration that Figure 14 shows. Figure 14 shows a measurement of the demand for care based on all request forms for inpatients and outpatients, where we assume that the patients only receive care for the treatment phase registered in the request forms of patients. Figure 14 also shows a measurement of the demand for care based on all request forms for inpatients and outpatients with the assumption that all inpatients with a treatment duration longer than 2 weeks do not only receive care for the diagnostic phase, but also for the treatment phase. According to the management, almost all patients who are admitted to the hospital do not only receive care for the diagnostic phase as is shown in Table 6, but also receive care for the treatment phase.

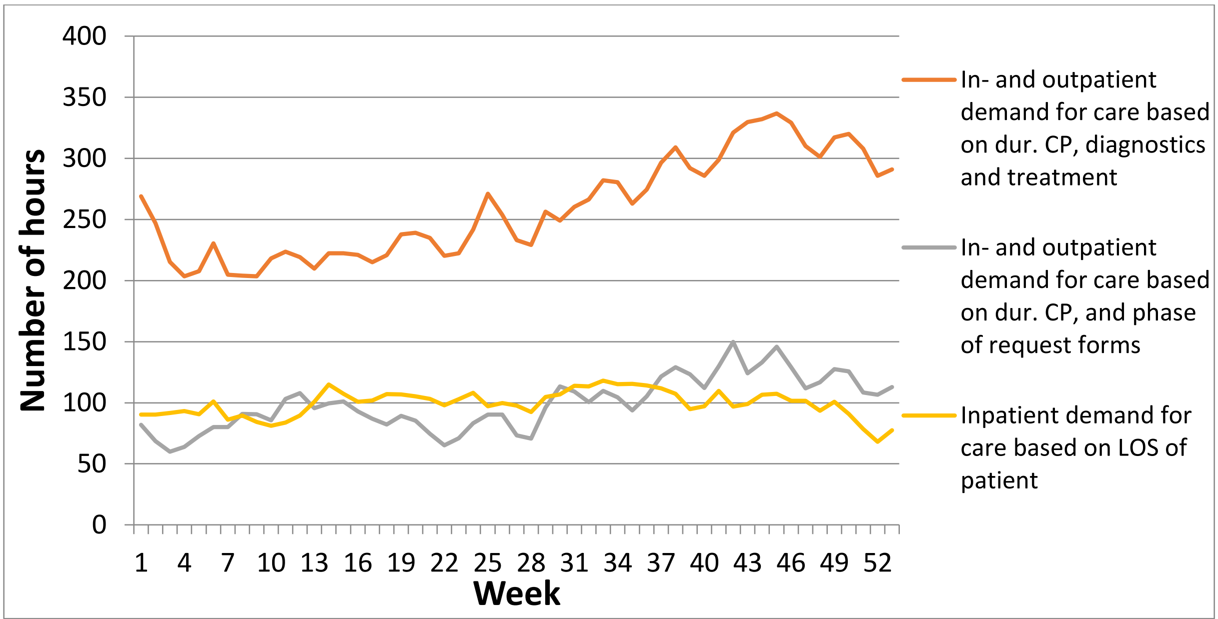

Figure 14; The demand for care for Physiotherapy in 2015 using different measurement methods

Table 9; Theoretical duration of the inpatient care pathways and the average LOS between 2013 and 2015

Care pathway	Duration diagnostics phase (weeks)	Duration treatment phase (weeks)	Total duration (weeks)	Realised average LOS
Baclofen pump	-	2	2	1
Bolus baclofen	-	1	1	1
Decubitus	-	12	12	11
Spinal injury other	2	16	18	8
Spinal injury T6 and higher	2	22	24	13
Spinal injury T7 and lower	2	16	18	11
Guillain Barré	2	22	24	14
Oncology	-	4	4	5

Figure 15 shows the length of stay for all inpatients with the care pathway 'Spinal Injury T6 and higher' in the period 2013 until 2015. For this care pathway the duration of the diagnostic phase is 2 weeks and the duration of the treatment phase is 22 weeks. Figure 15 shows that there are large differences between the treatment duration in practice and the theoretical treatment duration of care pathways. For the measurement of balance between the demand for care and therapists capacity for care we use the practical treatment duration together with the treatment frequencies of the care pathways, since this is the most realistic method to measure demand.

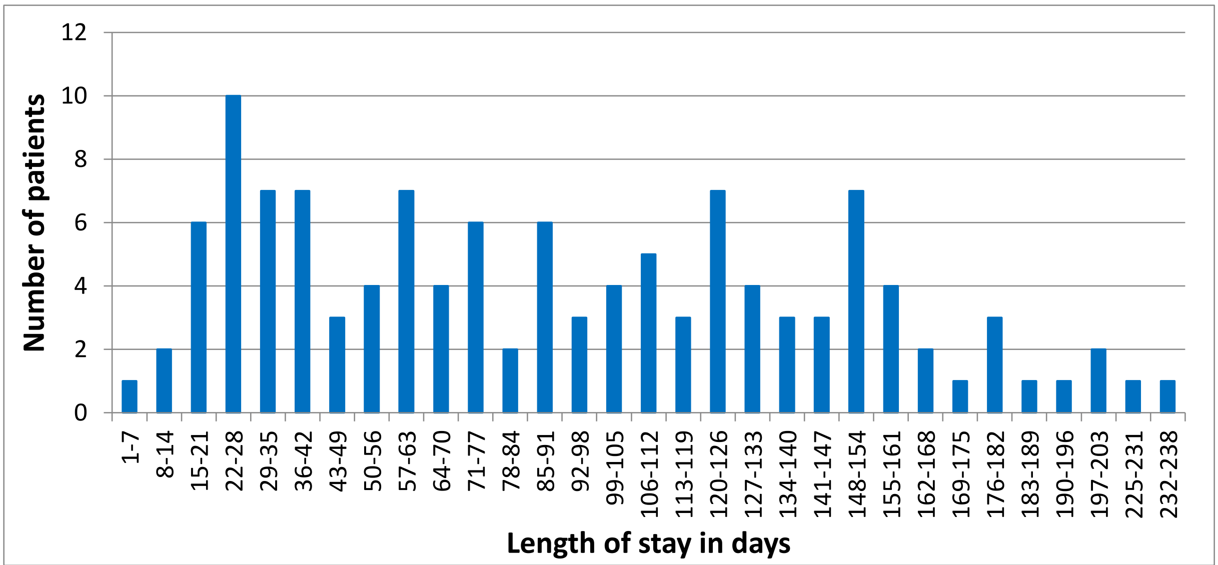

Figure 15; Length of stay of 'Spinal Injury T6 and higher' inpatients in the period 2013 until 2015

3.4 MEASUREMENT OF BALANCE AND OTHER MEASURES

This paragraph describes the measurements of balance and it shortly describes measurements from previous research at the SIR care unit in the SMK. Figure 16 shows the balance between demand for care and the therapist capacity for care for the discipline physiotherapy in 2015. The demand for care in Figure 16 is only the inpatient demand for care. The available therapists capacity for care is not only for inpatients, but also for outpatients. During the summer vacation period the availability of therapists is lower, where the demand for care is not lower in this period in 2015. As Figure 16 shows the inpatient demand for care is higher than the available capacity of therapists for inpatient and outpatient care in this period. We measure the availability for care using a theoretical percentage of VWS time. It is possible that the available therapists capacity for care is slighly higher in the summer vacation, as a result of a decrease in the use of VWS time in this period. Figure 16 shows that in the first and in the last period of 2015 there is a gap between the demand for care and the availability of therapists for care. Since inpatient care is the larger part of the care provided at the SIR care unit it is questionable whether outpatient care fills this gap completely. The most care intensive outpatients are the outpatient continuation patients. Since these patients currently start there outpatient treatment directly after there inpatient treatment it is not possible to use admission planning for these patients to balance the demand for care and the therapist capacity for care.

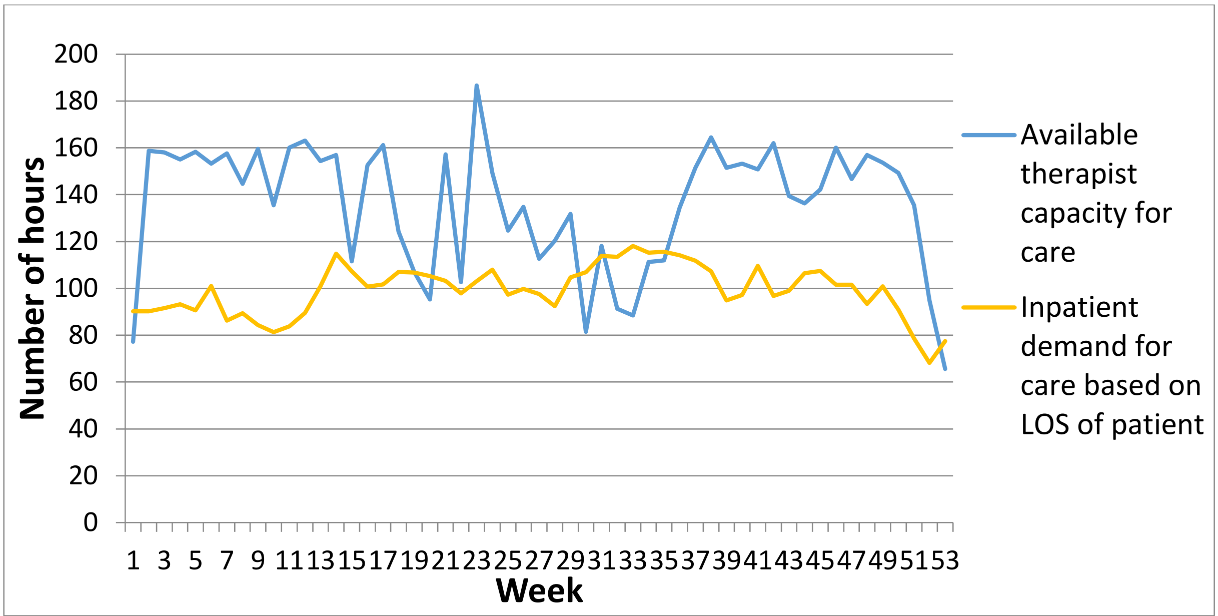

Figure 16; Balance between therapist capacity for care and the demand for care for Physiotherapy in 2015

Figure 17 shows the balance between the demand for care and the therapist capacity for care for the discipline occupational therapy in 2015. Figure 17 shows that the inpatient demand for care was relatively stable for occupational therapy in 2015. Between week 29 and 31 there is an increase in demand and between week 49 and 52 there is a decrease in demand. During the rest of the year the variations in demand are small. Since outpatients are not considered in the measurement the availability of therapists seems not sufficient in the second part of 2015.

Buil measured congruence at the SIR care unit and the Chronic pain, Amputation and Orthopedic rehabilitation (CAO) care unit. The frequency of treatments differed in 2013 and 2014 on average between 68 and 93 per cent from the frequencies in care pathways for these two care units [6]. Although Buil mentions that the results should be interpreted with care, the results indicate that in the SIR care unit differences between the care pathways and the realised care are enormous. For a more extensive description of the congruence measurements at the SIR care unit we refer to Buil [6]. Trentelman performed measurements of the access times for patients at the SIR care unit [3]. The access times for outpatients were in 2013 and 2014 higher than the standards for access times of outpatients of the Dutch government, which states that for 80 percent of the outpatients treatment should start within 3 weeks after registration on the waiting list [3]. The access time of inpatients were within the standards in 2013 and 2014.

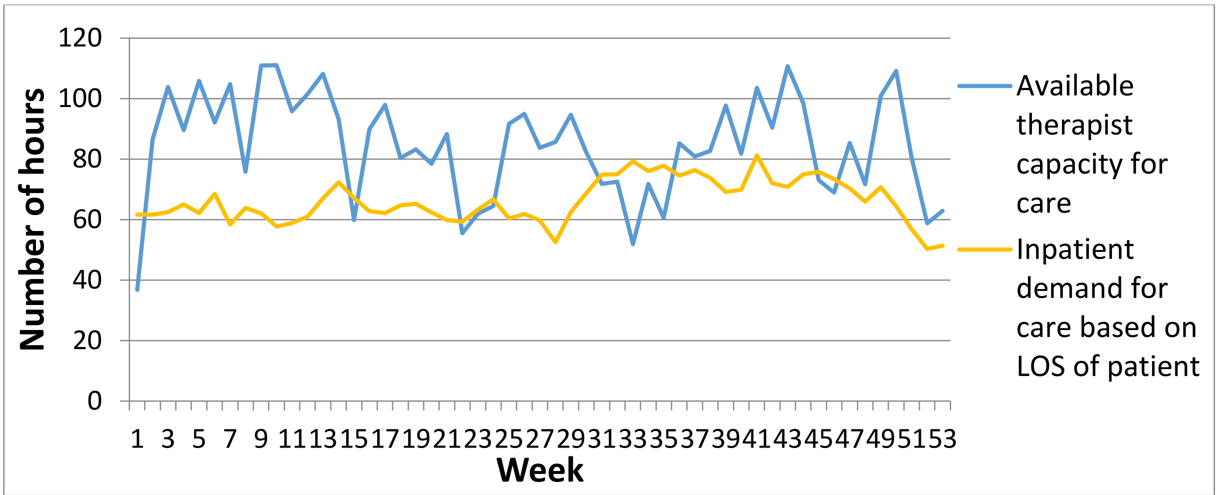

Figure 17; Balance between therapist capacity for care and the demand for care for Occupational therapy in 2015

3.5 RECOMMENDATIONS

It is not possible to perform a reliable zero-measurement of the staffing performance, because the current registration methods are not accurate. To perform a reliable measurement in the future and to make it possible to accurately forecast demand, it is essential to improve registration of the demand. Therefore, we recommend to:

- Register treatment plans in a way that enables automated analysis of the demand for care based on treatment plans.

- To register changes in treatment plans of patients in the HIS instead of using only e-mail or oral communication.
- To register the reason for cancellation when a request for a care pathway is cancelled, such that it is possible to forecast demand more accurately by taking organisational cancellation into account.
- To reconsider the request form for care pathways, such that it is not possible to make contradicting choices as for instance requesting an inpatient care pathway for an outpatient treatment. Appendix E gives a more extensive description.
- Not only register the requests for a care pathway, but also the start and ending of the treatment for a certain care pathway. When the start and ending time of the treatment for a certain request (care pathway) are known it is possible to link the given treatments and the treatment plans with a care pathway.
- Register the start and ending time of different treatment phases within the care pathways.
- Reconsider the outpatient care pathways. Over 50 percent of the requests for a care pathway are for the care pathway ‘Other’ for outpatients.
- Reconsider the duration of the care pathways. Currently, the theoretical duration of the care pathways are not in accordance with the realised average length of stay.

3.6 CONCLUSIONS

The key performance measure for therapist resource allocation is the balance between demand for care and the therapist capacity for care. Unfortunately, it was not possible to perform a quantitative performance measurement of the balance between demand for care and the therapist capacity for care, mainly because of the current poor registration methods of demand for care. The performed measurements of the inpatient demand for care show that there are fluctuations in the demand for care, as a result of differences between the care pathways of patients in treatment. There are also fluctuations in the available capacity of therapists and these fluctuations are currently not synchronised with the inpatient demand for car. The performed measurements show that in 2015 there were for both the disciplines Physiotherapy and Occupational therapy a few weeks that the demand for care of inpatients based on their care pathways was higher than the capacity of therapists for in- and outpatient care. The core problems we identify are the shortage of insight in the demand for care for the coming period, the resulting imbalance between the need for therapists based on the demand for care and the deployment of therapist capacity and the current poor registration methods. Currently, the therapy patients require is known short before scheduling (one week in advance), but even for the next week there is not an overview of the demand for care per discipline. The available therapist capacity is determined before demand is known, however it is possible that there are changes in the availability of therapists based on their preferences. As a result, it is not possible to balance the capacity of therapists for care and the demand for care. The next chapter describes solution directions.

4 LITERATURE REVIEW

This chapter shortly describes the existing literature for this research. Paragraph 4.1 describes general resource capacity planning and control decisions in healthcare. Paragraph 4.2 focusses on the existing resource capacity planning literature for rehabilitation care. Paragraph 4.3 describes forecasting literature related to this research. Paragraph 4.4 concludes the chapter and describes the contribution of this research to the existing literature.

4.1 RESOURCE CAPACITY PLANNING AND CONTROL

This research focuses on resource capacity planning, therefore this paragraph gives a short overview of resource capacity planning decisions for the different hierarchical levels of the theoretical framework for planning and control of Hans et al. [5]. The framework consists of a division on a strategic, tactical, offline and online operational level on the horizontal axis. On the vertical axis there is a division in medical planning, resource planning, materials planning and financial planning. In Figure 18, an example application of the framework is shown for a general hospital.

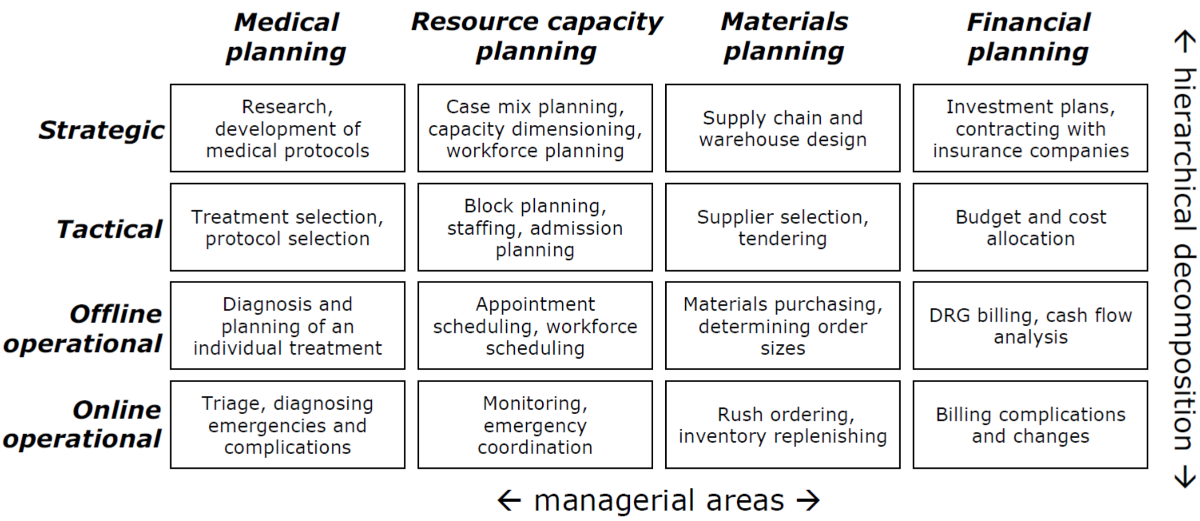

Figure 18; Example application of the framework for health care planning and control to a general hospital [5]

Hulshof et al. provide a comprehensive overview of the typical decisions to be made in resource capacity planning and control in health care for six different types of health care services. The type of service that resembles the care services at the SIR care unit of the SMK the most are inpatient care services. Hulshof et al. give a structured review of relevant articles from the field of Operations Research and Management Sciences (OR/MS) for each planning decision [8], which was the starting point of the literature research. Appendix G gives a description of the search strategy.

Strategic planning addresses structural decision making [8]. Decisions that are made on the strategic level are the service mix and the case mix that a facility serves. The service mix stipulates which patient types can be consulted and the case mix determines the volume and composition of patient groups that the facility serves [8]. One of the most important decision for resource capacity planning on this level is the long-term dimensioning of resource capacities, such that the overall available workforce and the need for resources are in balance.

Tactical planning addresses the organisation of the operations/ execution of the health care delivery process (i.e. the “what, where, how, when and who”) [8]. Tactical planning translates strategic planning decisions to guidelines that facilitate operational planning decisions. On this level, blueprints are created that allocate resources for the operational planning [8]. An example of a decision on the tactical level is the use of temporary bed capacity change and the related admission control of patients. This may for instance be in response to predicted seasonal demand. Another example is the staff-shift scheduling that can be performed [8]. Shift scheduling deals with the problem of selecting what shifts are to be worked and how many employees should be assigned to each shift to meet patient demand [10, 11]. Also, decisions about admissions of patients and temporary capacity expansions like hiring staff or overtime are part of tactical planning [8].

Operational planning, both “offline” and “online”, involves the short – term decision making related to the execution of the health care delivery process [8]. Offline operational planning concerns the in advance planning of operations, whereas online operational planning involves the monitoring of the process and reacting on unforeseen or unanticipated events [8]. In general, the capacity planning flexibility is low on this level, since decisions on higher levels have demarcated the scope for the operational level decision making [5, 8]. Therefore, it is important that decisions are accurate on the tactical and strategical level. An example of offline operational planning is the staff-to-shift assignment. In staff-to-shift assignment, a date and time are given to a staff member to perform a particular shift

[8]. Another example is the appointment scheduling: the scheduling of patient appointments with therapists to specific time slots. At the online operational level, rescheduling could take place because of for instance unforeseen unavailability of therapists or patients.

In general, the unique characteristics of different industries and organisations mean that specific mathematical models and algorithms must be developed for personnel scheduling solutions in different areas of application [10]. Therefore, the next paragraph describes the resource capacity planning literature in rehabilitation centres.

4.2 RESOURCE CAPACITY PLANNING IN REHABILITATION CENTRES

Compared to the substantial number of publications dealing with planning and scheduling in acute hospitals, only a few papers address the scheduling problems in rehabilitation hospitals [12]. Most of the rehabilitation planning studies have addressed an offline scheduling problem [13]. Podgorelec and Kokol describe an automated offline scheduling method based on genetic algorithms and machine learning [14]. The method described is applied to a problem of scheduling patients with different therapy needs to a limited number of resources available. Chien et al. describe a method to schedule rehabilitation patients, wherein partial precedence constraints for different therapy sessions and waiting time constraints are modelled [15]. Chien et al. use an evolutionary approach based on a genetic algorithm to solve the problem of sequencing patients who receive different types of physical therapy sessions.

Ogulata et al. schedule physiotherapy treatments for rehabilitation patients using a model divided into 3 different steps, namely (1) selection of patients, (2) assignment of patients to the staff and (3) the scheduling of patients throughout a day [16]. The model maximises the number of selected patients to be treated in a predetermined staff capacity, balances workload among different physiotherapists and minimises waiting time throughout a working day for patients. Schimmelpfeng et al. develop formal mixed-integer linear programs to schedule appointments for patients of rehabilitation hospitals [12]. The objective of the model is to schedule as many of the prescribed activities as possible, given the available resources and the exogenous scheduling decisions, for a planning horizon of a month. Braaksma et al. present a methodology to plan treatments for rehabilitation outpatients [2]. The methodology plans series of appointments for patients who require treatments by therapists from various disciplines. The model can deal with a planning request online, whereas most other rehabilitation planning literature considers offline scheduling [2]. Braaksma et al. model the rehabilitation treatment planning problem as an integer linear program (ILP) that can schedule a series of appointments for one patient at a time. Research of Dedden focusses on resource capacity planning in rehabilitation care on a tactical level [17]. Dedden describes a method to improve the allotment of therapists to specialised teams and the effects of different policies for the formation of specialised teams [17]. Dedden classifies the problem as a mixed integer nonlinear problem and solves it using a Simulated Annealing heuristic [17].

4.3 DEMAND MODELLING AS A FIRST STEP

In this paragraph we first describe the importance of demand forecasting in health care. Thereafter, we describe some general forecasting techniques. Then, we describe the objective of forecasting for the different hierarchical levels and we describe some forecasting techniques used in health care.

Braaksma et al. identify three steps for improving the organisation of a rehabilitation outpatient clinic [2]. These steps are also relevant for an inpatient organisation. The first step they identify, is to obtain insight into the demand and the supply of the rehabilitation care provided in a clinic [2]. Although seemingly trivial, this insight is often lacking in practice [2]. The second step that they identify, is the automated support of the planning task. Where the third step focusses on the development and implementation of intelligent planning algorithms to find planning proposals that are efficient for patients and clinicians. Ernst et al., identify personnel scheduling, or rostering, as the process of constructing work timetables for its staff so that an organisation can satisfy the demand for its goods or services [10]. They also identify that determining the number of staff, with particular skills, needed to meet the service demand, as the first part of the personnel scheduling or rostering process. Kellog and Walczak, study the nurse scheduling problem, which is part of the larger capacity-planning problem involving staffing and scheduling [11]. As they state, the staffing problem is generally solved first and involves forecast of demands, acuity of care forecasting, and integration with nursing availability and skills [11]. Once a staffing plan is finalised, a schedule is constructed that informs individual nurses and nurse managers of who is assigned when and where [11]. Concluding, the first step in resource capacity planning is to forecast demand.

Forecasting techniques can be broadly divided into two categories, namely qualitative and quantitative methods [18, 19]. Qualitative-based forecasting methods predict the future, usually using opinion and management judgment of experts in specified fields [18]. An example of such a qualitative-based method is the jury of executive opinion method. The jury of executive opinion method uses the consensus of a group of experts, often from several functional areas within a health care organisation, to develop a forecast [20]. Other qualitative-based forecasting methods are the Delphi method and naïve extrapolation, which are described in [20]. Quantitative forecasting methods make use of mathematical and statistical techniques [20]. Quantitative methods are divided into two categories [19]. Namely, time series methods, i.e. methods which involve the statistical analysis of past data of the variable to be forecast; and causal methods, where the variable to be forecasted is based on the statistical analysis of data for other variables related to the variable to be forecasted [19]. For the different hierarchical levels of the theoretical framework for planning and control of Hans et al. different forecasts are needed.

Long term (year(s))

On the strategic level it is determined how many therapists per discipline are required to meet the demand for care on the long term [8]. Decisions made for this long planning horizon are based on highly aggregate information and forecasts [5]. On this level there is need for a forecast of the case mix and the number of therapist needed to serve this case mix in the coming year(s). A qualitative forecasting technique as for instance the jury of executive opinion model can be used to forecast the number of patients that are treated per patient type per year. It is also possible to use a time series method to forecast the number of patient treated per patient type or to combine a time series method with a qualitative method. Thereafter, care pathways can be used to determine the number of therapists needed per discipline to treat these patients.

Mid-term (months/weeks)

On the tactical level blue prints for the roster of therapists are made. It is determined how many therapists per discipline are required to meet the demand for care on a monthly or weekly basis [8]. Therefore, the demand for care has to be forecasted for tactical planning in more detail than on the strategic level. Predictions about the demand for care can be based partially on information that is already available about patients who are currently treated or on waiting lists, and partially on predictions of patient arrivals with the use of historical data [5]. Treatment plans can be used to forecast the demand for care following from the current patients and patients on the waiting list, where for the patients that still have to arrive only the care pathways can be used to forecast the demand for care.

Short term (weeks/days)

Examples of operational planning are the staff-to-shift assignment and the appointment scheduling [8]. On the operational level, no forecast of the demand for care has to be made. Information about patients and the care they require is largely known and thus no prediction is required to adapt therapist deployment to the demand for care. The flexibility in adapting the therapist deployment to the demand for care is lower on the operational level than on the higher hierarchical levels [5]. Therefore, it is important that forecasts made on higher levels are accurate. On the operational level it is important that all stakeholders obtain the information they require and all information is registered, such that it can be used in the future on the tactical and strategic level to forecast demand.

Demand modelling is the process of translating some predicted pattern of incidents into associated duties and then using the duty requirements to ascertain a demand for staff [10]. A clear perception of demand can be acquired by constructing care pathways and treatment plans (per disease type or on an individual basis) [9]. These care pathways and treatment plans should prescribe all treatments to be realised during the course of a rehabilitation process [2]. Queuing theory and simulation modelling are the two approaches most commonly used to translate forecasted customer arrivals during different time intervals into the staffing levels (demand) needed to maintain required service standards [10]. An example of research where a method that makes use of queuing theory is used in demand modelling, is the research of Vanberkel et al. [1]. It describes an analytical approach to compute downstream workload distributions as a function of the master surgical schedule (MSS) for all departments that provide care for recovering surgical patients [1]. A strategic capacity planning decision is the long term allocation of OR time to the surgical specialties. From this strategic decision a master surgical schedule (MSS) is developed which divides OR time (aggregated into blocks) amongst the surgical specialties [1]. The model can be used to compute the ward occupancy distributions, the patient admission/discharge distributions and the distributions for the treatments required by recovering patients. Kros et al. forecast the bed census in an inpatient rehabilitation facility [21]. Kros et al. forecasts the number of patients in treatment using a multiple regression model. The outcome of the forecasting model is not the probability distribution on a certain number of patients in treatment, but rather a single value for the forecasted number of patients in treatment.

4.4 CONCLUSION

There are several decisions in resource capacity planning to balance the demand for care and the deployment of therapist capacity. It is possible to do this by adjusting the demand for care by using admission planning or varying the quantity of care given to patients and it is possible to do this by varying the deployment of therapist capacity. Before making these decisions, a demand forecast is needed. The literature on resource capacity planning is scarce for rehabilitation care. Most of the resource capacity planning literature for rehabilitation centres focusses on appointment scheduling methods, where the rest of this research focusses on predicting the inpatient demand for care as a first step in the staffing of therapists in a multidisciplinary setting. There are methods to forecast the number of patients in treatment. However, we did not find any literature on forecasting the workload following from patients for a multidisciplinary rehabilitation setting, which is the objective of the rest of this research.

5 MODEL DESCRIPTION

This chapter describes how we forecast the demand for care in an inpatient care unit. The objective is to forecast the distribution of the need for therapists in number of hours per discipline per week. First, we describe in paragraph 5.1 a model from the literature where the model we use is based on, and the objective of the forecasting model that we describe in this chapter. Thereafter, we describe the working of the model in paragraph 5.2 and the assumptions we make in the forecasting model in paragraph 5.3.

5.1 COMPUTING WORKLOAD DISTRIBUTIONS

We base the working of the forecasting model on a method of Vanberkel et al. [1]. Vanberkel et al. describes an analytical approach to compute downstream workload distributions as a function of the master surgical schedule (MSS) for all departments that provide care for recovering surgical patients. Based on the long term allocation of OR time to surgical specialties a master surgical schedule is developed, which divides OR time (aggregated into blocks) amongst the surgical specialties. The main output of the model is the distribution for the number of patients anticipated in the system on each day of the master surgical schedule. Vanberkel et al. calculates the probability distribution for the number of recovering patients on each day in three steps. Step 1 computes the distribution of recovering patients from a single OR block of a certain specialty, i.e. Vanberkel et al. precalculates the distribution of recovering patients expected from an OR block of a specialty. In Step 2, Vanberkel et al. considers a given master surgical schedule and uses the result from Step 1 to compute the distribution of recovering patients given a single cycle of the master surgical schedule. Finally, in Step 3 Vanberkel et al. incorporates recurring master surgical schedules and compute the probability distribution of recovering patients on each day.

5.1.1 OBJECTIVE OF THE FORECASTING MODEL

The objective of forecasting in this research is to predict the distribution of the need for therapists per discipline per week following from the inpatient demand for care. Figure 19 gives an example of such a distribution for a certain discipline in a certain week. For every workload in Figure 19, there is a probability that that specific workload is the need for therapists for that discipline in that week. For example the probability that the workload is equal to 75 hours is equal to 0.016 for the distribution in Figure 19. The different colours show prediction intervals (PIs) with different confidence levels. Figure 20 shows the cumulative probability distribution corresponding with the probability distribution in Figure 19. The cumulative probability distribution gives information about the probability that the workload is smaller than a certain value. Figure 20 shows that in this example the probability that the workload is smaller than or equal to 75 hours is equal to 0.5. Note that the form of the distribution does not necessarily have to be the form of the normal distribution, but the distributions we show here solely exists to serve as an example of the result of the forecast.

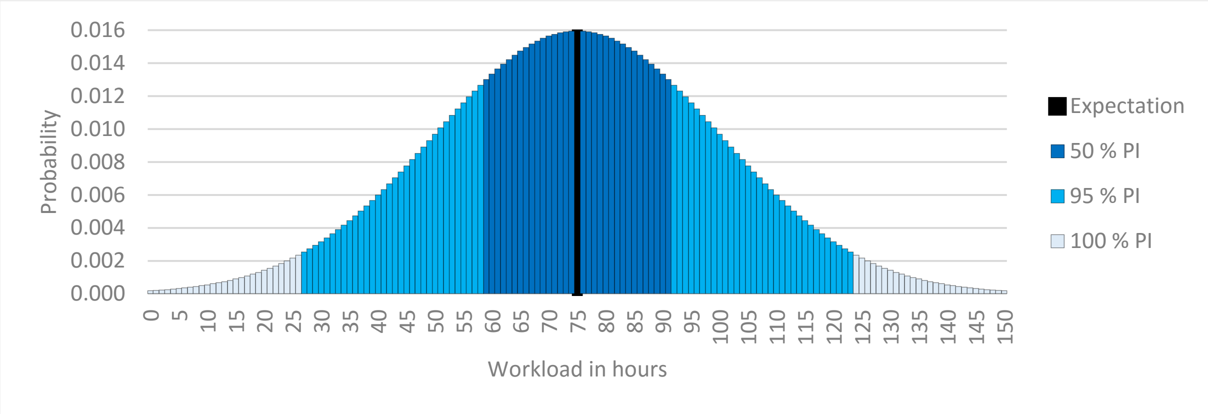

Figure 19; Example of the probability distribution of the workload for a single discipline in a certain week.

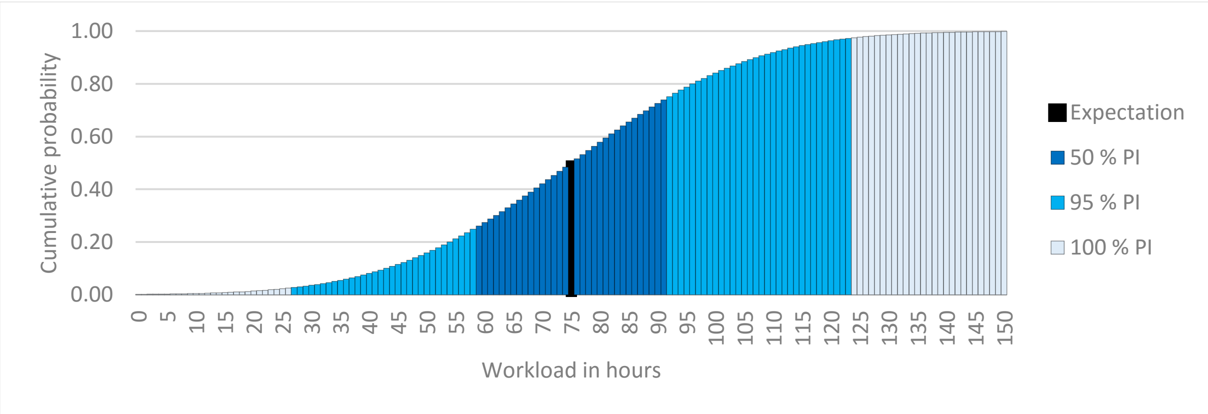

Figure 20; Example of the cumulative probability distribution of the workload for a single discipline in a certain week.

5.2 CONCEPTUAL MODEL

Since care pathways are a guideline according to which patients are treated, we assume that the demand for care is equal to the need for treatment following from the care pathways. Care pathways prescribe the frequency and duration of treatments, thus it is possible to calculate the demand for care using the care pathways, i.e. there follows a certain need for therapists from the care pathways of patients. In contrast with the prediction model of Vanberkel et al. we do not predict the distribution of recovering patients following from the different OR blocks in a MSS using discrete convolution. Instead, we compute the distribution of the demand for care following from multiple beds based on the distribution of workload following from the care pathways of patients who occupy a single bed. Where Vanberkel et al. precalculates the distribution of recovering patients expected from an OR block in step 1, we calculate the probability that a patient in a bed needs treatment for a certain care pathway in step 1. This probability, on a patient that needs treatment for a certain care pathway in a bed, implicates a probability on a certain workload following from a bed. In step 2, we calculate the aggregated distribution of workload following from all the beds of a care unit using discrete convolution. Summarising, our model contains the following steps:

1. Calculating the probability distribution of the workload following from a specific bed
    a. Determine for a specific bed the probability that the patient in that bed needs treatment for a certain care pathway
    b. Incorporate the probability that a bed is empty
    c. Incorporate known information, i.e. information about patients who are already in treatment at the moment of prediction
2. Calculating the aggregated distribution of the workload following from the beds

In paragraph 5.2.1 we describe the content of step 1 and in paragraph 5.2.2 we describe the content of step 2. The input we use in the model contains the following information:

- The patients in treatment at the moment of prediction (current patients)
    - The number of known current patients (and thus known care pathways)
    - The length of stay of current patients
    - The distribution of the current patients over the care pathways
- The distribution of yet to arrive patients over the care pathways
- The care pathways
    - Length of the different care pathways
    - Content of the care pathways (workload per week per discipline for every care pathway)
    - The number of different care pathways
- The number of beds in use

5.2.1 CALCULATING THE PROBABILITY DISTRIBUTION OF THE WORKLOAD FOLLOWING FROM A SPECIFIC BED

In step 1 we compute the probability distribution of the workload, $h_n^{j,k}$, following from bed j for discipline k in week n. $h_n^{j,k}(x)$ is the probability that the workload following from bed j is equal to x hours for discipline k in week n where $j \in \{1, 2, \dots, J\}$, $k \in \{1, 2, \dots, K\}$, $n \in \{1, 2, \dots, N\}$ and $x \in \mathbb{N}$. J is the number of beds of the care unit under consideration, K is the number of disciplines providing care in the care unit, N is the number of weeks in the prediction and $\mathbb{N}$ is the set of all natural numbers. For example $h_2^{3,1}(4) = 0.3$ means that the probability is 30 percent that the workload in bed 3 is equal to 4 hours for discipline 1 in week 2. In other words, there is a 30 percent probability that there are 4 hours of therapists capacity needed for discipline 1 in week 2 to treat the patient in bed 3 according to his care pathway.

In step 1a we determine for a specific bed the probability that the patient in that bed needs treatment for a certain care pathway. We assume that the case mix distribution of yet to arrive patients determine the probability that an arriving patient needs treatment for a certain pathway. A possibility is to base this case mix distribution of yet to arrive patients on the historical distribution of arriving patients over the care pathways. We assume that in the first week after the discharge of a patient, the probability that there is a new patients that needs treatment for a care pathway is equal to the probability that a patient needs treatment for a specific care pathway based on the distribution of yet to arrive patients over the care pathways. As a result of differences in the durations of the care pathways of the possibly arrived patients, the probability that there is a patient that needs treatment for a specific care pathway is different in the following weeks. Every time that the care pathway of a patient ends, the probability that this patient was in treatment for his care pathway is redistributed over the different care pathways according to the case mix distribution of yet to arrive patients. When the treatment for the care pathway of a patient is not over yet, the probability that this patient arrived is not redistributed. As a result, the probability to find a patient that needs treatment for care pathway i in a bed is not equal to the probability that an arriving patient needs treatment for that care pathway. Part of the probability of care pathways with short duration is redistributed to longer during care pathways. Thus, the probability of finding a care pathway with a relatively long duration in a bed is higher than the arrival probability for that care pathway, where for care pathways with relatively short duration the probability to find that care pathway in a bed is lower than the arrival probability. The probability to find a patient in a bed that needs treatment for a certain care pathway i converges to:

$$Pr^i_{n\to\infty} = \frac{P^i_{arrival} * Duration_i}{\sum_i (P^i_{arrival} * Duration_i)}, \tag{5.1}$$

with $P^i_{arrival}$ the probability that an arriving patient needs treatment for care pathway i, and $Duration_i$ is the duration of care pathway i. In Example 5.1 we show how to calculate the probability to find a patient in a bed that needs treatment for a certain care pathway.

Example 5.1: Calculating for a specific bed the probability that the patient in that bed needs treatment for a certain care pathway

In this example there are 2 care pathways. The probability that an arriving patient needs treatment for these care pathways are 0.3 and 0.7 respectively. The duration of these care pathways are 2 and 3 weeks respectively. The workload following from the care pathways is equal to 2 and 4 hours per week respectively. In this example, we assume that the bed in consideration is empty at the start. We first show the possible sequences of arriving patients, and the care pathways for which they need treatment, for the first 3 weeks in this example. To every sequence belongs a certain probability. Note that the last care pathway in a sequence is the care pathway to which the probability belongs to for that week.

Week 1:

A patient that needs treatment for care pathway 1 arrives with probability 0.3 and a patient that needs treatment for care pathway 2 arrives with probability 0.7:

Care pathway 1: 0.3

Care pathway 2: 0.7

Week 2:

In both cases, the case in which a patient that needs treatment for care pathway 1 arrived in week 1 and the case in which a patient that needs treatment for care pathway 2 arrived in week 1, the patient is still in treatment for his care pathway in week 2. Thus, the probabilities in week 2 are equal to:

Care pathway 1: 0.3

Care pathway 2: 0.7

Example 5.1 continued: Calculating for a specific bed the probability that the patient in that bed needs treatment for a certain care pathway

Week 3:

In the case that a patient that needs treatment for care pathway 1 arrived in week 1 this patient is discharged after his treatment in week 2, and thus a new patient is treated in week 3. Again, the arriving patient needs treatment for care pathway 1 with probability 0.3 and treatment for care pathway 2 with probability 0.7. If in week 1 a patient arrived that needs treatment for care pathway 2, then this patient is still in treatment in week 3. Thus, the probabilities for the different possible sequences in week 3 are equal to:

Care pathway 1 → Care pathway 1: 0.3*0.3

Care pathway 1 → Care pathway 2: 0.3*0.7

Care pathway 2: 0.7

Note that as a result of the difference in the durations of the care pathways the probability to find a patient that needs treatment for care pathway 1 in a bed in week 3 is equal to 0.09, where the arrival probability for patients that need treatment for care pathway 1 equals 0.3.

The probabilities to find a patient that needs treatment for a certain care pathway in a bed based on the possible sequences in the first five weeks are:

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
Care pathway 1	0.3	0.3	0.3*0.3	0.3*0.3+0.7*0.3	0.3*0.3*0.3+0.7*0.3
Care pathway 2	0.7	0.7	0.7+0.3*0.7	0.3*0.7+0.7*0.7	0.3*0.3*0.7+0.3*0.7+0.7*0.7
Sum	**1**	**1**	**1**	**1**	**1**

The resulting probabilities to find a patient that needs treatment for a certain care pathway in a bed, and thus the probability that there follows a workload for a certain discipline from a bed, are:

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Workload for discipline k**
Care pathway 1	0.3	0.3	0.09	0.3	0.237	2
Care pathway 2	0.7	0.7	0.91	0.7	0.763	4
Sum	**1**	**1**	**1**	**1**	**1**	

The approach we use is not complete yet, because there also is a probability that a bed is empty. We model the probability that a bed is empty as if an empty bed contains a patient that needs treatment for a care pathway with a workload of 0 and a duration of 1 week. We calculate the probability that a bed will remain empty based on the occupancy of beds. We assume that a bed only becomes empty when a care pathway of a patient is completed. It is possible to determine how many weeks all patients occupied beds using historical data. When the number of beds used in this period is known it is possible to calculate the number of weeks that there was an empty bed in that period. When this number of weeks is divided by the total number of weeks in the analysis (number of beds * number of weeks), the arrival probability of the care pathway ‘empty’ is known. In formula:

$$P_{arrival}^{empty\ bed} = \frac{J * N - \sum_i (Arrivals_i * Duration_i)}{J * N} \tag{5.2}$$

Since the empty bed is modelled as a care pathway with a duration of 1 week, the number of arrivals of empty beds is relatively high. Since the care pathway has a duration of 1 week the probability that a bed is empty becomes smaller fast. Every week the probability particle is redistributed over all the care pathways. This means that the probability is relatively large that a bed is empty short after a care pathway has ended. The probability becomes smaller over time. It seems logical that a bed is empty in the first weeks after a treatment has ended. It does not have to be the case that directly after a treatment has ended a new patient is available for treatment, but over time the probability becomes higher that a new patient arrives. In Example 5.2 we show how to calculate the probabilities that a patient in a bed needs treatment for a certain care pathway including the probability on an empty bed.

Example 5.2: Calculating the probabilities including the probability on an empty bed

In this example there are 2 care pathways. The probabilities that an arriving patient needs treatment for these care pathways are respectively 0.2 and 0.5. The arrival probability of the care pathway “Empty” is equal to 0.3 in this example. The duration of the care pathways are respectively 2 and 3 weeks, where the duration of the care pathway “Empty” is equal to 1 week. The calculation of probabilities including the probability on an empty bed example goes as follows:

	Week 1	**Week 2**	**Week 3**
Care pathway 1	0.2	0.3*0.2 + 0.2	0.3*0.3*0.2 + 0.2*0.2 + 0.3*0.2
Care pathway 2	0.5	0.3*0.5 + 0.5	0.3*0.3*0.5 + 0.2*0.5 + 0.3*0.5 + 0.5
Empty	0.3	0.3*0.3	0.3*0.3*0.3 + 0.2*0.3
Sum	**1**	**1**	**1**

The resulting probabilities are:

	Week 1	**Week 2**	**Week 3**	**Workload for discipline k**
Care pathway 1	0.2	0.26	0.118	2
Care pathway 2	0.5	0.65	0.795	4
Empty	0.3	0.09	0.087	0
Sum	**1**	**1**	**1**	

The last step in determining the probabilities that there lies a patient that needs treatment for a certain care pathway in a certain bed is to incorporate known information. The care pathway is known for patients who are in treatment at the moment of prediction. Therefore, for the period from the start of the prediction until the discharge date of this patient, the probability that a patient that needs treatment for a certain care pathway lies in a bed is equal to 1. After the discharge date the patient is replaced by another patient. Example 5.3 shows how to incorporate known information.

Example 5.3: Incorporating known information

In this example we use the same care pathways, with the corresponding arrival probabilities, as in Example 5.2. Suppose that at the moment that the prediction is made a bed is occupied by a patient of care pathway 2 for two more weeks, then the table below illustrates the influence of this known patient on the probabilities that the patient in a bed has a certain care pathway. The probabilities in week 3, 4 and 5 are equal to the probabilities in the first 3 weeks of the example with a probability on an empty bed. The last column shows the workload belonging to the different care pathways. Note that for the probabilities in the third week in the example below it does not matter whether there was a patient with care pathway 1 or a patient with care pathway 2 in the first 2 weeks. The resulting probabilities are:

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Workload for discipline k**
Care pathway 1			0.2	0.26	0.118	2
Care pathway 2	1	1	0.5	0.65	0.795	4
Empty			0.3	0.09	0.087	0
Sum	**1**	**1**	**1**	**1**	**1**	

5.2.2 CALCULATING THE AGGREGATED DISTRIBUTION OF THE WORKLOAD FOLLOWING FROM ALL BEDS

This paragraph shows how the we compute the probability distribution of the workload for multiple beds using discrete convolution. In this step we use the previously computed probability distribution $h_n^{j,k}$ as input.

Let H_n^k be a discrete distribution for the total workload in week n for discipline k resulting from all the beds in a care unit. We assume that the workload following from the different beds do not interfere with each other. Thus, we can iteratively add the distributions $h_n^{j,k}$ for all the beds corresponding to week n to get H_n^k. Adding two independent discrete distributions is done by discrete convolutions, which we indicate using $\otimes$. Let A and B be two independent discrete distributions, then $C = A \otimes B$ is computed by:

$$C(x) = \sum_{k=0}^{\tau} A(k)B(x-k) \tag{5.3}$$

where τ is equal to the largest x value with a positive probability that can result from $A \otimes \mathrm{B}$. Using this notation, $H_n^k\ (x)$ is computed by:

$$H_n^k\ (x) = h_n^{1,k} \otimes h_n^{2,k} \otimes \ldots \otimes h_n^{J,k} \tag{5.4}$$

In Example 5.4 we show how to calculate the total workload in a certain week n using discrete convolution for a situation where the number of beds J is equal to 3. We presume that the probabilities $h_n^{j,k}(x)$ are known after the calculations in paragraph 5.2.1.

Example 5.4: Computing total workloads using discrete convolution

This example shows the calculation of the workload following from 3 beds for an arbitrarily chosen week n. We first show the calculation of the workload following from bed 1 and bed 2. Thereafter, we show the calculation for bed 1 and 2 and bed 3. We need the probabilities that the patient treated in bed 1, 2 and 3 receive treatment for a certain care pathway in week n, for the computation of the total workload in week n. These probabilities are calculated according to the method described in paragraph 5.2.1.

Probabilities for bed 1 in week n:

	Workload	**Probability**
Empty	0	0.2
Care pathway 1	2	0.3
Care pathway 2	4	0.5

Probabilities for bed 2 in week n:

	Workload	**Probability**
Empty	0	0
Care pathway 1	2	0
Care pathway 2	4	1

Probabilities for bed 3 in week n:

	Workload	**Probability**
Empty	0	0.09
Care pathway 1	2	0.26
Care pathway 2	4	0.65

We show the working of the convolution using two steps. In the first step we calculate the probabilities for all possible workloads following from the beds under consideration and in the second step we aggregate the probabilities that result in the same workload.

Example 5.4 continued: Computing total workloads for discipline k using discrete convolution

Step 1: Convolution of bed 1 and bed 2: calculating the probabilities on a certain workload

Total workload	Workload bed 1	Workload bed 2	Probability
0	0	0	0.2*0 = 0
2	0	2	0.2*0 = 0
	2	0	0.3*0 = 0
4	0	4	0.2*1 = 0.2
	2	2	0.3*0 = 0
	4	0	0.5*0 = 0
6	2	4	0.3*1 = 0.3
	4	2	0.5*0 = 0
8	4	4	0.5*1 = 0.5
Sum			**1**

Step 2: Convolution of bed 1 and bed 2: aggregation of probabilities

Total workload	Aggregated probability
4	0.2
6	0.3
8	0.5
Sum	**1**

We now show the calculation of the convolution for bed 1 and 2 and bed 3. This time we show, next to the aggregated probability, also the cumulative probability in step 2.

Step 1: Convolution of bed 1 and 2 and bed 3: calculating all probabilities

Total workload	Workload bed 1 & 2	Workload bed 3	Probability
4	4	0	0.2*0.09 = 0.018
6	4	2	0.2*0.26 = 0.052
	6	0	0.3*0.09 = 0.027
8	4	4	0.2*0.65 = 0.13
	6	2	0.3*0.26 = 0.078
	8	0	0.5*0.09 = 0.045
10	6	4	0.3*0.65 = 0.195
	8	2	0.5*0.26 = 0.13
12	8	4	0.5*0.65 = 0.325
Sum			**1**

Step 2: Convolution of bed 1 and 2 and bed 3: aggregation of probabilities

Total workload	Aggregated probability	Cumulative probability
4	0.018	0.018
6	0.052 + 0.027 = 0.079	0.018 + 0.079 = 0.097
8	0.13 + 0.078 + 0.045 = 0.253	0.097 + 0.253 = 0.35
10	0.195 + 0.13 = 0.325	0.35 + 0.325 = 0.675
12	0.325	0.675 + 0.325 = 1
Sum	**1**	

Next to the probability distribution H_n^k, we also calculate the cumulative probability distribution $\mathbf{H}_n^k$. Where the probability distribution gives information about the probability that the total workload is equal to a certain value, the cumulative probability distribution gives information about the probability that the total workload is smaller than or equal to a certain value. Let $\mathbf{H}_n^k$ be the cumulative distribution function of H_n^k. Then, $\mathbf{H}_2^1(75) = 0.5$ means that the probability is 50 percent that the total workload is smaller than or equal to 75 hours for discipline 1 in week 2. Using the cumulative probability distribution it is possible to determine prediction intervals for certain confidence levels. To determine for instance the 95 percent prediction interval we use the first workload x for which the cumulative probability is larger than 2.5 percent and the last workload y for which the cumulative probability is smaller than 97.5 percent. In Example 5.4 we show the cumulative probability distribution for the total workload in a certain week n for a certain discipline k, which is the objective of the forecasting model.

5.3 ASSUMPTIONS

The following assumptions are made in the model:

- The care pathways describe the need for therapy of patients, thus we assume that the therapy needs are deterministic and constant over time as long as patients receive treatment for a care pathway.
- The treatment duration of yet to arrive patients is equal to the duration of the care pathways for which the patients receive treatment.
- The workload following from the different beds does not interfere with each other, i.e. the therapy needs of the patients in treatment are independent of each other.
- The expected case mix distribution of yet to arrive patients is known.
- The probability that a patient that replaces a patient in a bed has a certain pathway, is determined based on the case mix distribution of yet to arrive patients.
- Beds are filled with patients according to the case mix distribution of yet to arrive patients, independent of the number of beds used. Thus, we assume that there is enough demand to fill the number of beds according to the case mix distribution of yet to arrive patients.
- A bed becomes empty when a care pathway of a patient is completed only and empty beds are caused by a difference in timing of the availability of beds and arriving patients.
- The average ratio between patients and therapists during group therapy is known.
- The discharge dates of current patients are known. In the case of the SIR care unit in the SMK either based on duration of the care pathways or based on estimates by the treatment team.
- Patients receive treatment for one care pathway at a time.

- Currently, the model ignores seasonality in arrivals of patients that need treatment for certain care pathways, i.e. we assume that the distribution of yet to arrive patients over the care pathways (including the probability on an empty bed) is the same for the whole year.

In this chapter we described a forecasting model of multidisciplinary rehabilitation therapy demand for inpatients together with the assumptions behind the model. The next chapter describes the validation and experimentation we perform with this model.

6 EXPERIMENTATION

This chapter describes the experiments we perform with the model and the results following from this experimentation. To perform the experimentation we implemented the model in R [22]. R is a free software environment for statistical computing and graphics. For the convolution we made use of a function that was already available in the SMK. We extracted the data that we need for the forecasting model from the HIS for the period of 2013 until 2015. Paragraph 6.1 describes validation of the model. Paragraph 6.2 describes the experiment setup. Paragraph 6.3 describes the results of the experimentation and paragraph 6.4 describes managerial implications. Paragraph 6.5 concludes the chapter.

6.1 VALIDATION OF THE MODEL

6.1.1 VERIFICATION

Verification exists to verify whether the in software implemented model works in the same way as the conceptual model. We verified the implemented model by discussing the effects of different input settings on the results and checking whether the results show these effects. Moreover, we ran through the code in debugging mode to control the working of the model every time we added code to the model. We verified that the probabilities to find a patient in a bed that needs treatment for a care pathway sums up to 1 for all the care pathways, for every bed j, in every week n, in the implemented model. In formula:

$$\sum_i Pr_n^{i,j} = 1 \tag{6.1}$$

The distribution of the workload for a certain discipline k converges to a steady-state distribution of the workload based on the case mix of yet to arrive patients for the number of beds used. The expected mean of the distribution converts to:

$$\mathrm{E}[H_{n\to\infty}^k] = J * \sum_i (Pr_{n\to\infty}^i * Workload^{i,k}) \ , \tag{6.2}$$

where $Workload^{i,k}$ is the workload following from care pathway i for discipline k, J is the number of beds in use in a care unit and $Pr^{i}_{n\to\infty}$ (the long term probability to find a patient in a bed that needs treatment for a certain care pathway i) follows from formula 5.1. By calculating the results of the model for a long period, we verified whether the results of the implemented model are in accordance with formula 6.2, the maximum of the distribution ($J * \max(Workload^{i,k})$), and the minimum of the distribution ($J * \min(Workload^{i,k})$). Table 11 in appendix H shows the values for $Pr^{i}_{n\to\infty}$ based on the realised length of stay in the SMK and the expected workload following from one bed based on these values. Table 12 in appendix H shows the values for $Pr^{i}_{n\to\infty}$ based on the theoretical duration of the care pathways in the SMK.

6.1.2 VALIDATION

Since treatment plans, which describe the true demand for care of patients, are currently not registered in a way that enables automated analysis, it is not possible to measure the actual demand for care. Therefore, it is at this moment not possible to perform a quantitative validation of the forecasting model. However, we expect, based on conversations with therapists, schedulers and a rehabilitation specialist, that there are currently differences between the treatment plans and the care pathways. As a result of this, we expect that there is a difference between the predicted workload and the actual workload. If the care pathways are in accordance with the treatment plans, then this difference does not occur. Since the treatment plans are not registered, it is currently not possible to quantitatively validate whether these differences exist and how large these differences are. When it is possible to measure the actual workload their might show up differences between the actual workload and the predicted workload. If the actual workload does not lie within the prediction interval in the first few weeks of the forecast, then it is possible that these differences are caused by differences between the care pathways and the treatment plans. In the first few weeks the prediction relies on known information about the care pathways where patients receive treatment for, and thus it is not logical that a possible forecasting error in these weeks is caused by the prediction of the care pathways of the patients in treatment. Another possible reason, for differences between the predicted workload and the actual workload in the first weeks of the prediction, is a difference between the ratio used for group therapy treatment and the realised ratio for group therapy treatment. A situation where the predicted workload and the actual workload are approximately equal in the first weeks of the prediction, but start to differ further on in the prediction (week 10 or larger), could indicate that the used forecasting method, to determine the care pathways for which yet to arrive patients need treatment, is not in accordance with practice. A possible reason why the used method is not in accordance with practice, is that seasonality in the arrivals of patients is currently not modelled in the developed forecasting model.

6.2 INPUT SETTINGS FOR EXPERIMENTATION

Before we perform experimentation with the forecasting model described in chapter 5, we define input settings. The input of the model consist of four different parts as described in paragraph 5.2. It is possible to vary the input for these four different parts. During most of the experiments we perform, we use settings that match the situation in the SMK. In the rest of the research we name these settings the basic settings. We give in this paragraph an overview of the possible variations in the input settings. Thereafter, we give a brief description of the possible variations and the basic settings.

1. The current patients
   - 1.1 The number of known current patients (and thus known care pathways)
     - Equal to number of beds
     - Less than number of beds
     - More than number of beds
   - 1.2 The differences in discharge dates as a result of the length of stay of patients
     - Approximately equal to the discharge date differences of yet to arrive patients, which results in evenly divided discharges per care pathway
     - Centred discharges, many patients discharged in same weeks
   - 1.3 The distribution of the current patients over the care pathways (case mix of current patients)
     - Distribution equal to the distribution of yet to arrive patients
     - Many heavy care pathways
     - Many light care pathways
2. Yet to arrive patients
   - 2.1 The distribution of yet to arrive patients over the care pathways (case mix of yet to arrive patients)
     - Basic
     - Centred, largest percentage of arrivals is divided over one or two care pathways
     - Homogeneous, the number of arrivals is equal for the different care pathways
   - 2.2 Length of the care pathways
     - Basic

- Theoretical duration of care pathways in the SMK

3. Current patients and yet to arrive patients

   3.1 Content of the care pathways of patients (workload per week per discipline for every care pathway)

   - Basic
   - High variation in the workload following from the different care pathways

   3.2 The number of different possible care pathways

   - 8 care pathways (situation in the SIR care unit of the SMK)
   - 2 care pathways

4. The number of beds in use: only possible to set for the entire forecasting horizon

   - Equal to the number of current patients
   - Less than the number of current patients
   - More than the number of current patients

There are several possible variations in the information that is known about the patients who are already in treatment at the moment of prediction (called 'current patients' from now on). It is possible to vary the number of current patients. It is also possible to vary the length of stay of current patients and, as a result of this, the differences in discharge dates of the patients. It is possible that the length of stay of current patients varies from the length of stay of yet to arrive patients. Therefore, we use a setting where the differences between the discharge dates of the current patients are approximately similar to the average discharge date differences of yet to arrive patients and a setting where the discharge dates of current patients are more centred than the discharge dates of yet to arrive patients. More centred discharge dates represent a situation where many patients are discharged in the same period. We also vary the distribution of the current patients over the different care pathways. Table 13 in Appendix I gives an overview of the basic settings for the current patients. Table 13 and Table 14 in Appendix I give for the current patients the possible variations in the input settings.

We identify two possible variations in the input concerning the yet to arrive patients, namely the case mix of yet to arrive patients and the treatment duration of the different care pathways. For the case mix of yet to arrive patients it is possible to vary the distribution over the different care pathways. We define three possible situations, namely a situation where the case mix is equal to the historical case mix in the SMK, a situation where the largest part of the arrivals is divided over one or two care pathways and a situation where the division is homogeneous over the different possible care pathways. Table 15 in Appendix I gives an overview of these different settings. Table 16 shows the probabilities that an arriving patient needs treatment for a specific care pathway for the three different situations. For the treatment duration of the care pathways we use a situation where the length of the care pathways is equal to the realised length of stay in the SMK and a situation where the length of the care pathways are equal to the theoretical duration of the care pathways in the SMK. This setting applies to the yet to arrive patients, this means that the treatment duration of the current patients can be different. Table 17 in Appendix I gives the input settings for the treatment duration of the different care pathways.

Also, we identify two possible variations in the input that hold for the current patients and the yet to arrive patients. These variations concert variations in the care pathways. In the experiments we use a setting where the number of care pathways is equal to the number of care pathways in the SMK and a situation where there are only two different care pathways. We also vary the workload following from the care pathways. We define two different settings, namely a setting where the workloads are equal to the workload following from the care pathways in the SMK (Basic) and a setting with high variation in the workload following from the care pathways. Table 17 in Appendix I gives the input settings for the workload following from the care pathways. Table 18 gives an overview of the settings in the case of 2 care pathways.

The last input we vary is the number of beds in use for the forecasting horizon. Since the number of beds in use at the SIR care unit was equal to 24 in the period 2013 until 2015 we use this as basic setting for the number of beds. Table 10 gives an overview of the number of beds in all scenarios we perform.

6.2.1 EXPERIMENTS

Table 10 gives an overview of the scenarios we perform. Scenario 1 is the scenario where we use all the basic settings. In all the other scenarios we vary one input compared with scenario 1 to show the effect of changing this input variable.

Table 10; An overview of the input settings for the different scenarios

#	1.1: # of current patients	1.2: Discharge dates current patients	1.3: Case mix current patients	2.1: Case mix yet to arrive patients	2.2: Length of CPs for yet to arrive patients	3.1: Variation workload for CPs	3.2: # of CPs	4: # of beds
1	24	Basic	Basic	Basic	Basic	Basic	8	24
2	16	Basic	Basic	Basic	Basic	Basic	8	24
3	32	Basic	Basic	Basic	Basic	Basic	8	24
4	24	Centred	Basic	Basic	Basic	Basic	8	24
5	24	Basic	Heavy	Basic	Basic	Basic	8	24
6	24	Basic	Light	Basic	Basic	Basic	8	24
7	24	Basic	Basic	Centred	Basic	Basic	8	24
8	24	Basic	Basic	Homogeneous	Basic	Basic	8	24
9	24	Basic	Basic	Basic	Theoretical	Basic	8	24
10	24	Basic	Basic	Basic	Basic	High	8	24
11	24	Basic	Basic	Basic	Basic	Basic	2	24
12	28	Basic	Basic	Basic	Basic	Basic	8	28

6.3 RESULTS

6.3.1 EXPLANATION OF ILLUSTRATION METHODS

This paragraph describes the results following from the different scenarios we perform. We use the forecasts for the discipline physiotherapy as example in the results. The model also forecasts the workload distribution for the other disciplines, but since the effects of the different input settings are approximately the same for the different disciplines, and, the most important objective of this paragraph is to show these effects, we do not describe the results for the other disciplines. We forecast the workload distribution for a certain forecasting horizon in week 0, therefore the results of the forecast start in week 1.

Figure 21 shows the distribution of the workload for scenario 1 in a certain week, namely week 100, of the forecasting horizon for the discipline physiotherapy. The different colours in Figure 21 correspond to prediction intervals with different confidence levels. For instance, the 95 percent prediction interval (PI) shows the values for which the cumulative probability on a certain workload is between 2.5 percent and 97.5 percent. Since the values following from the prediction are discrete, we use the first workload x for which the cumulative probability is larger than 2.5 percent and the last workload y for which the cumulative probability is smaller than 97.5 percent to show the prediction interval. All values within a prediction interval with a certain confidence level fall within a prediction interval with a larger confidence level. This means that all values of the 50 percent PI are also part of the 95 percent PI. We use the same colours throughout this report to show the different PIs. Thus, we show the 50 percent PI using dark blue and the 95 percent PI using light blue.

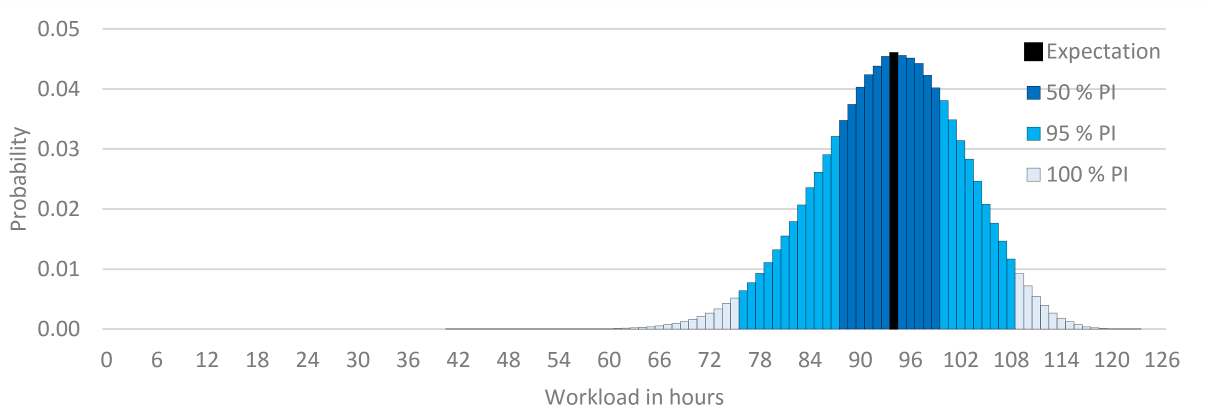

Figure 21; Forecast of workload distribution for physiotherapy based on scenario 1 in week 100

Figure 22 shows the forecast not for one certain week as in Figure 21, but for a forecasting horizon of 100 weeks. Figure 22 shows the PIs and the expectation of the workload for all 100 weeks of the forecasting horizon. Figure 22 does not show information about the distribution within a certain prediction interval. This means that, using the way of illustration as in Figure 22, a distribution where all weight for the workload between 2.5 percent and 25 percent lies on one value has the same appearance as a distribution where the weight is evenly distributed between 2.5 percent and 25 percent. However, we think that for illustrating the different effects, the prediction interval shows enough information. Thus, we use the illustration method as in Figure 22 in this paragraph, unless this method does not show the influences of a scenario in a clear way. As Figure 22 shows, the forecasts stabilises and stops broadening after twenty weeks. All current patients are discharged at this moment and new patients arrive according to the same distribution for the whole forecasting horizon, thus the workload distribution converges to the distribution of yet to arrive patients. In the scenarios all current patients are ultimately discharged after week 24 (longest duration of a care pathway is 24 weeks). Therefore, we only show the first 25 weeks of the forecasts when describing the results for the scenarios where we change the input settings for current patients. For the scenarios where we change the settings for the yet to arrive patients, we show the results for week 76 until week 100, such that the influences of current patients do not affect the results.

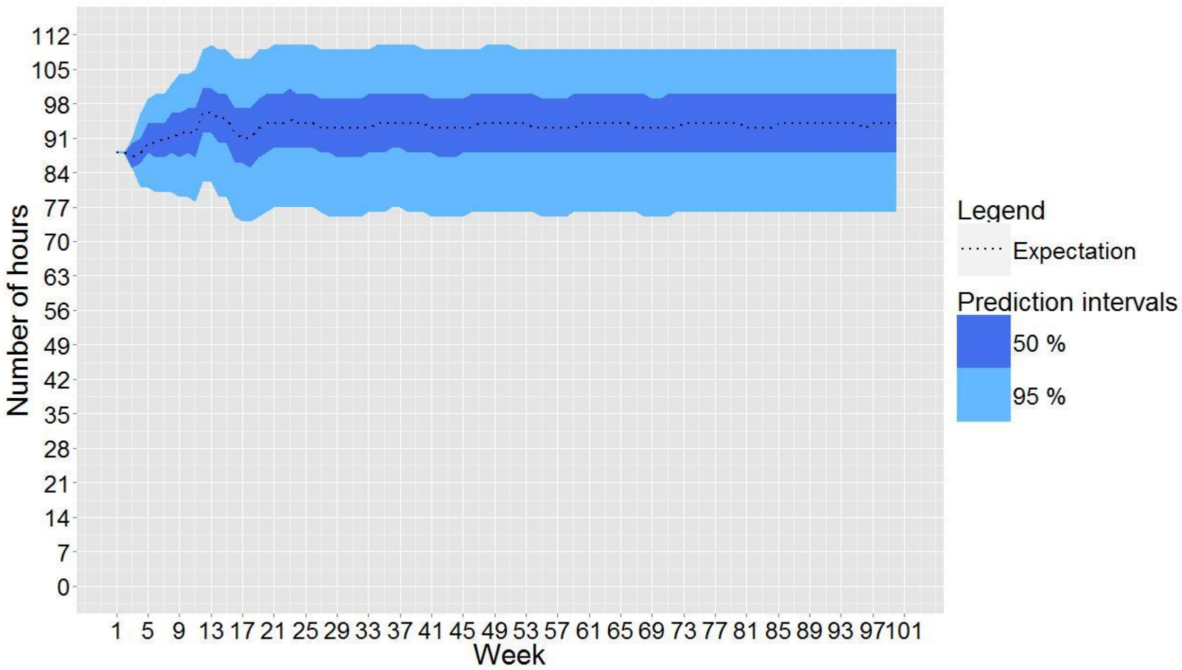

Figure 22; Forecast of workload distribution physiotherapy based on scenario 1 with forecasting horizon of 100 weeks

6.3.2 RESULTS

Figure 23 shows the forecast for scenario 1 for the first 25 weeks of the forecast. Figure 23 shows that in the first week the care pathways are known for all beds. Over time the forecast becomes broader, because of uncertainty about the patients who are admitted in the future. In week 6 of the prediction the bandwidth of the 95 percent PI is equal to 20 hours. In week 25 of the prediction the bandwidth of the 95 percent PI is equal to 33 hours. The bandwidth of the 50 percent PI is equal to 7 hours in week 6 and equal to 12 hours in week 25. A therapists is on average 21.1 hours per week available for care (59 percent of a 36 hour contract, see Table 2), thus the bandwidth of 12 hours of the 50 percent PI in week 25 is approximately equal to half of the hours one therapist is available for care in a week. Figure 23 shows a small increase in the workload between week 11 and 12, the predicted workload is higher between week 12 and week 15 and between week 15 and 16 the predicted distribution of the workload decreases again. The reason for these fluctuations is that the case mix of patients in treatment in these weeks is slightly heavier than the average case mix. Since in almost all realistic cases the average case mix distribution of yet to arrive patients over the care pathways contains non-integer values for a certain number of beds, it is not possible to perfectly mimic the average case mix distribution with the case mix distribution of current patients (which contains an integer number of patients per care pathway). We compare the rest of the results of the scenarios with the results of scenario 1, therefore Figure 24 shows the forecast for scenario 1 in week 76 until week 100.

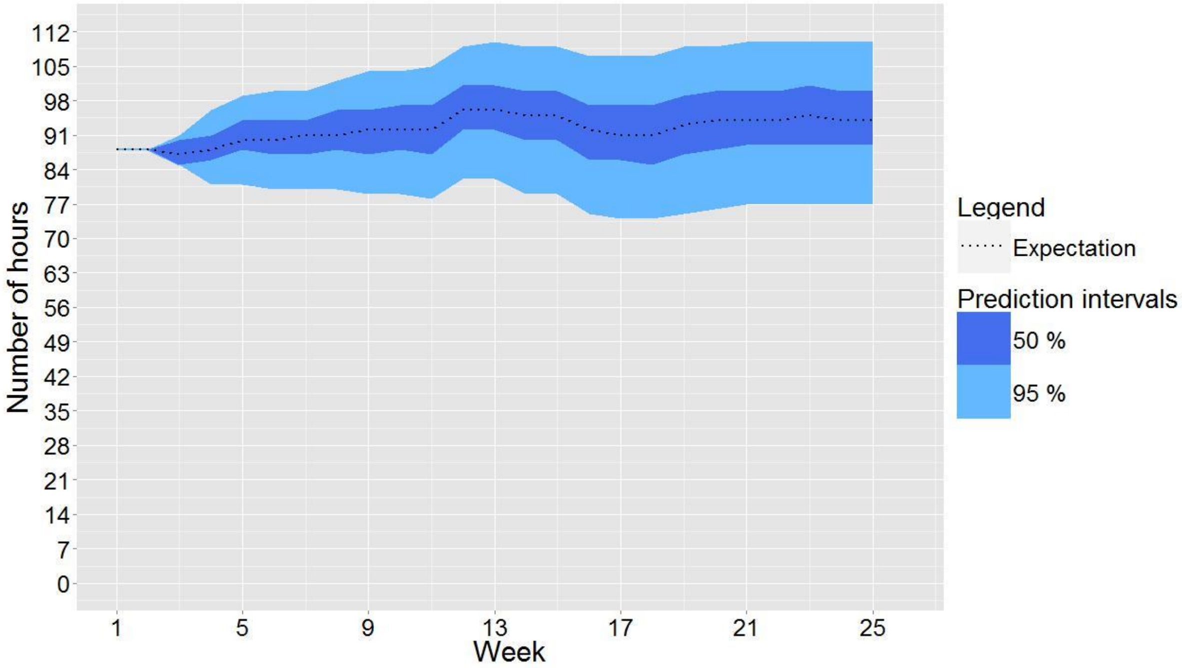

Figure 23; Forecast of the demand for care for discipline Physiotherapy based on scenario 1 for week 1 until week 25

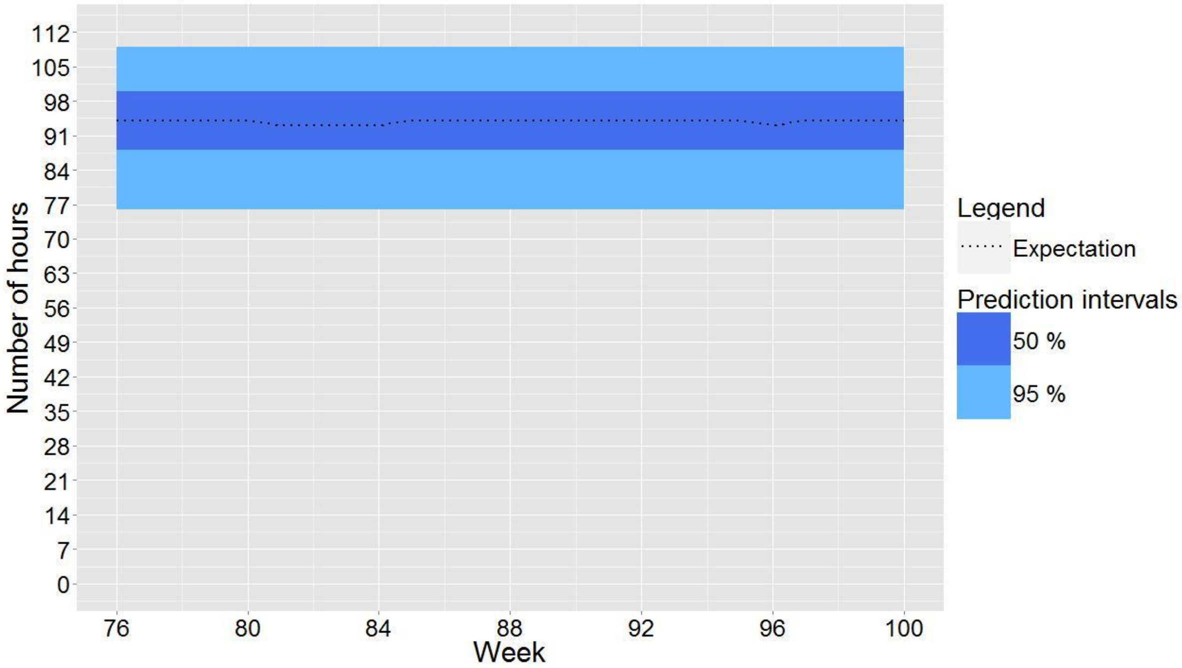

Figure 24; Forecast of the demand for care for discipline Physiotherapy based on scenario 1 for week 76 until week 100

Figure 25 shows the results for scenario 2 (less current patients than beds to use). Figure 25 shows the effects of the change in the number of known care pathways for patients at the moment of the prediction, while the number of beds in use is not changed. From the start on there is uncertainty in the care pathways of the patients in treatment and thus is the distribution relatively broad from the start on. Moreover, the workload increases over time because the number of beds occupied increases with time. Patients have to arrive before the beds are occupied and thus the workload will gradually increase. This scenario represents a situation where there are currently not many patients in treatment. Since the predicted workload is low in the first weeks, the number of therapists deployed can be lowered or a number of outpatients can be admitted for this period. It is important to take the forecast for all disciplines into account when deciding about the admissions of new patients, since a low predicted workload for one discipline does not necessarily mean that the predicted workload is also low for the other disciplines. Also, it is important to take the period for which the workload is lower into account together with the treatment duration of the patients, when admitting extra outpatients.

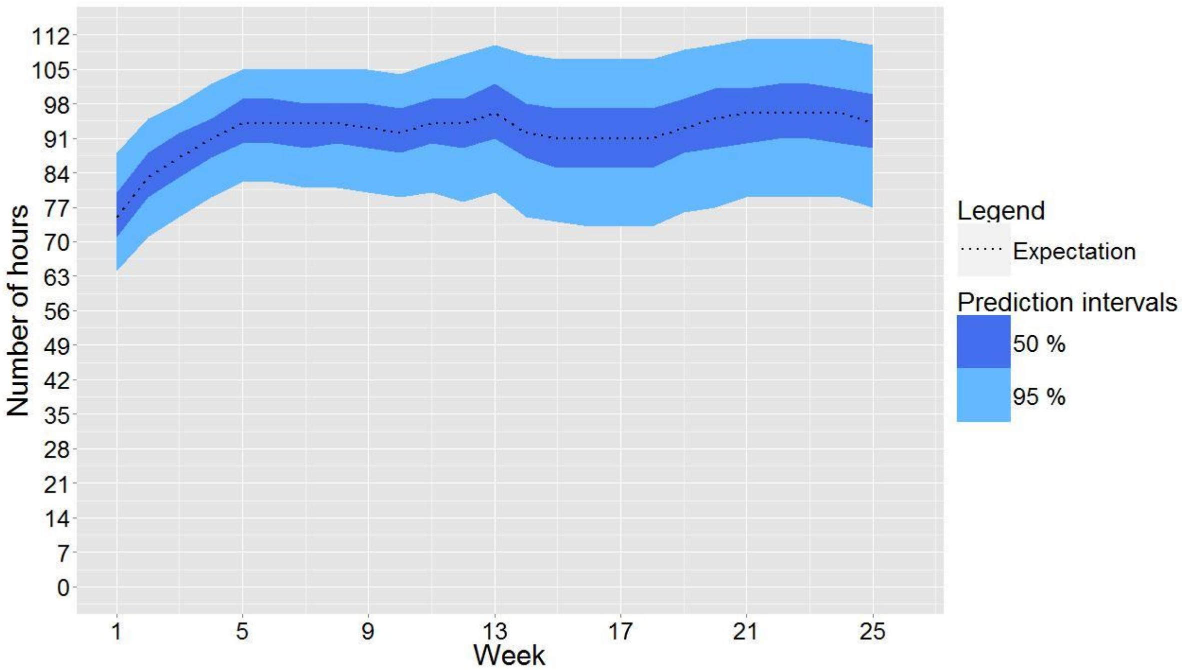

Figure 25; Forecast of the demand for care for discipline Physiotherapy based on scenario 2

Figure 26 shows the results for scenario 3 (more current patients than beds to use). The effects in scenario 3 are the opposite of the effects in scenario 2. Figure 26 shows that week six is the first week in which the predicted number of patients in treatment becomes lower than the number of beds in the scenario, because the distribution starts to broaden in this week. When the number of current patients in treatment is higher than the number of beds for the forecasting horizon, these patients are not directly discharged. The patients are discharged according to their discharge date and no new patients are admitted until the number of patients becomes lower than the number of beds used for the forecasting horizon. If the number of patients in treatment is higher than the number of beds to use in the coming period, the distribution of the workload slowly decreases to the average workload following from the number of beds to use. In the first period patients are discharged and no new patients are admitted such that beds become empty and the number of beds to use in the forecasting horizon is attained. This scenario shows the results for a situation where the number of beds in use is lowered to decrease the workload. As a result of the treatment duration of the patients in treatment, it takes some time before beds become empty and the workload decreases.

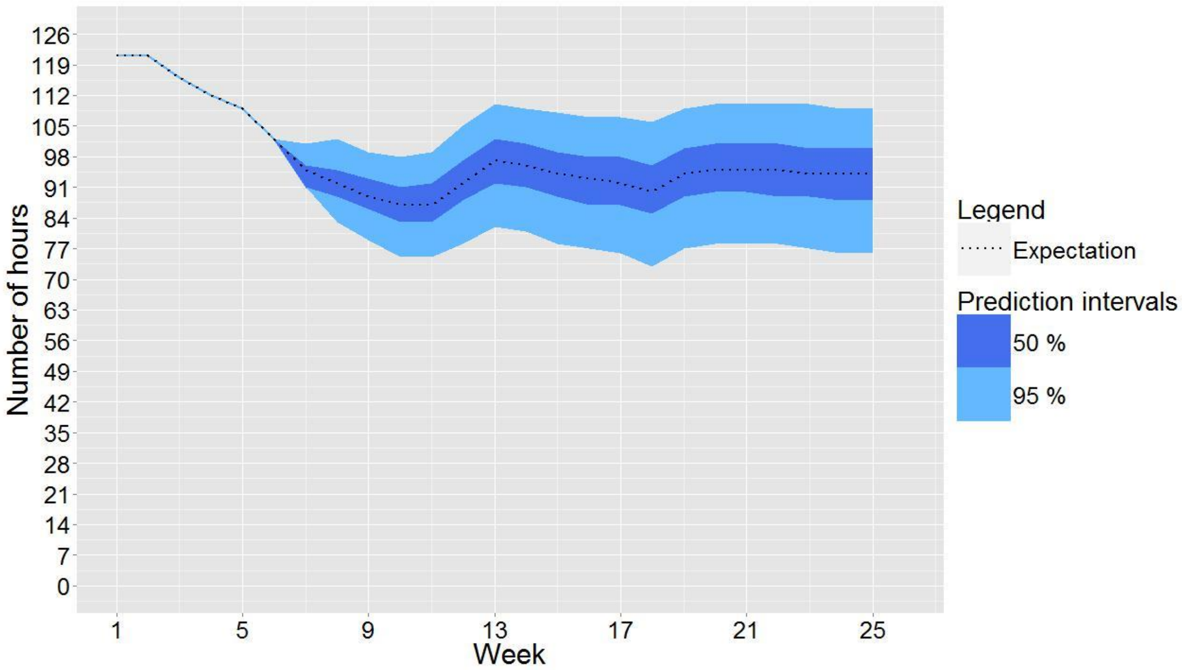

Figure 26; Forecast of the demand for care for discipline Physiotherapy based on scenario 3

If the discharge dates of a group of patients are closer together than the average centeredness of the discharge dates, then the distribution of the workload falls in the period that these patients are discharged. Scenario 4 (centred discharge dates) contains the effects of this phenomenon. Figure 27 shows the effect. Many patients are discharged in week 7, and thus decreases the predicted workload in this week. In the following weeks the beds become occupied again and the predicted workload increases as a result of this. The effect does not repeat itself after a certain period, because of the differences in duration of the care pathways of yet to arrive patients and the differences in the arrival time of new patients. If many beds become empty beds at the same time, then part of the beds are not directly filled and thus some of beds stay empty. The workload distribution is lower in these weeks and it is possible to admit extra outpatients in this period (with a short duration) or to decrease the use of therapists capacity for care in this period.

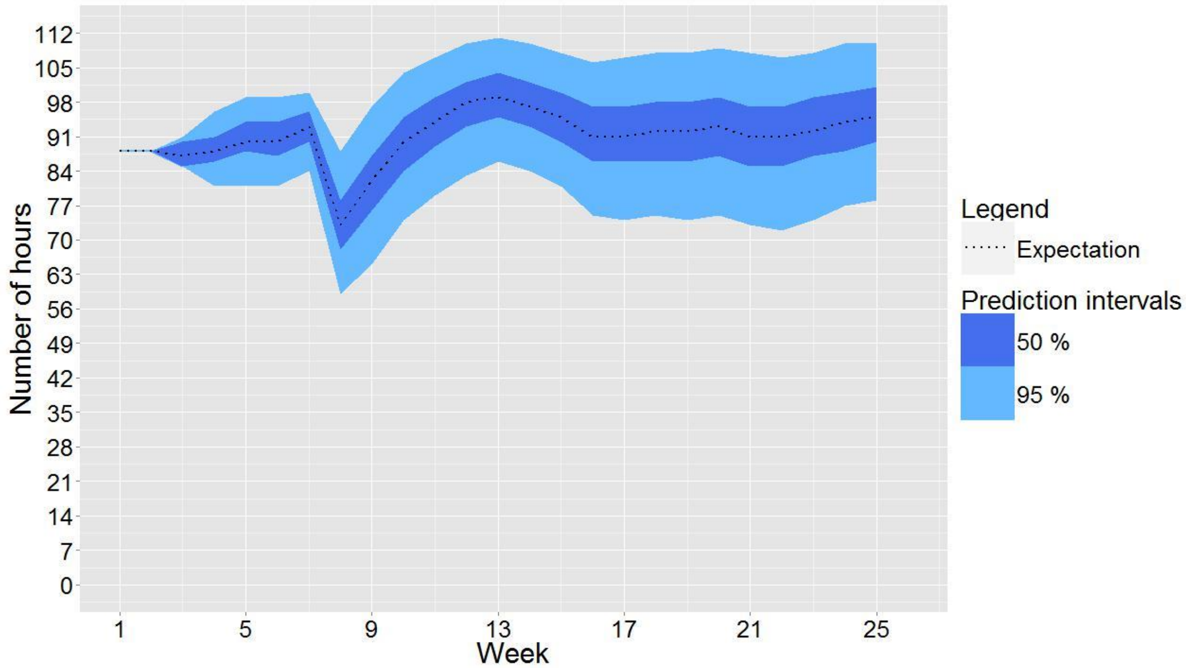

Figure 27; Forecast of the demand for care for discipline Physiotherapy based on scenario 4

If the workloads of the care pathways of the current patients are on average higher than average workload following from one bed for the case mix higher, then the predicted workload distribution is higher in the first few weeks and will slowly convert to the average. Figure 28 shows this situation, it corresponds to scenario 5 (heavy case mix for current patients). Table 11 in Appendix I shows that the expected workload following from one bed is equal to 3.9 hours for the basic scenario. This means that the average workload following from the 24 beds is equal to 93.6 hours. The average workload converts to this value, as Figure 28 shows. It is possible to increase the use of therapist capacity for care in this period if the expectation is that the therapy need of outpatients is not lower than on average.

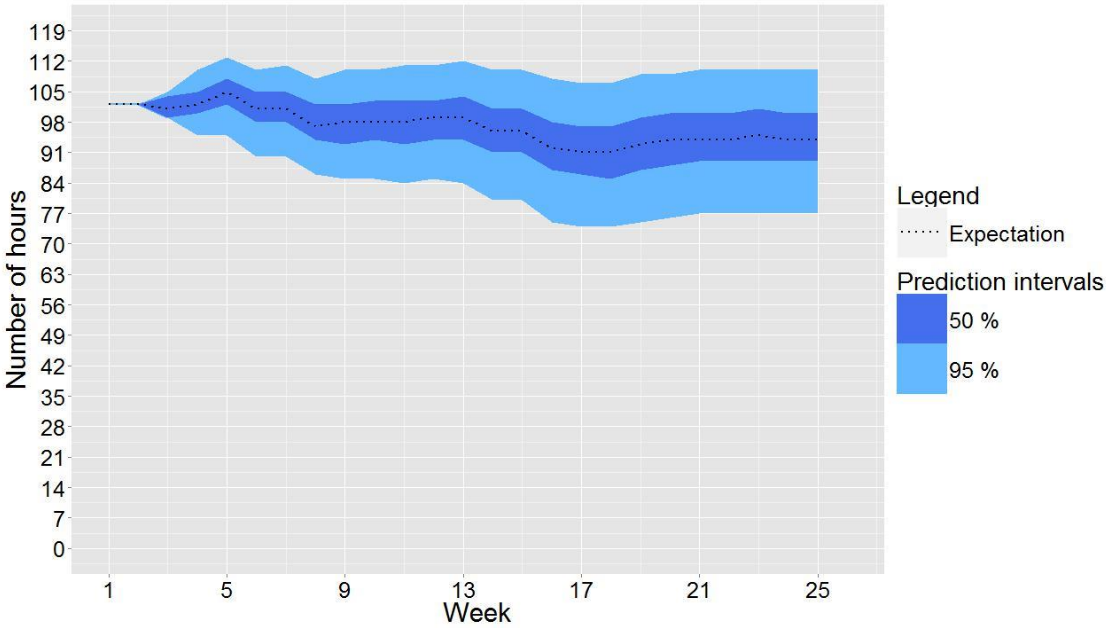

Figure 28; Forecast of the demand for care for discipline Physiotherapy based on scenario 5

If the workload of the care pathways of the current patients are on average lower than the average workload then the predicted workload is lower in the first few weeks and slowly converts to the average. Figure 29 shows this effect. This corresponds to scenario 6 (light case mix for current patients). The effect is the opposite of the effect for scenario 5. It is possible to admit extra outpatients in this period or to decrease the use of therapists capacity for care in this period.

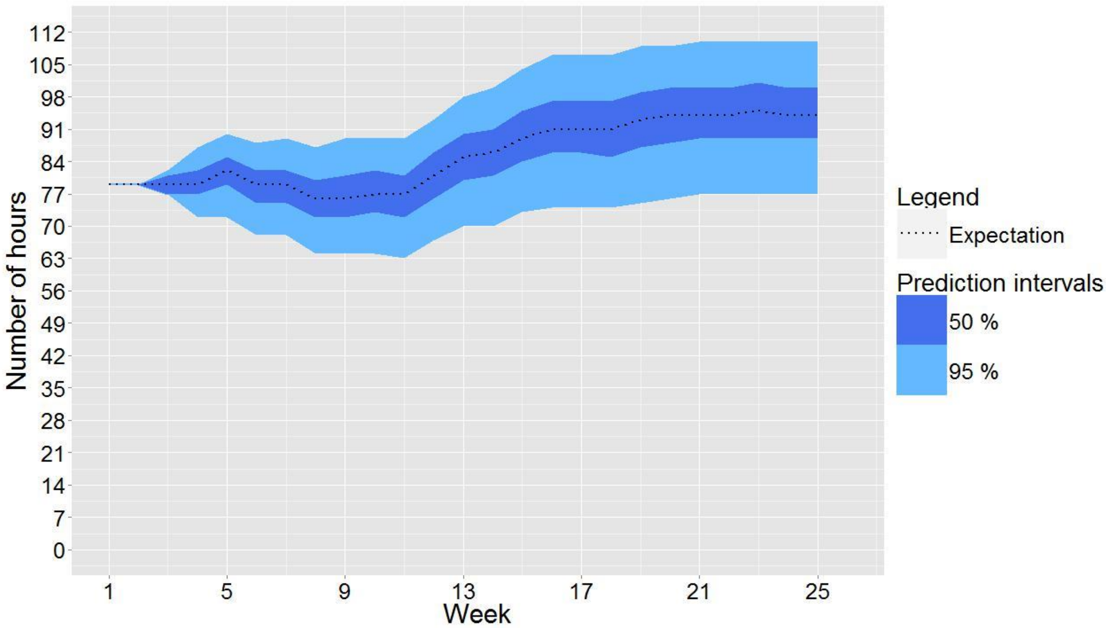

Figure 29; Forecast of the demand for care for discipline Physiotherapy based on scenario 6

Figure 30 and Figure 32 show the effects for scenario 7 (centred case mix for yet to arrive patients) and scenario 8 (homogeneous case mix for yet to arrive patients). Figure 30 shows that the bandwidth of the prediction intervals is smaller than in scenario 1 and scenario 8, because of the centration of patients to specific care pathways (and thus a centration to specific workloads). The main effects of these scenarios are not clearly visible in Figure 30 and Figure 32. Figure 31 and Figure 33 show the distribution of the workload for the discipline physiotherapy in week 100 for scenario 7 and scenario 8. We forecasted the workload for a long period, such that there are no influences of the patients in treatment at the start of the prediction on the results. Figure 31 and Figure 33 show the effects of scenario 7 and scenario 8. As a result of the centration of the arrivals to one or two care pathways the weight of the distributions concentrates to specific values for the workload. A homogeneous distribution of yet to arrive patients over the care pathways as in scenario 8 results in a more evenly distributed workload. The scenarios show that there is little uncertainty in the predicted workload if there are many patients that need treatment for the same care pathway because the treatment needs are in that case the same for many patients.

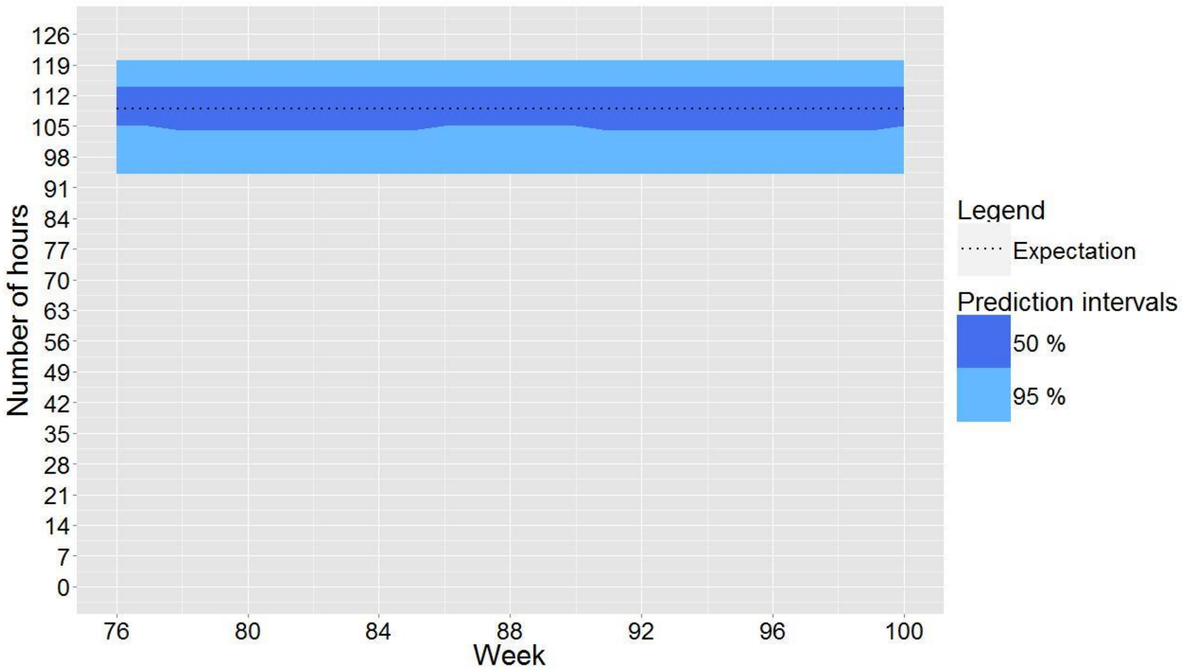

Figure 30; Forecast of the demand for care for discipline Physiotherapy based on scenario 7 for week 76 until week 100

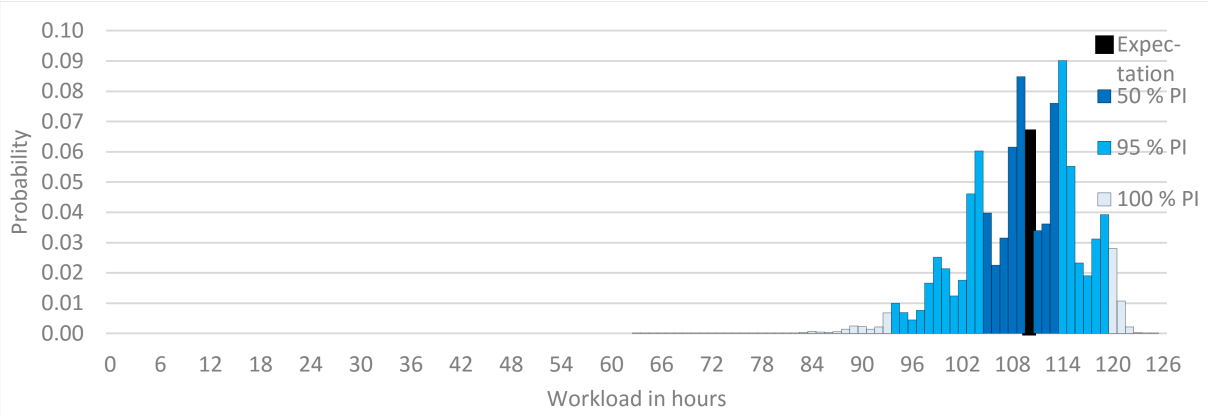

Figure 31; Forecast of the demand for care for discipline Physiotherapy based on scenario 7 in week 100

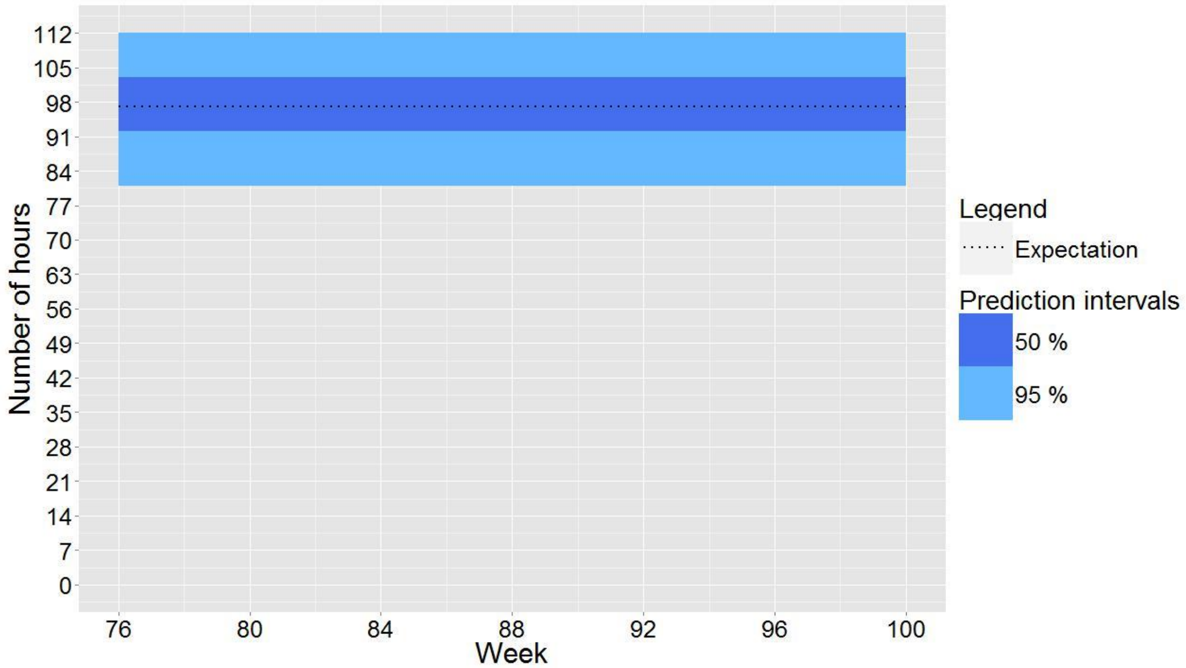

Figure 32; Forecast of the demand for care for discipline Physiotherapy based on scenario 8 for week 76 until week 100

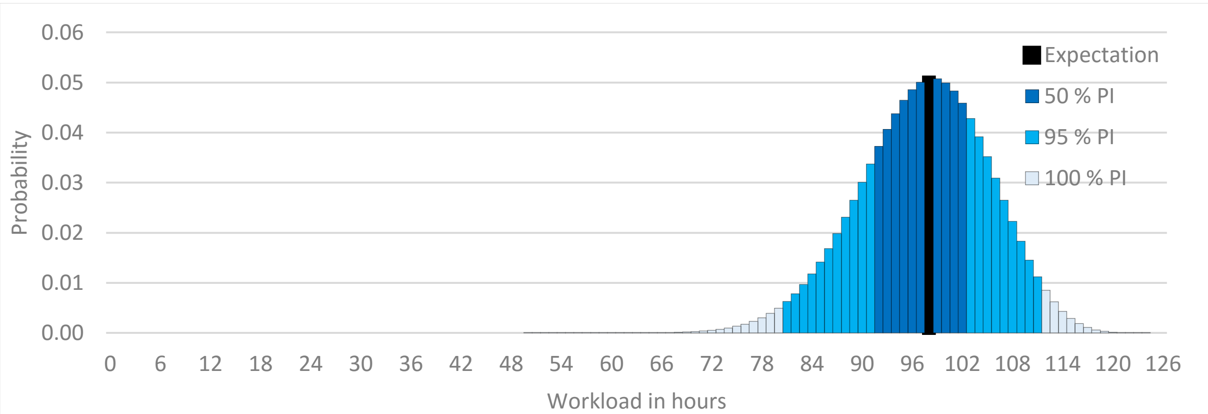

Figure 33; Forecast of the demand for care for discipline Physiotherapy based on scenario 8 in week 100

Figure 34 shows the result for scenario 9 (length of stay of yet to arrive patients based on theoretical duration). The forecast is almost the same as for scenario 1. The distribution is for scenario 9 slightly smaller than for scenario 1, because the duration of the care pathways are longer in this scenario. Longer care pathways cause less changes of the care pathways in the beds. Therefore, there are less possibilities how the beds are filled, which results in a smaller distribution. Moreover, the prediction of the workload is slightly higher in scenario 9 than in scenario 1. The reason for this is that mainly the duration of care pathways with high workloads becomes longer as Table 17 in appendix I shows. Care pathways with a longer duration result in less uncertainty about the predicted workloads and thus result in a smaller workload distribution.

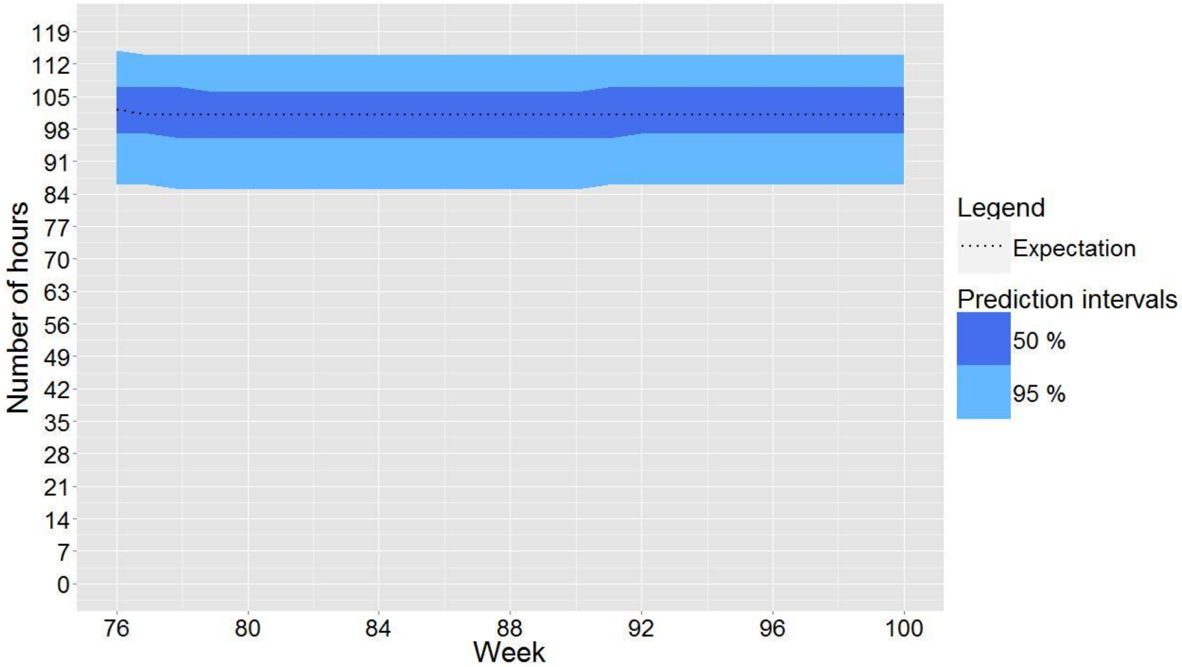

Figure 34; Forecast of the demand for care for discipline Physiotherapy based on scenario 9 for week 76 until week 100

Figure 35 shows the results for scenario 10 (high variation in workload of care pathways). In scenario 10 the variation in workloads between care pathways is higher than in the other scenarios. This results in a broader distribution as Figure 35 shows. Thus, when differences in therapy needs between care pathways are high, the distribution of the workload is broad and there is less certainty about the need for therapists.

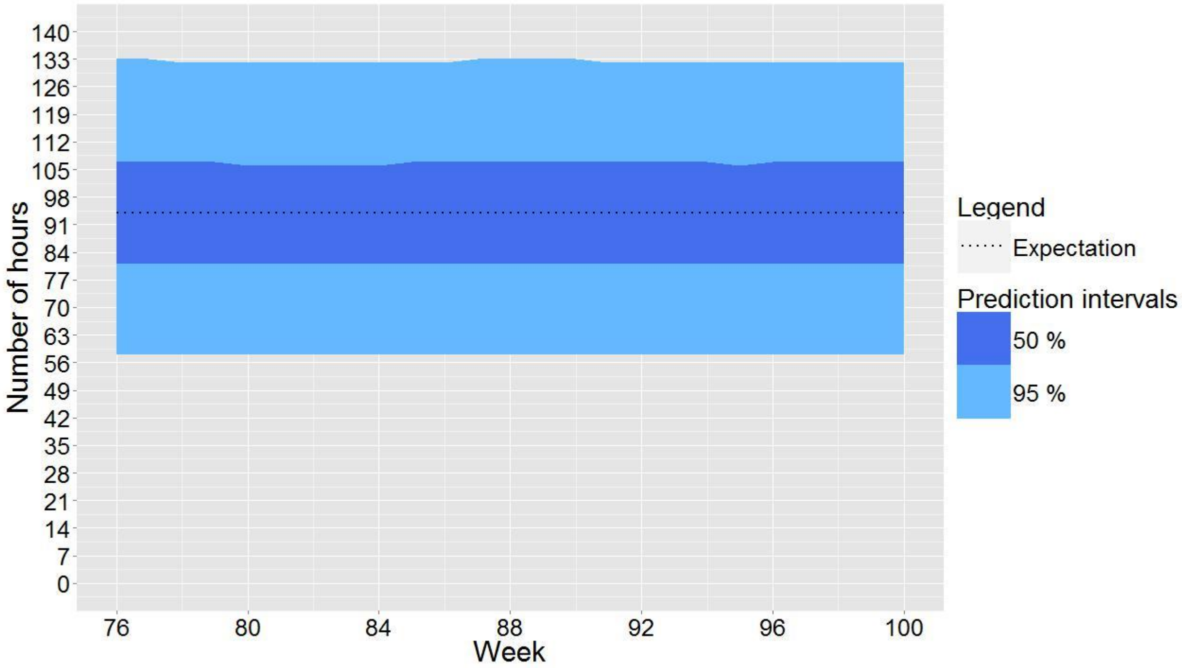

Figure 35; Forecast of the demand for care for discipline Physiotherapy based on scenario 10 for week 76 until week 100

Figure 36 shows the distribution of the workload for the discipline physiotherapy in week 100 for scenario 11 (two care pathways) and Figure 37 shows the forecasted distribution of the workload for week 76 until week 100 for scenario 11.We forecasted the workload for a long period, such that there are no influences of the patients in treatment at the start of the prediction on the results. Figure 36 shows that the weight of the probability distribution shifts to specific workloads if there are only two care pathways, compared with a situation where there are more care pathways. The effects of the settings are for this scenario comparable with effects in scenario 7 (centred case mix for yet to arrive patients). When there are less care pathways there are less possible workloads, and thus concentrates the distribution to specific workloads. If a care unit treats patients for only a few different care pathways, and the workloads per discipline are approximately the same for these care pathways, then the probability distribution of the workload will be small for this care unit if the number of patients in treatment is constant.

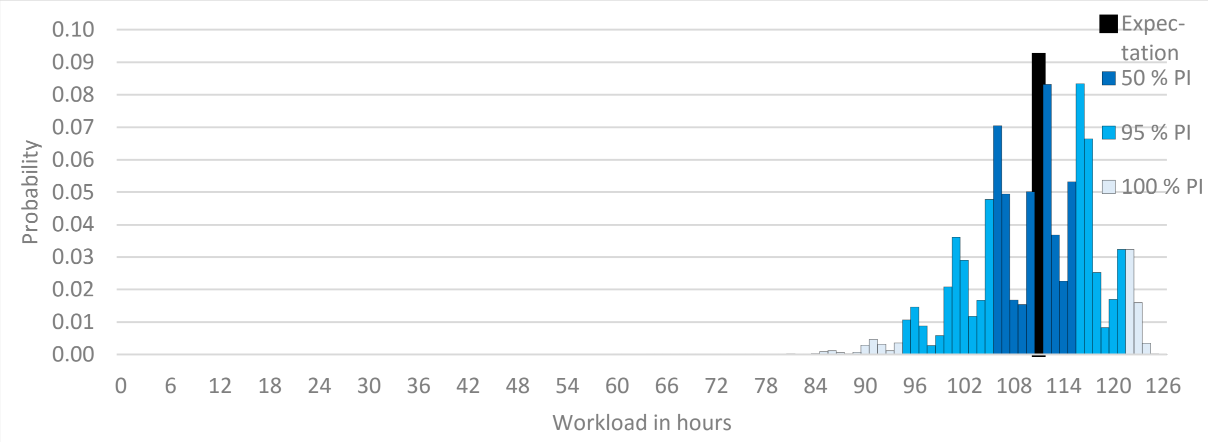

Figure 36; Forecast of the demand for care for discipline Physiotherapy based on scenario 11 in week 100

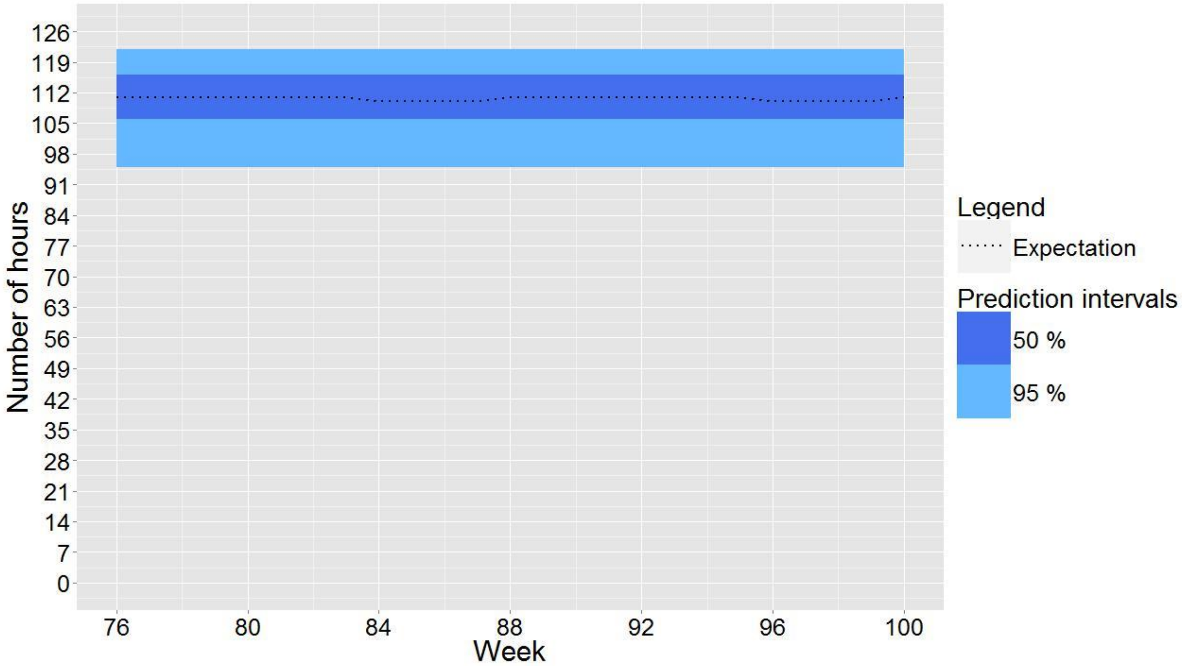

Figure 37; Forecast of the demand for care for discipline Physiotherapy based on scenario 11 for week 76 until week 100

Figure 38 shows the results of the forecast for scenario 12 (higher number of beds in use). The difference with the other scenarios is that the number of beds in use was 28 in scenario 12, where it was 24 in the other scenarios. The effect of this difference is that the predicted distribution of the workload is higher than in the other scenarios, since there are more patients treated when there are more beds in use. The PIs of the forecasted workload distribution are slightly broader in scenario 12 than in scenario 1 as Figure 39 shows. However, the 95 percent PI is relatively to the mean smaller for scenario 12 than for scenario 1. Also, variations are relatively smaller because of the average higher workload.

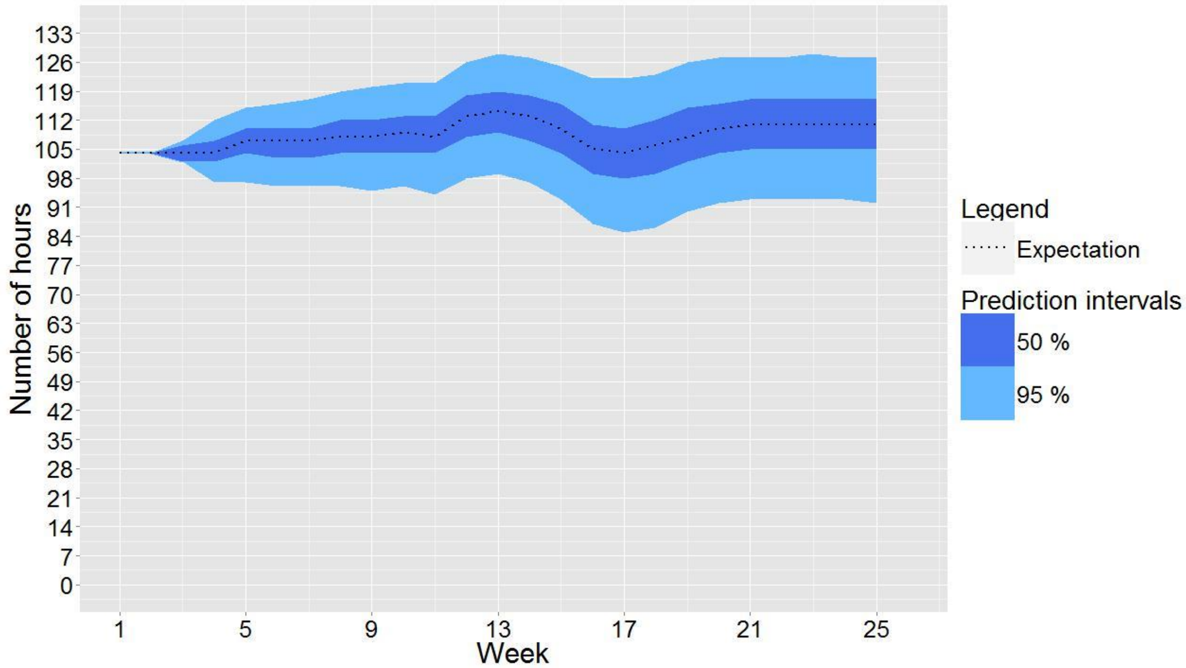

Figure 38; Forecast of the demand for care for discipline Physiotherapy based on scenario 12

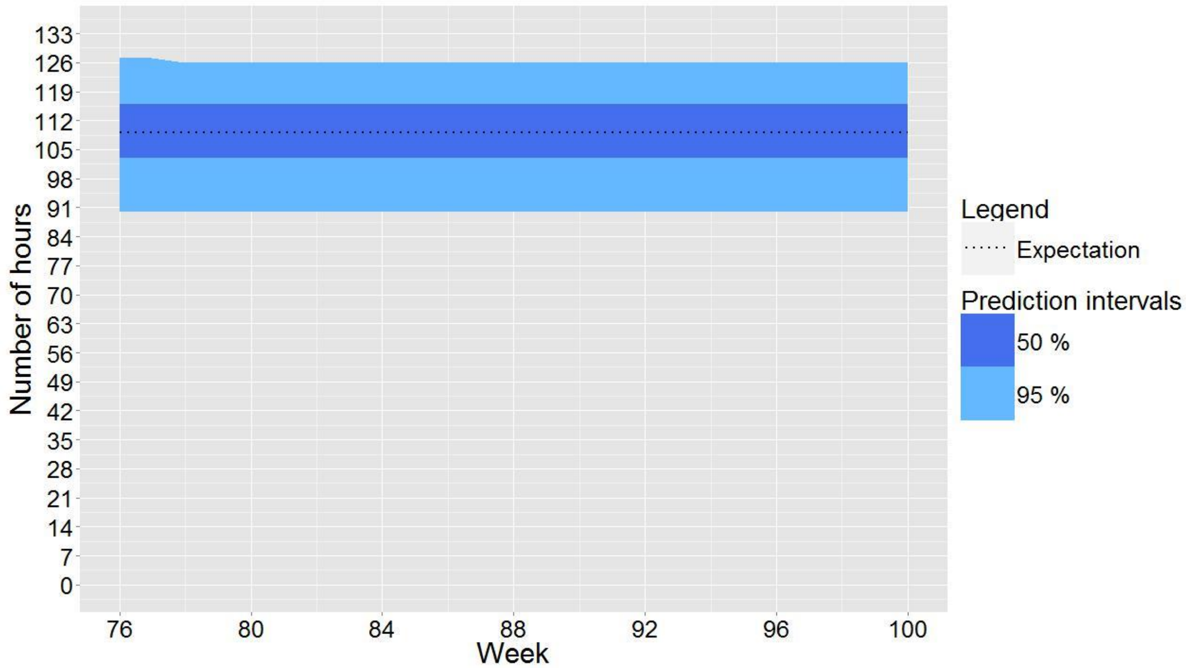

Figure 39; Forecast of the demand for care for discipline Physiotherapy based on scenario 12

6.4 MANAGERIAL IMPLICATIONS

With the developed forecasting model it is possible to forecast the probability distribution of the workload following from the inpatients that are treated in a care unit for the different disciplines. When data registration is improved, a quantitative validation can be performed. Thereafter, it is possible to use the model in practice. The forecasting model forecasts per discipline the distribution of the total workload following from the care pathways where patients need treatment for. The number of therapist hours needed to schedule the workload is probably higher than the workload following from the forecasting model, because it is almost certainly not possible to schedule all therapy appointments perfectly. It is important to take this into account when using the forecasting model. It is essential that there is balance between the demand for care and the available capacity for care, such that patients can receive the treatments that they need and resources can be used efficiently. Cancelling therapies might increase the length of stay of patients. At least it decreases the speed of rehabilitation of patients. As a result of an increase in the length of stay of patients the number of patients who can be treated will be lower for the same amount of beds than with an lower length of stay. Moreover, it increases the costs of treatment per patient. The forecast gives information about the expected workload in the coming period, and thus it can be used to support in making medium-term decisions about the admissions of (out)patients, the use of the annual hour system for deployment of therapist capacity and the division of therapist capacity over VWS time and patient-related time in a certain period to balance the demand for care and the available capacity for care. It is possible to use the forecasting model for instance once in every four weeks to forecast the demand for care for a time horizon of ten weeks. In this way it can support in medium-term decisions and possibly needed short-term corrections. One of the findings from the experiments performed with the model is that the more information is known, the narrower the bandwidth of the forecast becomes. The bandwidth of the forecast becomes smaller because of an increase in the number of current patients, an increase in the duration of care pathways, or a lower variation in workload between care pathways. These parameters increase the information known about possible future workloads or decrease the uncertainty about possible future workloads. If the predicted workload is high in a certain period, because of for instance a heavy case mix of current patients, then it is not the time to admit new (out)patients and methods to increase the therapists capacity for care can be used. If the predicted workload is low, because there are currently not many patients in treatment, or because many patients are discharged in the same period, then the number of therapists deployed can be decreased or a number of (out)patients can be admitted. It is important to take the forecast for all disciplines into account when deciding about the admissions of new patients and it is important to take the period for which the workload is lower into account when admitting new patients. It is important that all disciplines are considered when the model is used to make decisions about the admissions of patients and it is important to take the period for which the workload is lower into account when admitting new patients. As a result of the multidisciplinary nature of rehabilitation care it seems more challenging to admit patients in such a way that the demand for care is in balance with the therapist capacity for care for all disciplines than to adapt the deployment of therapists to the demand for care for all disciplines, certainly in a situation where most patients need to be admitted soon after referral to the hospital because of the nature of their disease.

6.5 CONCLUSION

With the developed forecasting model it is possible to forecast the probability distribution of the workload following from the inpatients that are treated in a care unit for the different disciplines. When data registration is improved, a quantitative validation can be performed. Thereafter, it is possible to use the model in practice. It is possible to use the forecasting model not only at the SIR care unit in the SMK, but also at other care units in other hospitals or rehabilitation centres with different care pathways and different arrival rates. The forecast gives information about the expected workload in the coming period. Thus, the forecast can be used to support in making medium-term decisions about the admissions of (out)patients, the use of the annual hour system for deployment of therapist capacity and the division of therapist capacity over VWS time and patient-related time in a certain period to improve the balance between the demand for care and the deployment of therapists. One of the most important findings from the experiments performed with the model is that the more information is known, the more the probability distribution concentrates to specific values for the workload and the more certainty there is about the future workload.

7 CONCLUSION AND DISCUSSION

We discuss the main conclusions of this research in this chapter. Paragraph 7.1 describes the conclusion of this research. Paragraph 7.2 discusses the results and limitations of this research and paragraph 7.3 describes model extensions, recommendations for the SMK and recommendations for further research.

7.1 CONCLUSION

At the start of this research it was unknown what the demand for care was at the SIR care unit for the coming period, which resulted in an imbalance between the need for therapists based on the demand for care and the deployment of therapist capacity. Therefore, we identified the following research objective:

The research objective is to design a prototype decision support model to support the staffing of therapists on a tactical level for the Spinal Injury Rehabilitation care unit of the SMK.

Based on the research objective we formulated research questions. In the rest of this paragraph, we describe a conclusion of the research by answering the research questions.

- *How is the care process and the planning and control process for therapist resource allocation currently organised and what are the main bottlenecks in these processes?*

During the context analysis it became clear that the therapist capacity is fixed long before execution of the care process and it is not clear what the demand for care is for the coming period. Currently, decisions about the deployment of therapists capacity are based on the preferences of therapists since demand is not known for the coming period. As a result, it is difficult to balance deployment of therapists with the demand for care, which is needed to provide the patients with the treatments that they need and to use the available resources efficient. Therefore, we identified a shortage of insight in the demand for care for the coming period as the main bottleneck in this research.

- *What are the key performance measures for therapist resource allocation and what is the current performance on these measures at the SIR care unit of the SMK?*

The key performance measure for therapist resource allocation is the balance between the demand for care and the available therapist capacity for care. Unfortunately, it was not possible to quantify the measurement of the balance, because of the current poor registration methods. The performed measurements of the inpatient demand for care show that there are fluctuations in the demand for care, as a result of differences between the care pathways of patients in treatment. There are also fluctuations in the available capacity of therapists for care and these fluctuations are currently not synchronised with the inpatient demand for care. The performed measurements show that in 2015 there were for both the disciplines Physiotherapy and Occupational therapy a few weeks that the demand for care of inpatients based on their care pathways was higher than the capacity of therapists for in- and outpatient care.

- *What models are there in the literature that support in therapist resource allocation on a tactical level?*

There are several decisions in resource capacity planning to balance the demand for care and the deployment of therapist capacity. It is possible to do this by adjusting the demand for care by using admission planning or varying the quantity of care given to patients and it is possible to do this by varying the deployment of therapist capacity. Before making these decisions, a demand forecast is needed. The literature on resource capacity planning is scarce for rehabilitation care. Most of the resource capacity planning literature for rehabilitation centres focusses on appointment scheduling methods. There are several methods to forecast the number of patients in treatment. We did not find any literature on forecasting the workload following from the patients that are in treatment for a multidisciplinary rehabilitation setting.

- *What is the design of a model to support resource allocation of therapists applicable in the SMK?*

Since care pathways are a guideline according to which patients are treated, we assumed that the demand for care is equal to the need for treatment following from the care pathways. Therefore, we developed a model to forecast the inpatient demand for care based on the care pathways of yet to arrive patients and based on the care pathways of patients in treatment at the moment of the prediction. We computed the probability that a bed is occupied by a patient that needs treatment for a certain care pathway and compute the distribution of the workload following from the patients with their corresponding care pathways for all beds in a care unit. This results in a probability distribution of the demand for care in hours per week per discipline for the forecasting horizon.

- *What are the potential benefits of using the designed model for resource allocation compared with the current situation?*

With the developed forecasting model it is possible to forecast the probability distribution of the workload following from the inpatients that are treated in a care unit for the different disciplines. When data registration is improved at the SIR care unit in the SMK, a quantitative validation can be performed. Thereafter, it is possible to use the model in practice. It is possible to use the forecasting model not only at the SIR care unit in the SMK, but also at other care units in other hospitals or rehabilitation centres with different care pathways and different arrival rates. One of the findings from the experiments performed with the model is that the more information is known, the more the probability distribution concentrates to specific values for the workload and the more certainty there is about the future workload. An increase in the number of known care pathways for which patients need treatment, an increase in the duration of care pathways, and a lower variation in workload between care pathways increase the information known about possible future workloads or decrease the uncertainty about possible future workloads. The forecast gives information about the expected workload in the coming period, and thus it can be used to support in making medium-term decisions about the admissions of (out)patients, the use of the annual hour system for deployment of therapist capacity and the division of therapist capacity over VWS time and patient-related time in a certain period. These methods can be used to improve the balance between the demand for care and the deployment of therapists, which is needed to provide the patients with the treatments that they need and to use the available resources efficient. If the predicted workload is high in a certain period, because of for instance a heavy case mix of current patients, then it is not the time to admit new (out)patients and methods to increase the therapists capacity for care can be used. If the predicted workload is low, because there are currently not many patients in treatment, or because many patients are discharged in the same period, then the number of therapists deployed can be decreased or a number of (out)patients can be admitted. It is important to take the forecast for all disciplines into account when deciding about the admissions of new patients and it is important to take the period for which the workload is lower into account when admitting new patients. Concluding, we made in this research a first step towards supporting the staffing of therapists, by developing a forecasting model which forecasts the inpatient multidisciplinary rehabilitation therapy demand at the SIR care unit in the SMK.

7.2 DISCUSSION

In this paragraph we first describe the limitations of the research. Thereafter, we discuss the assumptions made.

As a result of the current poor registration habits it was not possible to perform a valid quantitative zero-measurement of the therapist resource allocation performance during this research. A quantitative measurement increases the insight in performance and makes it easier to recognise bottlenecks and directions for improvement. The current registration habits are also the reason why it was not possible to perform a validation of the developed forecasting model. We advise to compare the results of the forecast with the workload following from the inpatients based on their treatment plans for a certain amount of time to ensure the validity of the forecast model before using the model. The performed zero-measurement and the developed forecasting model provide insight in the inpatient demand for care. The largest part of the therapy provided in the SIR care unit (approximately 70 percent) is provided to inpatients, but insight in the outpatient demand for care is needed to gain full understanding in the balance between the demand for care and the capacity of therapists. The forecasting model forecasts the distribution of the total workload following from the care pathways where patients need treatment for per discipline. The number of therapist hours needed to schedule the workload is probably higher than the workload following from the forecasting model, because it is almost certainly not possible to schedule all therapies perfectly.

In the forecasting model developed we made several assumptions. In the forecasting model we assume that the care pathways describe the need for therapy of patients. Thus, we assumed, because of the content of the currently used care pathways, that the therapy needs are deterministic and constant over time, as long as patients receive treatment for a care pathway. However, this assumption is currently in practice not true. From discussion with therapists, schedulers and rehabilitation specialists it became clear that there is variation in the treatment needs between patients that need treatment for the same care pathway and that depending on the patient in consideration it is possible that the treatment needs vary over time. When it is desirable, it is possible to extent the forecasting model by making use of stochastic and variable workloads following from the care pathways. This will eliminate the assumption. Variation in the treatment needs of patients because of specific events such as for instance Christmas holidays (we assume that next to the therapists, also patients want to be with their family during the Christmas holidays) or temporary absence of patients (during their inpatient stay) are not taken into account in the model. In this case the forecasting model can be seen as an upper bound of the treatment needs. We assumed that the average ratio between patients and therapists during group therapy is known and that the workload following from the different beds does not interfere each other. However, the ratio between therapists and patients for a group therapy session depends on the number of patients in treatment that need treatment for that specific group therapy. Therefore, it is possible that there are small differences between the predicted workload and the required therapist capacity, because of differences between the realised group therapy ratios in a certain period and the used group therapy ratios. The realised group therapy ratio depends on the number of patients in treatment that need treatment for a specific group. Thus is the therapist capacity needed for the group therapy sessions of a patient not completely independent of the other patients that are in treatment in the current formulation of the forecasting model. In the developed forecasting model we assume that patients receive treatment for one care pathway at a time. In some cases patients are diagnosed for more than one care pathway. However, when patients are diagnosed for two care pathways it does not necessarily mean that patients receive the sum of all treatments described in both care pathways, especially since the frequencies of treatments in the care pathways can be high in rehabilitation care. In the formulation of the forecasting model we assumed that the discharge dates of current patients and the treatment duration of yet to arrive patients are known. Moreover, we assume that the treatment duration of yet to arrive patients is deterministic for the care pathways. This assumption was not true for the patients treated in the period from 2013 until 2015, as Figure 15 shows. However, the care pathways are a guideline according to which patients are treated and it is not known what the reason for the deviations shown in Figure 15 are. It is possible to extent the forecasting model by making use of a stochastic treatment duration to eliminate this assumption, when this is desirable. The current formulation of the model ignores seasonality in arrivals of patients that need treatment for certain care pathways. We assumed that the distribution of yet to arrive patients over the care pathways (including the probability on an empty bed) can be determined and is the same for the whole year. Based on the historical arrivals of patients it is not clear whether there is a seasonal pattern in the arrivals of patients (see Table 8).

7.3 MODEL EXTENSIONS, RECOMMENDATIONS AND FURTHER RESEARCH

7.3.1 FURTHER DEVELOPMENT OF THE FORECASTING MODEL

There are several possible extensions of the forecasting model. A possible extension is to incorporate information from the waiting list. Part of the care pathways is already known for patients who are not in treatment yet, but are admitted when a bed becomes empty. Using this information makes the probability distribution of the workload smaller. Another possible extension is to make use of a probability distribution for the discharge week of a patient, instead of using a strict transition from in treatment to discharged based on the length of the care pathway. This can be based on the realised length of stay of patients or based on an expectation of the discharge date by the multidisciplinary treatment team. It is possible to incorporate a stochastic discharge week in the forecasting model in the same way as Vanberkel et al. calculates the probability that patient is discharged on a certain day [1]. Another possible extension is to make use of time dependent arrival probabilities. Table 8 gives an overview of the division of requests for care pathways over the year at the SIR care unit. It is possible that there are seasonal patterns in the arrivals of care pathways. When that is the case, it is better to use time dependent arrival probabilities. Another possible extension concerns the workload following from the care pathways where patients receive treatment for. It is possible to make use of stochastic and variable workloads following from the care pathways in the forecasting model, instead of deterministic and constant workloads. With stochastic workloads following from the care pathways where a patient receives treatment for, we mean that instead of a deterministic workload it is possible to use a probability distribution for the workload following from the care pathway where a patient needs treatment for, in a certain week. With variable workloads, we mean differences in the workload between the different weeks of the treatment. Furthermore, it is possible to make use of the treatment plans of current patients when these are registered, instead of their care pathways, to improve the accuracy of the prediction.

7.3.2 RECOMMENDATIONS FOR THE SIR CARE UNIT

This paragraph describes the most important recommendations for the SIR care unit in addition to the recommendations described in paragraph 3.5.

The most important recommendation for the Spinal Injury Rehabilitation care unit in the Sint Maartenskliniek is to improve the registration of care pathways and treatment plans. Registering the care pathways and the treatment plans of patients is essential for calculating the capacity required to serve the case mix in resource capacity planning. When data registration is improved it is also possible to perform a quantitative validation of the forecasting model. Conversations with one of the rehabilitation specialists indicate that the course of the frequency of individual and group treatments in the care pathways are currently not in accordance with the treatment needs of the patients. When treatment plans (i.e. the true demand for care) are registered it is possible to determine stochasticity and variation in the workload following from the treatment needs of patients for a certain care pathway based on historical data, which makes it possible to validate the currently used care pathways. Also, it is possible to research the influences of patient characteristics as for instance age, gender and reason of spinal cord injury on the course of treatment when the registration of treatment plans is improved. One of the possible moments to register these treatment plans at the SIR care unit in the SMK is the weekly meeting in which the multidisciplinary treatment team discusses the progress of all inpatients. In Table 11 and Table 12 in Appendix H the differences between the realised duration of the care pathways and the theoretical duration of the care pathways can be seen and Figure 15 in paragraph 3.3 showed that the duration of the treatments currently varies between patients that receive treatment for the same care pathway. Therefore, we recommend to reconsider the durations of the care pathways. We also recommend to register the start and ending of the treatment for a certain care pathway and the different phases within a care pathway. When the start and ending time of the treatment for a certain request are known it is possible to link the given treatments and the treatment plans with the corresponding care pathways.

Research of Chen et al. shows that there was seasonal variation in the number of Spinal Cord Injuries in the United States between 2005 and 2011 [23]. Table 8 shows that the number of 'Spinal injury T6 and higher' in July in the SMK is higher than in the other months of the year. The main reason for this was that there were eleven 'Spinal injury T6 and higher' patients in 2015. Seasonal variation could be a possible reason for this. Therefore, we suggest to register care pathways of patients even when patients are not are not admitted, such that it becomes possible to identify possible seasonal patterns in the arrivals of patients. Since outpatients have to travel to the SMK and inpatients need time for activities of daily living before 09:00, patients start to become available for therapy from 09:00. Most therapists shifts start between 07:30 and 08:30. Therefore, we recommend to reconsider the starting times of the shifts of therapists or at least schedule meetings between therapists, physicians, nurse specialists, schedulers and management without patients in the first hours of the day. Moreover, we recommend to reconsider the division of therapist capacity over the week. The demand for care is, according to the schedulers, evenly divided over the week for the SIR care unit, in contrast with the current therapist capacity division. A last recommendation for the SMK is to research the effects of using a team of generalised therapists for the different care units at the rehabilitation department in the SMK, since research of Dedden shows that this can increase the number of scheduled therapies for patients [17].

7.3.3 DIRECTIONS FOR FURTHER RESEARCH

Next to the possible extensions for the forecasting model, which we described in paragraph 7.3.1, there are directions for further research, which we describe in this section. Since in most cases therapists do not only treat inpatients, but also outpatients, further research can focus on forecasting the demand for care of outpatients. At the SIR care unit in the SMK, a part of the outpatient demand for care comes from patients that continue with outpatient treatment after inpatient treatment in the SMK. If it is possible to forecast whether patients continue with outpatient treatment, then a part of the outpatient demand for care can be forecasted. Another part of the outpatients is on the waiting list for several weeks and starts with their treatment when there is therapist capacity available for their treatment. For the outpatients on the waiting list it is known what their therapy needs are, thus the demand for care coming from these patients can be forecasted if it is possible to forecast when these patients receive their treatment. Another direction for further research is to forecast demand in more detail. The model developed in this research forecasts demand on a weekly basis, but for operational scheduling of therapists a forecast on daily or even hourly basis is useful. After gaining full insight in the demand for care, the next step in resource capacity planning is the automated support of the planning task [2]. This support can, next to focussing of scheduling therapists, also focus on admission planning to balance demand and the deployment of resource capacity. Thus, a direction for further research is the effect of admission planning on the forecasted demand. The last direction for further research we mention is the development and implementation of appointment scheduling algorithms to find appointment scheduling proposals that are efficient for both patients and therapists [2].

BIBLIOGRAPHY

1. Vanberkel, P.T., et al., *An exact approach for relating recovering surgical patient workload to the master surgical schedule.* Journal of the Operational Research Society, 2011. **62**(10): p. 1851-1860.
2. Braaksma, A., et al., *Integral multidisciplinary rehabilitation treatment planning.* Operations Research for Health Care, 2014. **3**(3): p. 145-159.
3. Trentelman, E., *Resource capacity planning of a spinal injury rehabilitation care unit*, in *Centre for Health Care Operations Improvement and Research (CHOIR)*. 2015, University of Twente.
4. *Collectieve Arbeidsovereenkomst Ziekenhuizen 2014 – 2016*. [Cited: 12-01-2016]; Available from: http://maartensnet/bronnen/peno/handboek/arbeidsvoorwaarden/CAO.ZH.2014-2016.
5. Hans, E.W., M. Van Houdenhoven, and P.J. Hulshof, *A framework for healthcare planning and control*, in *Handbook of healthcare system scheduling*. 2012, Springer. p. 303-320.
6. Buil, J., *Defining and improving congruence between treatment plans and realization in rehabilitation care*, in *Centre for Healthcare Operations Improvement and Research (CHOIR)*. 2015, University of Twente.
7. Hasaart, F., *Incentives in the diagnosis treatment combination payment system for specialist medical care: a study about behavioral responses of medical specialists and hospitals in the Netherlands.* 2011.
8. Hulshof, P.J., et al., *Taxonomic classification of planning decisions in health care: a structured review of the state of the art in OR/MS.* Health systems, 2012. **1**(2): p. 129-175.
9. De Bleser, L., et al., *Defining pathways.* Journal of nursing management, 2006. **14**(7): p. 553-563.
10. Ernst, A.T., et al., *Staff scheduling and rostering: A review of applications, methods and models.* European Journal of Operational Research, 2004. **153**(1): p. 3-27.
11. Kellogg, D.L. and S. Walczak, *Nurse scheduling: from academia to implementation or not?* Interfaces, 2007. **37**(4): p. 355-369.
12. Schimmelpfeng, K., S. Helber, and S. Kasper, *Decision support for rehabilitation hospital scheduling.* OR spectrum, 2012. **34**(2): p. 461-489.
13. Kortbeek, N., *Quality-driven efficiency in healthcare.* 2012.
14. Podgorelec, V. and P. Kokol, *Genetic algorithm based system for patient scheduling in highly constrained situations.* Journal of medical systems, 1997. **21**(6): p. 417-427.
15. Chien, C.-F., F.-P. Tseng, and C.-H. Chen, *An evolutionary approach to rehabilitation patient scheduling: A case study.* European Journal of Operational Research, 2008. **189**(3): p. 1234-1253.
16. Ogulata, S.N., M. Koyuncu, and E. Karakas, *Personnel and patient scheduling in the high demanded hospital services: a case study in the physiotherapy service.* Journal of medical systems, 2008. **32**(3): p. 221-228.
17. Dedden, A.L., *Therapist capacity planning*, in *Centre for Health Care Operations Improvement and Research (CHOIR)*. 2014, University of Twente.
18. Kadri, F., et al., *Time series modelling and forecasting of emergency department overcrowding.* Journal of medical systems, 2014. **38**(9): p. 1-20.
19. Archer, B.H., *Forecasting demand: quantitative and intuitive techniques.* International Journal of Tourism Management, 1980. **1**(1): p. 5-12.
20. Ozcan, Y.A., *Quantitative methods in health care management: techniques and applications*. Vol. 4. 2005: John Wiley & Sons.
21. Kros, J.F., et al., *Census forecasting in an inpatient rehabilitation facility*, in *Advances in Business and Management Forecasting*. 2013. p. 3-13.
22. Team, R.C., *R: A language and environment for statistical computing. R Foundation for Statistical Computing*. 2015: Vienna, Austria.
23. Chen, Y., et al., *Causes of spinal cord injury.* Topics in spinal cord injury rehabilitation, 2013. **19**(1): p. 1-8.
24. Hulshof, P.J.H., et al., *ORchestra: an online reference database of OR/MS literature in health care.* Health Care Management Science, 2011. **14**(4): p. 383-384.

APPENDICES

APPENDIX A

Abbreviations:

ADL	Activities of Daily Living
AT	Activity therapist (*activiteitentherapeut*)
BAG	Movement therapist (*bewegingsagoog*)
CAO	Chronic pain, amputation and orthopedic rehabilitation (*chronische pijn, amputatie en orthopedische revalidatie*)
CP	Care pathway (*zorgpad*)
DIET	Dietician (*diëtist*)
DTC	Diagnosis Treatment Combination (in Dutch DBC)
ET	Occupational therapist (*ergotherapeut*)
FT	Physiotherapist (*fysiotherapeut*)
HIS	Hospital information system (*ziekenhuisinformatiesysteem*)
LG	Speech therapist (*logopedist*)
LOS	Length of stay
MW	Social worker (*maatschappelijk werk*)
MSS	Master Surgical Schedule
PI	Prediction Interval
PS	Psychologist (*psycholoog*)
SIR	Spinal Injury Rehabilitation (*dwarslaesierevalidatie*)
SKL	Sexologist (*sexuoloog*)
SMK	Sint Maartenskliniek

APPENDIX B

Sjabloon zorgprofiel

Naam zorgprofiel: Zorgpad Dwarslaesie T6 en hoger diagnostiek
Verantwoordelijk arts: Ilse van Nes
Behandelend team: Dwarslaesie

Hoofddiagnose (zet een kruisje achter juiste groep):

Aandoeningen bewegingsapparaat	
Amputatie	
Hersenen	
Neurologie	
Dwarslaesie	X
Organen	
Chronische pijn	
Anders/ combinatie	

Fase behandeling (zet een kruisje achter juiste fase):

01 Intake	
02 Diagnostiek	X
03 Poliklinische behandeling	
04 Klinische behandeling	
05 Ontslag	
06 Nazorg	

Betrokken disciplines (zet een kruisje bij betrokken disciplines):

Activiteitentherapie (AT)	X
Bewegingsagoog (BAG)	
Cognitief trainer (CT)	
Diëtist (DIET)	
Ergotherapeut (ET)	X
Fysiotherapeut (FT)	X
Logopedist (LG)	X
Medische dienst (MD) (incl verpleegkundig specialist)	X
Maartschappelijk werk (MW)	X
Orthopedagoog (OP)	
Psycholoog (PS)	X
Peuterleidster (PG)	
Psychomotore therapeut (PMT)	
Psychologisch medewerker (PSM)	
Sexuoloog (SKL)	
Verpleegkundige (VPK)	

Voorschrift capaciteitsinzet per week gedurende 2 weken:

Discipline	AT	BAG	CT	DIET	ET	FY	LG	MD	MW	OP	PS	PG	PMT	PSM	SKL	VPK
Frequentie individuele behandeling	1				8	9	2	1	1/1		1					
Duur behandeling (30 of 60 minuten)	60				30	30	30	90	60/30		60					
Frequentie groepsbehandeling																
Duur behandeling (30 of 60 minuten)																
Indirecte tijd (totaal aantal min)	30				60	60	30		30		30					
Totaal aantal weken	1				2	2	2		1		1					

Opmerkingen voorschrift:

APPENDIX C

Sjabloon zorgprofiel

Naam zorgprofiel: Zorgpad Dwarslaesie T6 en hoger behandeling
Verantwoordelijk arts: Ilse van Nes
Behandelend team: Dwarslaesie

Hoofddiagnose (zet een kruisje achter juiste groep):

Aandoeningen bewegingsapparaat	
Amputatie	
Hersenen	
Neurologie	
Dwarslaesie	X
Organen	
Chronische pijn	
Othere/ combinatie	

Fase behandeling (zet een kruisje achter juiste fase):

01 Intake	
02 Diagnostiek	
03 Poliklinische behandeling	
04 Klinische behandeling	X
05 Ontslag	
06 Nazorg	

Betrokken disciplines (zet een kruisje bij betrokken disciplines):

Activiteitentherapie (AT)	X
Bewegingsagoog (BAG)	X
Cognitief trainer (CT)	
Diëtist (DIET)	X
Ergotherapeut (ET)	X
Fysiotherapeut (FT)	X
Logopedist (LG)	X
Medische dienst (MD) (incl verpleegkundig specialist)	
Maartschappelijk werk (MW)	X
Orthopedagoog (OP)	
Psycholoog (PS)	X
Peuterleidster (PG)	
Psychomotore therapeut (PMT)	
Psychologisch medewerker (PSM)	
Sexuoloog (SKL)	X
Verpleegkundige (VPK)	

Voorschrift capaciteitsinzet per week gedurende 22 weken:

Discipline	AT	BAG	CT	DIET	ET	FY	LG	MD	MW	OP	PS	PG	PMT	PSM	SKL	VP K
Frequentie individuele behandeling	3	2		1	5	8	2		1		1				1	
Duur behandeling (30 of 60 minuten)	60	30		30	30	30	30		60		60				30	
Frequentie groepsbehandeling		1			8	12			1							
Duur behandeling (30 of 60 minuten)		30			30	30			210							
Indirecte tijd (totaal aantal min)	10	10			30	15	12		15		15					
Totaal aantal weken	22	22		22	22	22	22		11/5		11				1	

Opmerkingen voorschrift: voorlichting 90 min door ET, FT, PS, MW, MD en VPS (2x)

APPENDIX D

Kies specialisme	○ Reumatologie ◉ Revalidatie
Verantwoordelijke arts	
Behandelend arts	
Wachtlijstcategorie	○ Acuut ○ Spoed ○ Electief ○ PM
Behandeltraject	◉ dagbehandeling ○ klinische behandeling
Reden gebruik formulier	◉ nieuw traject ○ doorlooptraject ○ mutatie traject ○ stop
Diagnose	
Opmerkingen	
Behandelteam REV	○ ACHN ◉ DWLS ○ Kind PRB ○ Neuro PRB ○ Zoom-In ○ CWZ ○ CHOR ○ Kind klinisch ○ Neuro klinisch ○ PEUT ○ Boxmeer ○ Tiel
Behandelfase DWLS	○ Diagnostiek ◉ Behandeling ○ Nazorg
DWLS behandeling protocol	☐ Baclofenpomp klinisch ☐ Doorloop poliklinisch ☐ Guillain barre ☐ Regulier poliklinisch ☐ Baclofenpomp poli ☐ Dwarslaesie overig ☐ Lokomat ☐ Sportloket ☐ Bolus baclofen ☐ Dwarslaesie T5 en lager ☐ Oncologie ☐ Wondenspreekuur ☐ Decubitus ☐ Dwarslaesie T6 en hoger ☐ Overig ☐ Zitadvies

DWLS Dwarslaesie T7 en lager	DWLS Dwarslaesie T7 en lager Individueel direct: • ACT 1x (30 min) • ET 3x (30 min) • FT 6x (30 min) • MD 1x (90 min) • MW 1x (60 min) • PS 1x (60 min)	Individueel indirect • AB 1x (30 min) -> eenmalig • ET (30 min) • FT (30 min) • MW 1x (30 min) -> eenmalig • PS 1x (30 min) -> eenmalig Duur: 2 weken

APPENDIX E

Care pathway	Outpatient treatment				Inpatient treatment				Total
	New trajectory	Continuation trajectory	Mutation trajectory	Stop	New trajectory	Continuation trajectory	Mutation trajectory	Stop	
Sitting advice	51	1	10						**64**
Wound consultation			2						**2**
Baclofen pump outpatient	1								**1**
Arm/hand function screening	6				1				**7**
Standard outpatient	38		3		1				**42**
Outpatient continuation		10	6			9	4	1	**30**
Sports desk	3		21	2			3		**29**
Lokomat	5		4						**9**
Other	367	13	164	3	34	1	7	5	**594**
After care	93								**93**
Not found	19	6	61	295	7	22	87	189	**690**
Spinal injury other	9	2	2		10	2	2	2	**29**
Baclofen pump					39		1	3	**43**
Bolus baclofen					14			1	**16**
Decubitus	5				61	2	4	3	**76**
Spinal injury T7 and lower	23	3	6	1	110	7	16	30	**198**
Spinal injury T6 and higher	23	4	12	4	146	5	18	30	**243**
Guillain Barré	1	1	2		10		4	7	**26**
Oncology	1		1		17			4	**23**
Total	**645**	**40**	**294**	**305**	**450**	**48**	**146**	**275**	**2215**

De zorgpaden van patiënten worden geregistreerd in de aanvraagformulieren behandelplan. In is een voorbeeld te zien van een aanvraagformulier behandelplan. De arts schrijft op basis van een doorverwijzing van een patiënt naar de SMK een aanvraag behandelplan uit. Vervolgens komt de patiënt op de wachtlijst terecht en zal hij na verloop van tijd starten met zijn behandeling.

In het aanvraagformulier wordt eerst aangegeven of het om een poliklinische of een klinische aanvraag gaat. Vervolgens kunnen verschillende redenen worden aangegeven waarom een aanvraag wordt gedaan. Wanneer het gaat om een aanvraag voor een nieuw zorgpad voor een patiënt kan er gebruik gemaakt worden van de optie 'nieuw traject'. De reden doorlooptraject kan gebruikt worden wanneer een aanvraag wordt gedaan voor een nieuw zorgpad bij de overgang van een klinisch behandeling naar een poliklinische behandeling, of eventueel in uitzonderlijke situaties van een poliklinische behandeling naar een klinische behandeling. Een formulier met de reden mutatie traject kan gebruikt worden wanneer er een wijziging in het behandelplan van een patiënt gedaan moet worden. Daarnaast wordt deze reden soms gebruikt om kleinere zorgpaden aan te vragen die een patiënt krijgt naast een behandeling van een groter zorgpad. Een formulier met de reden stop kan gebruikt worden om aan te geven dat een behandeling stopt of om een aanvraag te annuleren. Het annuleren van een aanvraag kan meerdere redenen hebben, het kan zijn dat het niet mogelijk is om een patiënt te behandelen vanwege organisatorische redenen, maar er kan ook een reden vanuit de patiënt zijn dat de patiënt niet meer in behandeling gaat. Op dit moment wordt de reden van annulering niet geregistreerd.

Nadat de reden van het gebruik van een aanvraagformulier behandelplan is gekozen kan worden aangegeven voor welk zorgpad een aanvraag wordt gedaan. Na het aanvinken van een zorgpad wordt automatisch de hoeveelheid zorg die dat zorgpad bevat ingeladen in het tekstveld, vervolgens kan de arts hier wijzigingen in aanbrengen wanneer een specifieke patiënt meer of minder zorg nodig heeft. Momenteel is het niet mogelijk om de geleverde zorg te koppelen aan een specifiek aanvraagformulier behandelplan, daarnaast is er geen koppeling tussen de aanvraag van een nieuw traject en tussen een mutatie of stop van dit traject mogelijk doordat een patiënt meerdere aanvragen tegelijkertijd open kan hebben staan. Doordat er geen koppeling is tussen de geleverde zorg en de aanvraagformulieren voor een behandeltraject is het niet bekend of een patiënt de voorgeschreven zorg ook ontvangen heeft. Daarnaast is het niet altijd mogelijk om te achterhalen wanneer een behandeling gestart is. Er wordt voor een patiënt een dbc traject gestart wanneer een patiënt in behandeling gaat, dus is bekend welke patiënten behandeld zijn. Echter is niet bekend voor welke zorgpad-aanvragen een behandeling is uitgevoerd.

APPENDIX F

Based on conversations with management and therapists we identified the following objectives and KPIs for the SIR care unit:

<table>
<tr><th></th><th>Quality of care</th><th>Quality of work</th><th>Quality of business</th></tr>
<tr><td>Goals</td><td>The right treatments at the right moment
Short access times
As few different therapists per discipline as possible</td><td>Balance between workload and available capacity
Balance between ‘work and private life’
Working pattern known in time
Limited use of overtime
Enough indirect patient time
Time for research and innovation
A right division between treating patients of your specialisation and treating other patients</td><td>Cost-effective care pathways
Patients receive treatments according to their care pathways
Productivity at the desired level
Working according to the collective agreements</td></tr>
<tr><td>KPIs</td><td>Congruence between realised treatment schedule and treatment plans
Division of treatments over the week
Access time
therapist per discipline for individual therapy</td><td>Balance between demand for care and therapist capacity for care
Ratio direct / indirect time</td><td>Margin on the care pathways
Congruence between realised treatment schedule and care pathways
Productivity
Bookings degree</td></tr>
</table>

APPENDIX G

We used three databases for literature research, namely: Orchestra, Web of Science and Scopus. The "ORchestra Bibliography" is a detailed bibliography provided by the Centre for Healthcare Operations Improvement & Research (CHOIR) at the University of Twente (http://www.utwente.nl/choir) [24].

We performed the following search queries:

Orchestra:

Medical subject: Rehabilitation Centers : 15 results

Included articles: [14], [16], [15], [12]

Web of Science (TS = Topic; TI = Title; SU = subject area):

TS=(Rehabilitation Center OR Rehabilitation hospital) AND SU= (OPERATIONS RESEARCH MANAGEMENT SCIENCE) : 70 results

Included articles: [15], [1], [12]

Scopus (ABS = Abstract; KEY = Keywords):

TITLE (rehabilitation) AND TITLE-ABS-KEY (resource OR workforce OR capacity) AND TITLE-ABS-KEY (planning OR staffing OR scheduling): 645 results

Included articles: [2], [12], [15]

Furthermore, we used reference search (forward & backward citing) from [8].

APPENDIX H

Table 11; Information care pathways for a specific bed based on realised length of stay at the SIR care unit

Care pathway	$Arrivals_{i}$	$P^{i}_{arrival}$	$Duration_{i,LOS}$	$Pr^{i}_{n\rightarrow\infty,LOS}$	$Workload^{i,F1}$	Expected workload
Baclofen pump	36	0.051	1	0.010	2.5	0.024
Bolus baclofen	14	0.020	1	0.004	2	0.007
Decubitus	53	0.075	11	0.155	1.667	0.258
Spinal injury other	8	0.011	8	0.017	4.583	0.078
Spinal injury T6 and higher	120	0.169	13	0.414	4.75	1.967
Spinal injury T7 and lower	87	0.123	11	0.254	5.25	1.333
Guillain Barré	8	0.011	15	0.032	5.25	0.167
Oncology	13	0.018	5	0.017	4.333	0.075
Empty	369	0.521	1	0.098	0	0.000
Total	**708**	**1**		**1**		**3.909**

Table 12; Information care pathways for a specific bed based on theoretical duration of care pathways

Care pathway	$Arrivals_{i}$	$P^{i}_{arrival}$	$Duration_{i,CP}$	$Pr^{i}_{n\rightarrow\infty,CP}$	$Workload^{i,FT}$	Expected workload
Baclofen pump	36	0.051	2	0.012	2.5	0.030
Bolus baclofen	14	0.020	1	0.002	2	0.005
Decubitus	53	0.075	12	0.107	1.667	0.179
Spinal injury other	8	0.011	18	0.024	4.583	0.111
Spinal injury T6 and higher	120	0.169	24	0.486	4.75	2.309
Spinal injury T7 and lower	87	0.123	18	0.264	5.25	1.388
Guillain Barré	8	0.011	24	0.032	5.25	0.170
Oncology	13	0.018	4	0.009	4.333	0.038
Empty	369	0.521	1	0.062	0	0.000
Total	**708**	**1**		**1**		**4.230**

APPENDIX I

Table 13; Basic input settings for input variable current patients (left) and input settings for a higher number of current patients (right)

Patient	Remaining LOS	CP
1	2	1
2	3	2
3	4	3
4	5	4
5	6	7
6	7	8
7	8	5
8	9	6
9	10	1
10	11	3
11	12	3
12	13	5
13	14	6
14	15	5
15	16	4
16	17	5
17	3	1
18	5	3
19	7	3
20	8	1
21	10	7
22	13	8
23	12	6
24	15	5

Patient	Remaining LOS	CP
1	2	1
2	3	2
3	4	3
4	5	4
5	6	7
6	7	8
7	8	5
8	9	6
9	10	1
10	11	3
11	12	3
12	13	5
13	14	6
14	15	5
15	16	4
16	17	5
17	2	1
18	3	3
19	4	3
20	5	1
21	6	7
22	7	8
23	8	6
24	9	5
25	10	7
26	11	3
27	12	2
28	13	5
29	14	6
30	15	5
31	16	4
32	17	5

Table 14; Variations in the input settings for the current patients (centered discharges (left), heavy case mix (middle) and light case mix (right))

Patient	Remaining LOS	CP
1	2	1
2	3	2
3	4	3
4	5	4
5	7	7
6	7	8
7	7	5
8	7	6
9	10	1
10	8	3
11	8	3
12	13	5
13	14	6
14	7	5
15	16	4
16	17	5
17	3	1
18	7	3
19	15	3
20	8	1
21	7	7
22	15	8
23	7	6
24	15	5

Patient	Remaining LOS	CP
1	2	1
2	3	2
3	4	3
4	5	4
5	6	7
6	7	7
7	8	5
8	9	6
9	10	1
10	11	7
11	12	3
12	13	7
13	14	6
14	15	7
15	16	6
16	17	5
17	3	1
18	5	7
19	7	6
20	8	1
21	10	7
22	13	6
23	12	6
24	15	5

Patient	Remaining LOS	CP
1	2	1
2	3	2
3	4	3
4	5	4
5	6	7
6	7	8
7	8	5
8	9	6
9	10	1
10	11	3
11	12	3
12	13	3
13	14	2
14	15	1
15	16	8
16	17	4
17	3	1
18	5	5
19	7	6
20	8	1
21	10	7
22	13	8
23	12	3
24	15	2

Table 15; Settings for distribution of yet to arrive patients over the care pathways (care pathway 9 is 'empty' care pathway)

Care pathway	Name of care pathway	Basic setting # of arrivals	Centred setting # of arrivals	Homogeneous setting # of arrivals
1	Baclofen pump	36	1	55
2	Bolus baclofen	14	1	55
3	Decubitus	53	1	55
4	Spinal injury other	8	1	55
5	Spinal injury T6 and higher	120	150	55
6	Spinal injury T7 and lower	87	135	55
7	Guillain Barré	8	1	55
8	Oncology	13	1	55
9	Empty	369	300	200

Table 16; Settings for distribution of yet to arrive patients over the care pathways in probabilities

Care pathway	Name of care pathway	Basic setting # of arrivals	Centred setting # of arrivals	Homogeneous setting # of arrivals
1	Baclofen pump	0.051	0.002	0.086
2	Bolus baclofen	0.020	0.002	0.086
3	Decubitus	0.075	0.002	0.086
4	Spinal injury other	0.011	0.002	0.086
5	Spinal injury T6 and higher	0.169	0.254	0.086
6	Spinal injury T7 and lower	0.123	0.228	0.086
7	Guillain Barré	0.011	0.002	0.086
8	Oncology	0.018	0.002	0.086
9	Empty	0.521	0.508	0.313

Table 17; Input settings for the care pathways

Care pathway	Name of care pathway	Basic duration CPs	Theoretical duration CPs	Basic workloads for discipline FT	High variation in workload for discipline FT
1	Baclofen pump	1	2	2.5	1.5
2	Bolus baclofen	1	1	2	1
3	Decubitus	11	12	1.667	0.5
4	Spinal injury other	8	18	4.583	5
5	Spinal injury T6 and higher	13	24	4.75	2
6	Spinal injury T7 and lower	11	18	5.25	10
7	Guillain Barré	15	24	5.25	8
8	Oncology	5	4	4.333	7
9	Empty	1	1	0	0

Table 18; Input settings for the case with two care pathways

Care pathway	Name of care pathway	# of arrivals	Duration of care pathways	Basic workloads for discipline FT
1	Spinal injury T6 and higher	95	13	4.75
2	Spinal injury T7 and lower	200	11	5.25
3	Empty	333	1	0