RESOURCE CAPACITY PLANNING OF A SPINAL INJURY REHABILITATION CARE UNIT

Sint Maartenskliniek

E. Trentelman

UNIVERSITY OF TWENTE.

Sint Maartenskliniek

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Eline Trentelman

Master Industrial Engineering & Management

Health Care Technology & Management

University of Twente

Supervisors

Centre for Healthcare Operations Improvement and Research (CHOIR):

Prof. dr. ir. Erwin Hans

Ingeborg Bikker, MSc

Sint Maartenskliniek:

Ted van den Boom, MHA

Preface

This research is the result of my graduation project, which I performed at the Sint Maartenskliniek in Nijmegen for my Master Industrial Engineering and Management. During my Bachelor in Health Sciences, I got interested in optimizing health care processes and I decided to follow the Master Industrial Engineering and Management. I look back at my master program as a nice and interesting challenge, during which I have learned a lot. Sometimes it was a bit of a struggle, but in the end always with a satisficing result, which confirmed my switch to Industrial Engineering and Management was a good decision.

I would like to thank Ted, my supervisor at the Sint Maartenskliniek, for his feedback and for providing me with the information I needed to conduct my research. I would like thank Lenneke, Ingeborg, Rob, Dianne, Jelle, Nikky, Ted and Hennie for their feedback on my intermediate presentations. And I thank everyone at the SIR care unit who took the time to answer my questions, in order for me to get a better understand of the planning and care process of the SIR care unit.

I would like to thank Erwin for his valuable feedback and for helping me to structure my research and improve the quality of my work. For helping me in the right direction when I needed it, and making me enthusiastic for operations management in health care in the first place. And a special thanks for Ingeborg, who was always there to answer my questions and help me when I was struggling with my data analyses or model. I could not have performed this research without your help and feedback.

Last but not least, I would like to thank my parents for always supporting me and making it possible for me to study. And the rest of my family and friends, for always supporting and encouraging me. It means a lot to me!

Management summary

Introduction

This study focuses on the patient admission planning of the spinal injury rehabilitation (SIR) care unit of the Sint Maartenskliniek in Nijmegen. The motivation for this study is the perception of the management of the SIR care unit that outpatients with a spinal injury have to wait too long after the first consult with the rehabilitation specialist, before their treatment can start. Also, it is perceived that patients do not receive therapy as prescribed in the treatment plan: some therapy sessions are cancelled and not all therapy sessions are scheduled, because the SIR care unit experiences a capacity shortage.

Problem description

The SIR care unit has difficulties predicting the demand for care and the treatment duration. The aim of the SIR care unit is to provide high quality of care, maximize patient satisfaction and simultaneously control labor costs. However, currently there is no balance between the deployment of therapists and the demand for care. The goal of this research is to develop a prototype planning model in order to meet access time standards, while controlling labor costs.

Methods

We have developed a patient admission planning tool, based on the model by Hulshof et al. (2013), that is suitable for long-term rehabilitation treatments. The model develops a patient admission plan and allocates resource capacity, whereby the objective is to meet access time standards and minimize excess use of therapist capacity. The decision that is made every week is how many and which patients from the waiting list to admit for treatment starting one week later. Hereby, the model takes into account each type of the patient (inpatient or outpatient) on the waiting list, the care pathway of the patient, the time the patient has already been waiting, the standard for the access time of the patient, the available therapist capacity, and the available bed capacity. We performed experiments with four different scenarios in order to measure the effect of changes in the resource capacity and the standards for the access time on the performance of the SIR care unit.

Results

The results of the experiments show that, when using the current resource capacity, the waiting list will continue to grow, resulting in increasing access times. Also the experiments show that the low therapist capacity of the discipline BAG currently is the bottleneck for patient admission. If we increase the capacity of BAG with 0.75 FTE, the capacity of ET with 0.25 FTE and the capacity of FT with 2.25 FTE, then all patients can be treated according to the care pathway and the standards for the average access time. If we increase the capacity of BAG with 1 FTE, the capacity of ET with 1.25 FTE, the capacity of FT with 5 FTE, the capacity of PS with 0.25 FTE and the bed capacity with 9 beds, then 25% more inpatients can be treated.

Conclusion

We conclude that our patient admission planning model helps to identify if there is insufficient resource capacity to treat all the patients according to the care pathway. In case there is sufficient resource capacity to treat all patients according to the care pathway, without continuously increasing waiting lists, our model helps to decide when to admit which patients such that the standard for the access times of as many patients as possible is met. To make sure that all patients can be treated according to the care pathway and the standards for the average access time, we recommend the SIR care unit to increase the capacity of BAG with 0.75 FTE, the capacity of ET with 0.25 FTE and the capacity of FT with 2.25 FTE. After the resource capacity has been increased, data registration has been approved and the current care pathways have been revised, the SIR care unit can use the proposed planning model as a decision support tool for the admission of patients. Since our model only allocates therapist capacity on a weekly basis, further research is needed in order to optimally allocate resource capacity to the days of the week and to the admitted patients.

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Abbreviations

ADL	Activities of Daily Living
ADP	Approximate Dynamic Programming
AT	Activity therapist
BAG	Movement therapist
DIET	Dietician
ET	Occupational therapist
FT	Physiotherapist
MDP	Markov Decision Process
MILP	Mixed Integer Linear Programming
MW	Social worker
PS	Psychologist
SIR	Spinal Injury Rehabilitation
SMK	Sint Maartenskliniek

1 Introduction

This study focuses on the planning of the spinal injury rehabilitation care unit of the Sint Maartenskliniek in Nijmegen. Section 1.1 describes the context of this study, section 1.2 describes the motivation for the study, section 1.3 contains the problem description and section 1.4 describes the research objective.

1.1 Context description

The Sint Maartenskliniek (SMK) is a leading specialized hospital in the Netherlands that provides treatment for diseases related to posture and movement. The hospital has four locations in the South-East of the Netherlands. The main location in Nijmegen contains an orthopedic center, a rheumatism center and a rehabilitation center. Every year 60.000 people are treated at the SMK and the hospital approximately has 1700 employees, including 80 specialists and assistant physicians in training.

The rehabilitation center of the SMK is divided in four care units: the pediatric rehabilitation care unit, the neurologic rehabilitation care unit, the chronic pain, amputation, and orthopedic rehabilitation care unit and the spinal injury rehabilitation care unit. Here, patients are treated on an outpatient basis (i.e. the patient visits the SMK one or multiple times per week for rehabilitation treatment) and on an inpatient basis (i.e. the patient is admitted to the SMK for rehabilitation treatment). In 2013, there were 434 inpatient admissions and more than 13.000 outpatient visits (Sint Maartenskliniek, 2015). At the spinal injury rehabilitation (SIR) care unit, patients with a spinal injury or related disease, such as Guillain Barré syndrome or Multiple Sclerosis, receive rehabilitation treatment. A spinal injury can have a traumatic cause (from the outside) or non-traumatic cause (from the inside). Examples of non-traumatic causes are: infections, tumors that are pressing on the spinal cord, disorders in the blood vessel supply and congenital defects (spina bifida).

1.2 Motivation of the research

This research is initiated in the spinal injury rehabilitation (SIR) care unit. The perception of the management of the SIR care unit is that patients with a spinal injury have to wait for a very long time before their treatment can start. The estimated time patients have to wait for a first consultation with the rehabilitation specialist is eight weeks. The estimated time patients have to wait after the first consultation with the rehabilitation specialist, before the treatment can start, is 21 weeks (Sint Maartenskliniek, 2015). Also, it is perceived that patients do not receive therapy as prescribed in the care pathway (i.e. a protocol that describes the relevant therapy for a specific diagnosis): some therapy sessions are cancelled and not all therapy sessions are scheduled, because the SIR care unit experiences a capacity shortage.

1.3 Problem description

The resource capacity planning of the spinal injury rehabilitation (SIR) care unit is complex. The SIR care unit has difficulties predicting the demand for care. Due to improved care provision from ambulance personnel, more patients who are admitted to the SIR care unit have an incomplete spinal injury. For these patients it is often unknown which functions are still intact and which functions are not. Therefore, it is difficult to predict the treatment duration, which causes deviations from the planned treatment duration. Also, there is an increase in the demand for rehabilitation care; people live longer and aftercare clinics experience more demand for therapy.

The rehabilitation care pathway is supported by therapists from multiple disciplines. A balanced deployment of therapists is essential to minimize the chance of medical errors, to maximize employee and patient satisfaction and to control labor costs. In addition to providing therapy, therapists often also engage in other activities such as training, research, hospital wide tasks, and tasks for specialized teams or workgroups. As a result, therapists are only partially available for the provision of rehabilitation care at the SIR care unit. Also, the availability of therapists fluctuates due to sickness, holidays etc. The treatment of a patient does not start until all involved disciplines are available. This means that if the physiotherapists for example have holidays this week and two weeks later the occupational therapists have holidays, the patient has to wait three weeks before the treatment can start.

The SIR care unit aims to provide high quality of care, maximize patient satisfaction and simultaneously control labor costs. The perception of the SIR care unit is that currently there is no balance between the deployment of therapists and the demand for care. However, an objective measurement of the demand for care and the time spent on patient care by therapists is lacking.

1.4 Research objective

The objective of this research is to:

> *Develop a prototype planning model in order to meet access time standards, while controlling labor costs.*

Based on this research objective, we formulate the following research questions:

1. *How is the planning at the SIR care unit currently organized?*

   Chapter 2 describes the care process and the planning and control process of the SIR care unit.

2. *How can the performance regarding access time and adherence to the care pathway be measured? What is the current performance of the SIR care unit regarding access time and adherence to the care pathway?*

   Chapter 3 describes the objectives of the SIR care unit, the corresponding performance indicators, the current performance and the bottlenecks.

3. *Which models for planning in rehabilitation care are suggested in the literature?*

   Chapter 4 describes methods and techniques for resource capacity planning that are suggested in literature.

4. *How can the planning process at the SIR care unit be modelled?*

   Chapter 5 contains an analysis of alternative models that can be used for resource capacity planning at the SIR care unit.

5. *What is the effect of the proposed planning model(s) on the performance?*

   Chapter 6 describes the effect of the proposed planning model(s) on the performance indicators.

6. *How should the proposed planning model be implemented at the SIR care unit?*

   Chapter 7 contains the discussion and conclusion and chapter 8 discusses the implementation of the proposed planning model.

2 Context analysis

This chapter contains a context analysis of the spinal injury rehabilitation (SIR) care unit. Section 2.1 describes the care process of spinal injury patients, section 2.2 describes the planning and control process and section 2.3 contains the conclusion.

2.1 Care process description

The SIR care unit provides rehabilitation care on an inpatient and outpatient basis. Both inpatients and outpatients can be divided into two groups: patients who have a fresh, i.e. recent, spinal injury and patients who have an old, i.e. longer existing, spinal injury. Within each group, several diagnosis groups are distinguished. Appendix I provides an overview of all diagnosis groups.

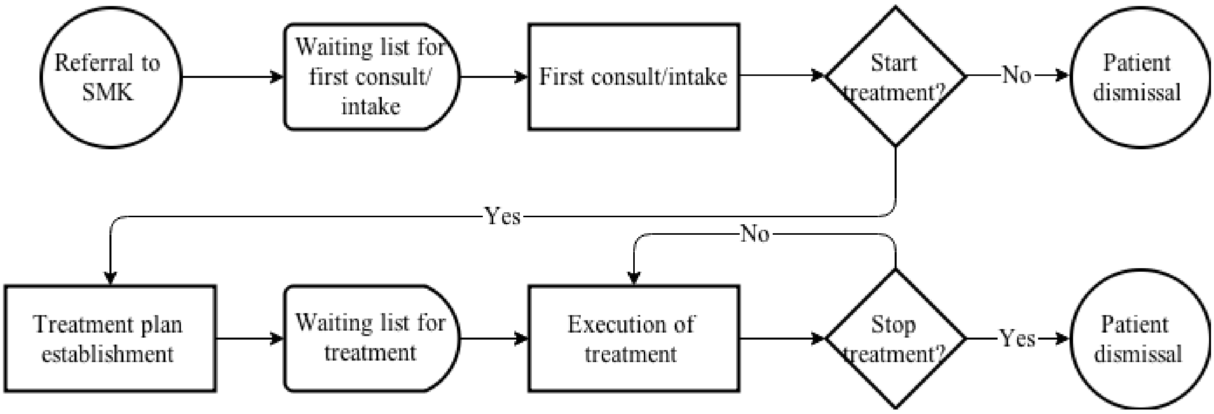

Figure 2.1 Care process for patients at the SIR care unit of SMK

Figure 2.1 provides the schematic overview of the care process of a patient who is referred to the rehabilitation center of SMK made by Buil (2015) with a minor adjustment. If a patient is referred to the SIR care unit for treatment on an outpatient basis, first an appointment is scheduled with the rehabilitation specialist. Based on the first consult, the rehabilitation specialist will decide if the patient is eligible for treatment. If the patient is eligible for treatment, the rehabilitation specialist will establish a treatment plan based on the care pathway. Care pathways are used as protocols that describe the frequency, duration, and number of appointments for all relevant therapy types of a specific diagnosis group (Buil, 2015).

If a patient is referred to the SIR care unit on an inpatient basis, the patient will not have a first appointment with the rehabilitation specialist. The referring physician decides whether the patient is eligible for inpatient treatment. The rehabilitation specialist writes an admission order which contains the treatment plan based on the care pathway of the diagnosis group of the patient. The ward physician will have an intake conversation with the patient on the day of admission. Most inpatients are admitted to the SIR care unit for approximately three months and continue with the rehabilitation treatment on an outpatient basis after they are discharged.

The multidisciplinary treatment team, which consists of the rehabilitation specialists, ward physicians, nurse practitioners, nurses, physiotherapists, occupational therapists, social workers, and psychologists, discusses the progression of each inpatient in a weekly meeting. If necessary, treatment plan mutations are made. However, treatment plan mutations are not just made during the multidisciplinary meetings: they can be made throughout the whole treatment phase. Two weeks before the planned discharge date, the multidisciplinary team determines whether the date is still accurate. Until recently, there was also a meeting to discuss the progression of outpatients, but this meeting is abolished. Now, mutations of the treatment plan of outpatients are discussed in between appointments or in the hallway. In addition to the weekly multidisciplinary meetings, once every six weeks there is a multidisciplinary meeting during which the patient is also present.

2.2 Planning and control

In this section we use the framework for health care planning and control by Hans, Van Houdenhoven, and Hulshof (2011) to identify and position the planning and control decisions of the SIR care unit. The framework for health care planning and control consists of four managerial areas in health care delivery operations: medical, resource capacity, materials and financial planning. The problem that is addressed in this research can be classified as a resource capacity problem, which concerns the planning and control of renewable resources. The framework also distinguishes four hierarchical levels of control: the strategic, tactical, offline operational, and online operational level. Below, the hierarchical levels are explained briefly and the resource capacity planning decisions of the SIR care unit are mentioned per level. For every planning decision, the current situation of the SIR care unit is described. Note that this does not mean that it is the optimal solution for the planning decision.

Strategic planning

Strategic planning has a long planning horizon and is based on highly aggregated information and forecasts. The SIR care unit faces the following strategic planning and control decisions:

- *How many beds are needed for inpatients in order to meet the demand for care?*

  The SIR care unit currently has 24 beds and can use 4 additional beds from the neurological rehabilitation care unit for decubitus patients. These are patients who have wounds that need to be treated first, before mobilization and therapy can start.

- *How many physicians and therapists (of which discipline) are needed in order to meet the demand for care?*

  The treatment team of the SIR care unit consists of various therapists: physiotherapists (FT), occupational therapists (ET), psychologists (PS), social workers (MW), activity therapists (AT), a dietician (DIET), and a movement therapist (BAG). Table 2.1 provides an overview of the number of therapists and FTEs per discipline.

Table 2.1. Number of therapists and FTE per discipline

Discipline	Therapists	FTE
FT	8	5.69
ET	4	3.53
PS	2	1.00
MW	3	1.11
AT	2	1.56
DIET	1	0.50
BAG	1	0.38

Tactical planning

Tactical planning addresses the organization of the operations and execution of the health care delivery process. Tactical planning has an intermediate planning horizon that lies somewhere between the strategic planning horizon and operational planning horizon. The SIR care unit faces the following tactical planning and control decisions:

- *On which days and what shifts do therapists work?*

  Most therapists work four days a week, either full-time (nine hours per day) or part-time (eight hours per day). Shift start between 7:30 and 8:30 and finish between 16:30 and 17:30.

- *On basis of which criteria are inpatients admitted?*

  Inpatients are admitted to the SIR care unit as soon as a bed becomes available. Hereby, the availability of therapists is not taken into account. However, in some cases a bed might remain empty because the SIR care unit has to wait for an operating room to become available before admitting the patient.

- *How are patients prioritized?*

  First new inpatients are admitted to the SIR care unit to make sure all beds are occupied. Then, new outpatients can start their treatment if there is still sufficient therapist capacity left.
- *How are meetings and group therapy session planned?*

  Group therapy sessions and meetings take place on fixed days and times. For example, the multidisciplinary meeting always takes place on Wednesday. This means that planners have to plan individual appointments for patients around those meetings and group therapy sessions. For group therapy session it is common to have more than one therapist available.
- *Do group therapy sessions start straight away or do they start as soon as the group is full?*

  For some group therapy sessions, patients can enter the group continuously, while for other group sessions there are fixed start and stop dates.
- *What is the (standard) duration of an appointment?*

  The standard duration of an appointment is 30 minutes. However, some appointments and group therapy sessions take 60 or 90 minutes.
- *How is the deployment of physicians and therapists adapted to busy/quiet periods?*

  During busy periods, there is no time scheduled for indirect patient time (i.e. administrative time related to a specific patient). As a consequence, therapists have to work in overtime. Also, sometimes the calendars of the rehabilitation specialists are so full that meetings have to be planned outside office hours and appointments with patients have to be planned outside outpatient clinic hours.
- *On basis of which criteria are inpatients discharged?*

  Two weeks after the admission of the patient, the duration of the stay is estimated and the discharge date is planned by the multidisciplinary team based on the prognosis of the patient’s progression.
- *On which basis is the treatment of outpatients terminated?*

  The termination of the treatment of outpatients is determined based on the care pathway and a prognosis of the patient’s progression.

Offline operational planning

Offline operational planning involves the short term in advance decision making related to the execution of the health care delivery process. The SIR care unit faces the following offline operational planning and control decisions:

- *How are patient appointments planned?*
  Planners manage the calendars of therapists in an electronic database system and manually book appointments with patients based on their treatment plan. The planner receives an order to schedule the treatment of a new patient. This orders is put on a waiting list. Each week, the planner determines when the treatment of outpatients can start, sometimes in consultation with therapists or physicians, by evaluating the urgency, the waiting time, and the availability of capacity. The treatment of inpatients starts once the patient is admitted to the nursing unit. This is determined by the team leader of the nursing unit, based on the availability of beds. Once the starting date of the treatment is determined, the planner schedules the appointments that are prescribed in the treatment plan. In case there is not sufficient capacity available, not all appointments in the treatment plan are scheduled. Appointments with the rehabilitation specialist, appointments for the aftercare clinic and multidisciplinary meetings with the patient are scheduled by the medical secretary.
- *On basis of which criteria are therapists assigned to a patient?*
  Patients are assigned to a fixed therapist, based on the availability of the therapist and a balanced workload. However, since most therapists work four days a week, patients who need therapy five days a week are assigned to a second fixed therapist on the day their own therapist is not present.

Online operational planning

Online operational planning involves the short term reactive decision making related to the execution of the health care delivery process. It includes monitoring the process and reacting to unforeseen or unanticipated events. The SIR care unit faces the following online operational planning and control decisions:

- In what way is anticipated on no-shows and cancelled appointments?
  In case a patient or therapist cancels an appointment, occasionally, treatment schedules are adjusted after they have been made final. Inpatient schedules generally provide more possibilities for adjustments than outpatient schedules, because inpatients usually have fewer availability constraints since they are admitted to the SIR care unit. For outpatients, appointments are only rescheduled if this has no consequences for the schedules of other patients. Otherwise, the appointments are cancelled. In the following situations appointments are cancelled or rescheduled:

- If a patient cancels a single appointment within a week before the appointment or does not show up, the appointment is not rescheduled.
- If the patient is absent for a longer period, appointments are rescheduled.
- In case of therapist absenteeism, appointments are rescheduled to other therapists depending on therapist capacity.
- If no capacity is available, the appointment is cancelled and the appointment is not rescheduled.

Because the planning horizon of lower hierarchical levels is shorter and there is more information available, focusing on problems on lower hierarchical levels reduces uncertainty. However, flexibility as regards to resource expansion is lower. Focusing on problems on higher hierarchical levels increases the potential impact, but often requires high investments and effects of interventions are felt on the long term (Hans, Hulshof, & Van Houdenhoven, 2011).

2.3 Conclusions

This sections contains the conclusion of the context analysis.

The SIR care unit provides rehabilitation care to patients with a spinal injury on an inpatient and outpatient basis. Patients are treated by a multidisciplinary treatment team, which consists of the rehabilitation specialists, ward physicians, nurse practitioners, nurses, physiotherapists, occupational therapists, social workers, and psychologists. The SIR care unit has 24 beds and can use 4 additional beds from the neurological rehabilitation care unit for decubitus patients. To make sure all beds are occupied, inpatients are currently prioritized over outpatients. This means that new outpatients can only start their treatment if there is sufficient therapist capacity left after all beds have been filled and the treatment sessions of current patients are scheduled. Therefore, it is often not possible to schedule new outpatients, which results in a long waiting list.

During busy periods, only direct patient time is scheduled, resulting in a lack of time for indirect patient time (reporting, transmissions etc.). Therefore, therapists experience a high workload during busy periods. Also some therapists experience a fluctuating workload, due to fluctuations in demand for care. Therapist’s shifts start between 7:30 and 8:30. However, patients with a spinal injury usually need a lot of time in the morning to perform Activities of Daily Living (ADL). Also, some outpatients need to travel quite far to get to SMK. Therefore, most patients are not available for therapy until 9:00 or 10:00. This makes it difficult for planners to schedule therapy sessions.

Sometimes a therapy session is cancelled, either by the SIR care unit or by the patient. In case an outpatient appointment is cancelled, therapists often treat an inpatient instead. This leads to deviations from the treatment plan of the inpatient and gaps in the treatment plan of the outpatients.

3 Performance measurement

This chapter discusses performance measurement of the SIR care unit. Section 3.1 describes the objectives of the SIR care unit, section 3.2 describes the indicators for performance and section 3.3 describes the current performance of the SIR care unit.

3.1 Objectives of the SIR care unit

In the rehabilitation process at the SIR care unit, there are many different stakeholders involved: patients, care providers, planners, the medical secretary, the manager, and the board of the hospital. The five main objectives of the SIR care unit are: timely access to care, high quality of care, high patient satisfaction, high employee satisfaction, and cost effectiveness.

Timely access to care

The SIR care unit aims to provide timely rehabilitation care to patients with a spinal injury. Therefore, the SIR care unit aims to realize short access times for all their patients. The Dutch government has set standards for the access times (in Dutch: treeknormen). According to these standards, for outpatients, the treatment of at least 80% of the patients should start within 3 weeks after they have been registered on the waiting list. The maximum time between registration on the waiting list and start of the treatment should be no more than 4 weeks. For inpatients, the treatment of at least 80% of the patients should start within 5 weeks after they have been registered on the waiting list. The maximum time between registration on the waiting list and start of the treatment should be no more than 7 weeks (RIVM, 2007).

High quality of care

The SIR care unit aims to provide a high quality of rehabilitation care conform the state of the art. Hereby, it is important that therapists are sufficiently skilled, that the patient receives the therapy he or she needs and that the therapy is provided by only one or two different therapists per discipline.

High patient satisfaction

The SIR care unit strives for a high patient satisfaction. This means that the patient should be leading in the rehabilitation care process. Each patient may have different preferences. In general, outpatients prefer to minimize the number of visits to SMK and the waiting time between therapy sessions, while inpatients generally prefer to have their therapy sessions evenly spread over the week.

High employee satisfaction

The SIR care unit strives for a high employee satisfaction. Therefore, work in overtime should be minimized and the distribution of the workload should be balanced.

Cost effectiveness

In order to keep the budget, the rehabilitation care at the SIR care unit should be cost effective. This means that the care that is provided should be reimbursed by the health care insurer. Therefore, it is important that the care pathways are cost effective and that the care is provided according to the care pathway.

3.2 Performance indicators

Based on the objectives of the SIR care unit, we formulate three key performance indicators of the rehabilitation process.

Access time

For outpatients, we define the access time 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. In formula:

$$AT_p = FT_p - OT_p,$$

where AT_p is the access time of patient *p*, FT_p is the date of the first therapy session of patient *p*, and OT_p is the date of the order for the treatment plan of patient *p*. We do not take into account the access time between the referral of the patient to SMK and the first appointment with the rehabilitation specialist.

For inpatients, we define the access time as the time (in weeks) between the order for admission and the actual admission. In formula:

$$AT_p = AA_p - OA_p,$$

where AT_p is the access time of patient *p*, AA_p is the date of the actual admission of patient *p* and OA_p is the date of the order for admission of patient *p*.

This performance indicator relates to the objective timely access to care.

Adherence to the care pathway

We define the adherence to the care pathway as the realized amount of therapy relative to the amount of therapy as prescribed in the care pathway. In formula:

$$A_{pdw} = \frac{R_{pdw}}{C_{pdw}},$$

where A_{pdw} is the adherence of patient p for discipline d in week w, R_{pdw} is the realized number of hours of therapy of patient p for discipline d in week w, and C_{pdw} is the number of hours of therapy as prescribed in the care pathway of patient p for discipline d in week w.

This performance indicator relates to the objective high quality of care.

Therapist capacity utilization

We define the therapist capacity utilization as the realized patient time relative to the available patient time. In formula:

$$TCU_{tw} = \frac{RPT_{tw}}{APT_{tw}},$$

where TCU_{tw} is the therapist capacity utilization of therapist t in week w, RPT_{tw} is the realized patient time of therapist t in week w, and APT_{tw} is the available patient time of therapist t in week w.

This performance indicator relates to the objective cost effectiveness.

3.3 Current performance

This section describes the current performance of the SIR care unit on the three performance indicators that are described in 3.2.

Access time

Appendix II provides an overview of the number of care pathways and patients who are registered in the Hospital Information System (HIS). We measured the access times of inpatients and outpatients for 2013 and 2014. Based on the orders that are registered in the Hospital Information System (HIS), we identified 398 new care pathways in 2013 and 281 new care pathways in 2014. In case a patient had more than one care pathway (for example because a patient had an inpatient care pathway followed by an outpatient care pathway), we only included the first care pathway of the patient. This resulted in 229 care pathways in 2013 and 166 care pathways in 2014. We excluded patients whose care pathway was not found and patients whose care pathway is classified as "other" (n=74 in 2013, n=43 in 2014), since the content of these care pathways is unknown. Also, we excluded patients who are categorized as PM on the waiting list (n=13 in 2013, n=26 in 2014), which means that the treatment of the patient cannot start due to external factors; including these patients might bias the measurement. Table 3.1 provides an overview of the number of included inpatients and outpatients and Figure 3.1 shows the average access times of inpatients and outpatients in weeks. The figure shows that the average access time of both inpatients and outpatients decreased between 2013 and 2014. If we compare the access times in Figure 3.1 to the average access times of inpatients and outpatients in case we do not excluded patients with an unknown care pathway (Figure 3.2), then we can conclude that the average access time of inpatients is higher in 2013 and the average access time of outpatients is lower in 2013 and 2014 in case patients with an unknown care pathway are excluded.

Table 3.1. Number of included inpatients and outpatients in 2013 and 2014

	2013	2014
Inpatients	77	68
Outpatients	65	29

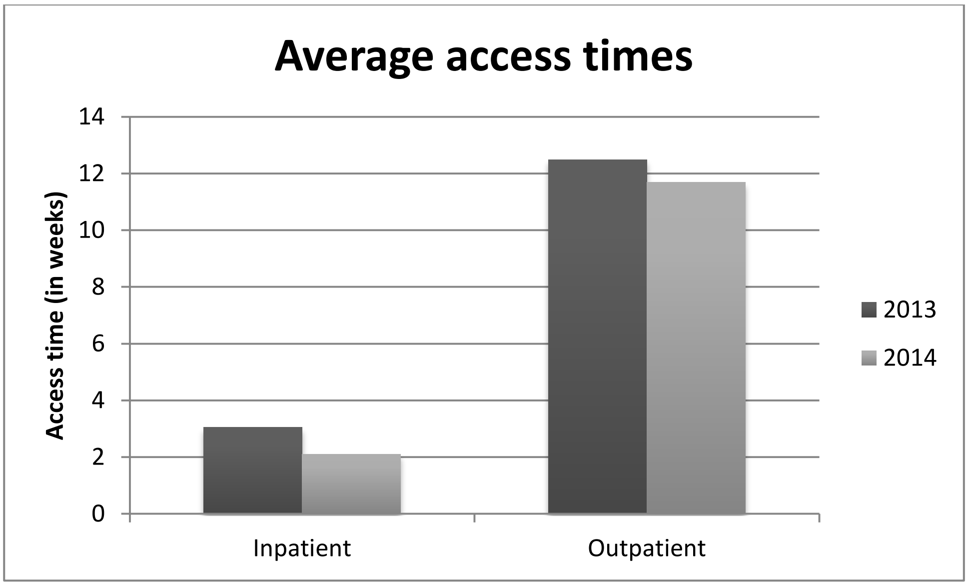

Figure 3.1. Average access times of inpatients and outpatients (in weeks)

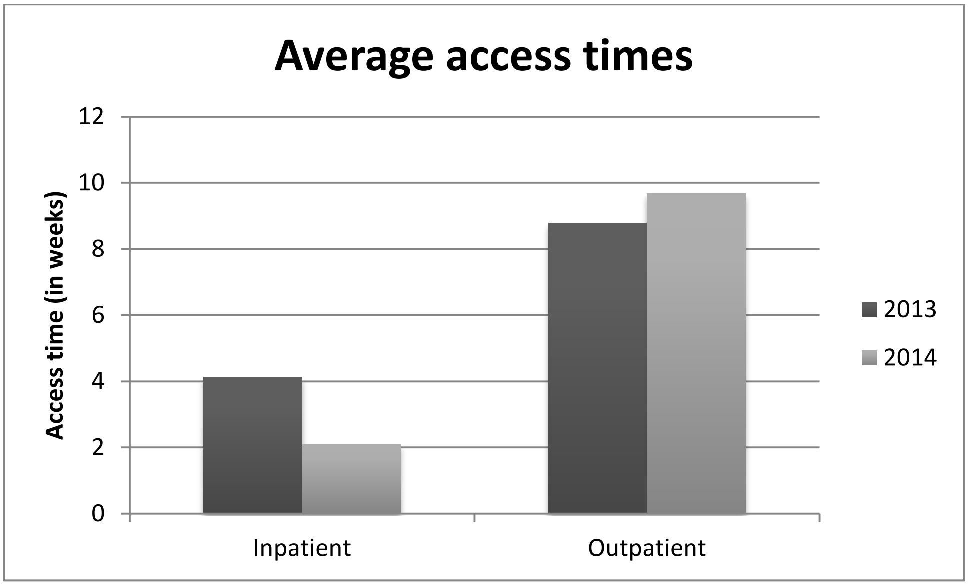

Figure 3.2. Average access times of inpatients and outpatients (in weeks)

Figure 3.3 shows the 80% percentile of the access times of the included inpatients and outpatients in 2013 and 2014. Figure 3.4 shows the 80% percentile of the access times of inpatients and outpatients in case we do not excluded patients with an unknown care pathway. Both figures show that the 80% percentile of the access times of inpatients is within the standard of 5 weeks. However, the 80% percentile of the access times of outpatient is far above the standard of 3 weeks.

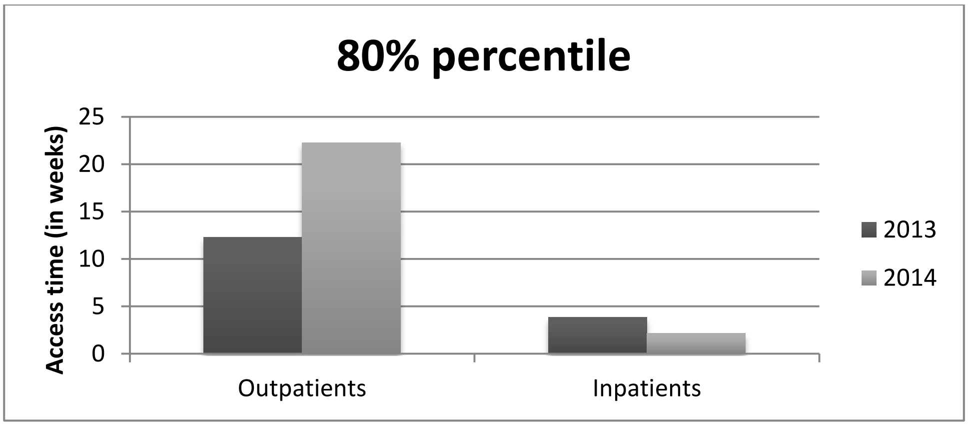

Figure 3.3. 80% percentile of inpatients and outpatients in 2013 and 2014 (in weeks)

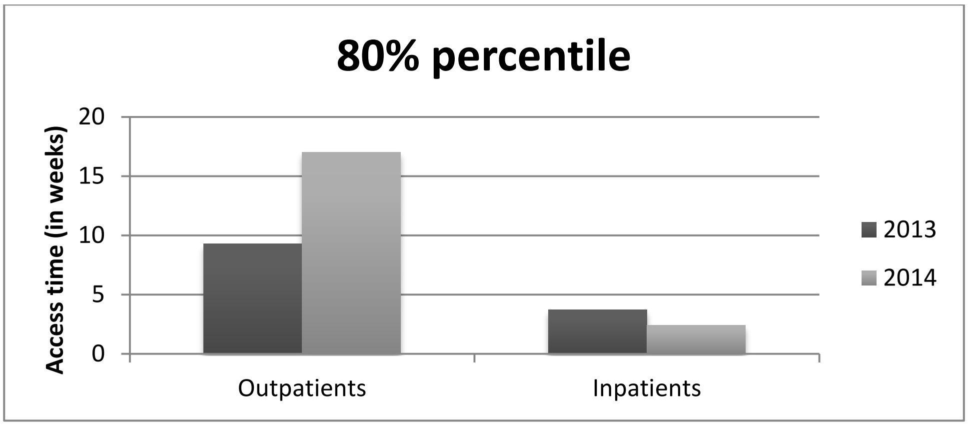

Figure 3.4. 80% percentile of inpatients and outpatients including patients with an unknown care pathway in 2013 and 2014 (in weeks)

Adherence to the care pathway

We measured the adherence to the care pathway for 2013 and 2014, by measuring the difference between the realized amount of therapy and the amount of therapy in the care pathway. Based on the appointments for therapy sessions that are registered in the Hospital Information System (HIS), we identified 540 care pathways in 2013 and 419 care pathways in 2014. We excluded patients whose care pathway was not found and patients whose care pathway is classified as "other" (n=306 in 2013, n=214 in 2014), since the content of these care pathways is unknown. In 2013, 67% of the patients received more than 20% more therapy than prescribed in the care pathway and 27% of the patients received more than 20% less therapy than prescribed in the care pathway. In 2014, 55% of the patients received more than 20% more therapy than prescribed in the care pathway and 25% of the patients received more than 20% less therapy than prescribed in the care pathway. Table 3.2 provides an overview of the difference between the realized amount of therapy and the amount of therapy in the care pathway per discipline in 2013 (see the overview on page 6 for the abbreviations of the disciplines). Table 3.3 provides an overview of the difference between the realized amount of therapy and the amount of therapy in the care pathway per discipline in 2014. The tables show that both in 2013 and in 2014, the realized amount of therapy is higher than the amount of therapy that is prescribed in the care pathway. However, the difference was larger in 2013 than in 2014.

Table 3.2. Difference between realized amount of therapy and therapy in the care pathway in hours per discipline in 2013

	AT	BAG	DIET	ET	FT	MW	PS
Realized	2164	935	361	3557	8541	589	691
Care pathway	2205	540	194	2701	6176	408	408
Difference	-41	395	167	857	2365	181	283
%	**-2%**	**73%**	**86%**	**32%**	**38%**	**44%**	**69%**

Table 3.3. Difference between realized amount of therapy and therapy in the care pathway in hours per discipline in 2014

	AT	BAG	DIET	ET	FT	MW	PS
Realized	2792	1226	400	3594	9878	749	785
Care pathway	2508	873	354	4051	8704	570	570
Difference	284	353	46	-457	1174	179	215
%	**11%**	**40%**	**13%**	**-11%**	**13%**	**31%**	**38%**

Therapist capacity utilization

We measured the therapist capacity utilization for 2013 and 2014. Based on the appointments for therapy sessions that are registered in the Hospital Information System (HIS), we determined the total time spent on therapy per discipline and compared this with the standard for direct patient time. Table 3.4 provides an overview of the difference between the total time spent on therapy and the standard for direct patient time per discipline in 2013. Table 3.5 provides an overview of the difference between the total time spent on therapy and the standard for direct patient time per discipline in 2014. Table 3.4 shows that the disciplines AT, BAG, and FT spent more time on therapy in 2013 compared to the standard, whereas the disciplines DIET, MW, and PS spent less time on therapy in 2013 compared to the standard. The discipline ET spent the same time on therapy in 2013 as the standard. Table 3.5 shows that only the discipline BAG spent more time on therapy in 2014 compared to the standard, whereas the disciplines DIET and MW spent less time on therapy in 2014 compared to the standard. The disciplines AT, ET, FT, and PS spent approximately the same time on therapy in 2014 as the standard. The high percentage for BAG, can be explained by the fact that BAG therapists of other teams sometimes also treat patients of the SIR care unit.

Table 3.4. Difference between total time spent on therapy and the standard for direct patient time in hours per discipline in 2013

	AT	BAG	DIET	ET	FT	MW	PS
Total time	2373	747	318	3165	6428	680	619
Standard	1714	419	453	3195	6270	870	783
Utilization	139%	179%	70%	99%	103%	78%	79%

Table 3.5. Difference between total time spent on therapy and the standard for direct patient time in hours per discipline in 2014

	AT	BAG	DIET	ET	FT	MW	PS
Total time	1657	732	348	3058	6158	685	738
Standard	1714	419	453	3195	6270	870	783
Utilization	97%	175%	77%	96%	98%	79%	94%

Table 3.6 and Table 3.7 compare the total amount of therapy in hours that was needed in 2013 and 2014 per discipline according to the care pathway to the time that therapists were available for therapy according to the standard for direct patient time per discipline. Hereby, we used the realized amount of therapy instead of the amount of therapy in the care pathway for patients with an unknown care pathway. Both tables show that there was a shortage of therapists, whereby the discipline FT had the largest shortage (3.4 FTE in 2013 and 4.3 FTE in 2014) followed by the discipline ET (1.8 FTE in 2013 and 3.0 FTE in 2014).

Table 3.6. Difference between the available time for therapy and the time needed according to the care pathway in hours and FTE per discipline in 2013

	AT	BAG	DIET	ET	FT	MW	PS
Available time	1714	419	453	3195	6270	870	783
Care pathway	1871	1088	583	4851	10067	963	1138
Absolute difference	-157	-669	-130	-1655	-3797	-93	-354
Difference in FTE	-0,1	-0,6	-0,1	-1,8	-3,4	-0,1	-0,5

Table 3.7. Difference between the available time for therapy and the time needed according to the care pathway in hours and FTE per discipline in 2014

	AT	BAG	DIET	ET	FT	MW	PS
Available time	1714	419	453	3195	6270	870	783
Care pathway	1993	1324	736	5914	11033	979	1069
Absolute difference	-279	-905	-283	-2719	-4763	-108	-285
Difference in FTE	-0,3	-0,8	-0,3	-3,0	-4,3	-0,1	-0,4

3.4 Bottlenecks of the rehabilitation process

This section describes the bottlenecks of the SIR care unit based on the performance measurement.

Access time

Figure 3.3 shows that the access time of 80% of the inpatients is 3.7 weeks or less in 2013 and 2.4 weeks or less in 2014. According to the standards for the access times, the treatment of 80% of the inpatients should start within 5 weeks (RIVM, 2007). So, the access times of inpatients are within the standard in both 2013 and 2014. In addition, Figure 3.3 shows that the access time of 80% of the outpatients is 9.3 weeks or less in 2013 and 17.0 weeks or less in 2014. According to the standards for the access times, the treatment of 80% of the outpatients should start within 3 weeks (RIVM, 2007). So, the access times of outpatients are far above the standard in both 2013 and 2014. From this we can conclude that the access time of outpatients is an important bottleneck of the rehabilitation process at the SIR care unit.

Adherence to the care pathway

A large amount of patients receive either more or less therapy than prescribed in the care pathway. Table 3.2 and 3.3 show that there is a difference between the realized amount of therapy and the amount of therapy that is prescribed in the care pathway for almost every discipline. Deviations from the care pathway could have a negative effect on the quality of care. Therefore, it is important to schedule therapy sessions according to the care pathway, in order to increase the adherence to the care pathway.

Therapist capacity utilization

Table 3.4 and 3.5 show that the time spent on therapy, i.e. the time spent on direct patient time, and the standard for direct patient time per discipline do not always correspond. This might have a negative effect on the cost effectiveness of the SIR care unit. Table 3.6 and 3.7 show that there was a shortage of therapists in 2013 and 2014, whereby the discipline FT and ET had the largest shortage.

3.5 Delimitation of the research scope

This section contains the delimitation of the scope of this research, based on the bottlenecks of the current performance.

The measurement of the current performance shows that the realized rehabilitation care deviates from the rehabilitation care that is prescribed in the care pathway. In order to improve the adherence to the care pathway, it is important that the care pathway is carefully composed and up to date, so that therapy sessions can be scheduled according to the care pathway. Therefore, we recommend the SIR care unit to check if the current care pathways are still up to date or if some modifications are needed. For this research we assume that therapy sessions are scheduled according to the current care pathways.

The measurement of the current access times shows that the access time of outpatients is an important bottleneck of the rehabilitation process at the SIR care unit. In order to achieve an equitable access for all patients, it is important to balance the admission of inpatient and outpatients. For this reason, this research focuses on designing interventions for patient admission planning. Hereby, the aim is to meet access time standards.

A third important bottleneck of the current performance of the SIR care unit is the available therapist capacity. In 2013 and 2014 there was a shortage of therapists. Therefore, we investigate what the effect of changes in the deployment of staff is on the access times.

4 Relevant literature

This chapter provides an overview of methods for patient admission planning that are provided in literature. We used the structured review by Hulshof, Kortbeek, Boucherie, Hans, & Bakker (2012) as a starting point for our literature search. Hulshof et al. (2012) present a taxonomy to position planning and control decisions. The taxonomy consists of a vertical axis, reflecting the hierarchical nature of decision making, and a horizontal axis, reflecting the various health care services. For each hierarchical level and health care service, the authors specify planning and control decisions and give an overview of the key Operations Research and Management Sciences (OR/MS) articles. The authors classify rehabilitation clinics as residential care services. However, the body of literature that focusses on planning in residential care is limited. For this reason and because rehabilitation care services have similarities to ambulatory care services and inpatient care services, we also consider literature regarding patient admission planning in ambulatory and inpatient care services. Appendix III provides an overview of our search strategy.

Elkhuizen, Das, Bakker, & Hontelez (2007) developed a simulation model to analyze access times for hospital services and to investigate the capacity required to reduce these access times. For this purpose, Elkhuizen et al. (2007) performed an initial rough analysis using a simple queuing model to obtain insight into the capacity needed to meet the access time target. For a more detailed analysis, they developed a simulation model that takes into account daily variations in demand and capacity schedules. The model can be used to gain insight into the possibilities of meeting fluctuating demand within the stated targets for access time.

Nunes, De Carvalho, & Rodrigues (2009) modelled the control of patients' admissions as a Markov decision process (MDP). At the tactical level, the model sets an admission policy at the beginning of each planning period that informs the number of admissions to be achieved for each specialty during the next period. Hereby, the number of patients being served, their specialties, and the pattern of resource consumption are taken into account. The model can be applied to admission processes in rehabilitation hospitals. However, the model deals with very large dimensions when realistic systems are evaluated. Garg, McClean, Meenan, & Millard (2010) also present a discrete time Markov model for admission scheduling and capacity planning. Their model can be used for resource requirement forecasting and resource allocation to satisfy demand or resource constraints or to meet expansion or contraction plans. Also, the model can be used to compare different admission planning strategies for a care system. The model facilitates decision making in elderly care, but can also be customized for other care systems. Zonderland, Boucherie, Litvak, & Vleggeert-Lankamp (2010) investigated the trade-off between cancellations of elective surgeries due to semi-urgent surgeries (which pose an uncertain demand on available hospital resources), and unused operating room time due to excessive reservation of operating room time for semi-urgent surgeries. They developed a decision support tool based on Markov decision theory that supports the allocation of semi-urgent surgeries. The tool provides a guideline for the weekly scheduling of semi-urgent patients (Zonderland, Boucherie, Litvak, & Vleggeert-Lankamp, 2010).

Hulshof, Boucherie, Hans, & Hurink (2013) present a method in a Mixed Integer Linear Programming (MILP) framework, to determine intermediate term tactical resource and admission plans to cope with fluctuations in patient arrivals and resource availability. These plans allocate available resources to care processes and determine the selection of patients to be served in order to improve compliance with access time targets, care process duration, and the number of patients served. Hulshof, Mes, Boucherie, & Hans (2015) propose a method to develop a tactical resource allocation and patient admission plan that takes variation in patient arrivals and patient transitions to other stages into consideration. Their method is developed in an Approximate Dynamic Programming (ADP) framework, and copes with multiple resources, multiple time periods, and multiple patient groups with uncertain treatment paths and an uncertain number of arrivals.

We conclude that, in the literature different methods for patient admission planning are suggested. However, none of the methods are applied in rehabilitation care. Therefore, this research focuses on developing a method for patient admission planning that is suitable for long-term rehabilitation treatments.

5 Patient admission planning model

This chapter introduces the patient admission planning model. Section 5.1 describes the model selection, section 5.2 describes the Mixed Integer Linear Programming (MILP) model that is used to develop a patient admission plan, and section 5.3 describes the solution method that is used to solve the MILP.

5.1 Model selection

Based on the current bottlenecks of the rehabilitation process, in our perception the SIR care unit would benefit from a patient admission planning tool that helps the SIR care unit to decide how many patients of which type to admit on a weekly basis. Hereby, the objective is to meet the access time standards, while taking into account the available therapist and bed capacity.

In the literature different methods for patient admission planning are suggested. Suitable methods for patient admission planning include Markov decision processes (Nunes, de Carvalho, & Rodrigues, 2009) (Garg, McClean, Meenan, & Millard, 2010), Approximate Dynamic Programming (Hulshof, Mes, Boucherie, & Hans, 2015), Mixed Integer Linear Programming (Hulshof, Boucherie, Hans, & Hurink, 2013), and simulation modelling (Elkhuizen, Das, Bakker, & Hontelez, 2007). Markov decision processes assume that a system is in a certain state in a certain time period and that it moves to another state in the next time period, depending on the decision that is made. In determining what decision to make, Markov decision processes also take into account what will happen in the future. For this reason, solving Markov decision processes to optimality takes a lot of computation time. An alternative to finding the exact solution for Markov decision processes is to use Approximate Dynamic Programming to find an approximate solution. However, Approximate Dynamic Programming also is a complex method that takes a lot of computation time. Linear Programming (LP) is a method that determines the optimal solution based on a linear objective function and constraints. In Mixed Integer Linear Programming (MILP) some variables are restricted to be integers. The MILP by Hulshof et al. (2013), which was mentioned in chapter 4, assumes that demand for care, resource requirements, and resource capacities are deterministic. For this reason, solving the MILP takes less computation time than solving a Markov decision process. The solution to the MILP might not be as good as the solution you would find if you also take into account the future, but it will result in a solution that could lead to major improvements for the SIR care unit. Therefore, we develop a MILP based on the model by Hulshof et al. (2013).

We adjust the MILP by Hulshof et al. (2013), such that it is suitable for long-term rehabilitation treatments. Instead of patients who move from one stage to another and have to queue for service at each stage, we consider patients who only queue at the beginning of the care process and have to receive all care as prescribed in the care pathway consecutively.

5.2 Mathematical model formulation

The MILP develops a weekly patient admission plan, whereby the objective is to meet the access time standards while controlling labor costs. Hereby, the MILP takes into account the type of the patient (inpatient or outpatient), the care pathway of the patient, the standards for the access time of the patient, the time the patient has already been waiting, the available therapist capacity, and the available bed capacity. The decision that is made every week is how many and which patients from the waiting list to admit for treatment starting one week later. In the decision which patient to admit, the model assumes that patients are treated according to the care pathway and that all patients with the same care pathway have the same urgency when they arrive. Table 5.1 provides an overview of the sets, indices, variables, and parameters that are used in the MILP.

Table 5.1. Overview of sets, indices, variables, and parameters

Sets	
J	Queues ($J = J^I \cup J^O$, where J^I are queues of inpatients, and J^O are queues of outpatients)
T	Time periods
R	Resource types
Indices	
$j \in J$	Queue
$t, p, q, s \in T$	Time period
$r \in R$	Resource type
n, m, N	Time period (to indicate waiting time)

Decision variables

$C_{j,t}^{n}$	The number of patients served from queue *j* during time period *t*, who had been waiting *n* time periods at the beginning of time period *t*
$C_{j,t}$	The total number of patients served from queue *j* during time period *t*

Auxiliary variables

$W_{j,t}^{n}$	The number of patients in queue *j* at the beginning of time period *t*, who have been waiting *n* time periods
$\rho_{r,t}$	The fraction of resource capacity *r* that have been allocated to care processes during time period *t*
B_t	Number of available beds at the beginning of time period *t*
$E_{r,t}$	Difference between the available resource capacity of discipline *r* during time period *t* and the allocated resource capacity of discipline *r* during time period *t*

Parameters

α	Weight (i.e. importance) of the part of the objective function that minimizes the weight of the patients on the waiting list
β_j^n	Weight (i.e. priority) of patients in queue *j* who have been waiting *n* time periods
$\lambda_{j,t}$	New demand in queue *j* at the beginning of time period *t*
$\varphi_{r,t}$	Capacity of resource type *r* during time period *t* in time units
φ_r	Capacity of resource type *r* during normal weeks (i.e. outside holiday periods)
e_r	Maximum percentage by which the capacity of resource type *r* may be exceeded
$s_{j,r}^{1}$	Expected capacity requirements from resource type *r* for a patient in queue *j* in time units → only once
$s_{j,r}^{2}$	Expected capacity requirements from resource type *r* for a patient in queue *j* in time units → weekly
$s_{j,r}^{3}$	Expected capacity requirements from resource type *r* for a patient in queue *j* in time units → every two weeks
$s_{j,r}^{4}$	Expected capacity requirements from resource type *r* for a patient in queue *j* in time units → every three weeks
k_j	The treatment duration of patients in queue *j* in time units

Sets

J: queues, where queue *j* reflects the care pathway of the patient. $J = J^I \cup J^O$, where J^I are queues of inpatients, and J^O are queues of outpatients.

T: time periods {0,1,2,…,T} in weeks

R: *r*esource types, where *r* reflects the discipline of the therapists.

Decision variable

The decision that needs to be made at the beginning of each time period *t*, is how many patients to serve from queue *j*. Decision variable $C_{j,t}^n$ indicates the number of patients served from queue *j* during time period *t*, who had been waiting *n* time periods at the beginning of time period *t*. Decision variable $C_{j,t}$ indicates the total number of patients who are served from queue *j* during time period *t*.

Objective function

$$\min \alpha * \frac{\sum_{j\in J}\sum_{n=0}^{\infty}\sum_{t\in T}\beta_j^n * W_{j,t}^n - Best_A}{Worst_A - Best_A} + (1-\alpha) * \frac{\sum_{r\in R}\sum_{t\in T}E_{r,t} - Best_E}{Worst_E - Best_E},$$

where:

$W_{j,t}^n \in \mathbb{N}$: the number of patients in queue *j* at the start of time period *t*, who have been waiting *n* time periods,

β_j^n: the weight (i.e. priority) of patients in queue *j*, who have been waiting *n* time periods,

$Best_A$: $\min \sum_{j\in J}\sum_{n=0}^{\infty}\sum_{t\in T}\beta_j^n * W_{j,t}^n$,

$Worst_A$: $\max \sum_{j\in J}\sum_{n=0}^{\infty}\sum_{t\in T}\beta_j^n * W_{j,t}^n$,

$E_{r,t}$: excess variable, i.e. difference between the available resource capacity of discipline *r* during time period *t* and the allocated resource capacity of discipline *r* during time period *t*,

$Best_E$: $\min \sum_{r\in R}\sum_{t\in T}E_{r,t}$,

$Worst_E$: $\max \sum_{r\in R}\sum_{t\in T}E_{r,t}$,

α: weight factor for the access time minimization.

The objective function consists of two parts. In the first part of the objective function, we minimize the total weight of the patients who are on the waiting list: $\min \sum_{j\in J}\sum_{n=0}^{\infty}\sum_{t\in T}\beta_j^n * W_{j,t}^n$. The weight factor β_j^n increases when *n*, the number of time periods the patient has already been waiting, increases. This means that by minimizing the total weight of the patients who are on the waiting list, we minimize the total access time of the patients. In the second part of the objective function, we minimize the excess variable: $\min \sum_{r \in R} \sum_{t \in T} E_{r,t}$. We use the best value and the worst value of both objectives to gradually optimize both objectives to the same extent. However, since the objectives are not equally important, we use the weight factor α to indicate the importance of the access time minimization.

Constraints

$W_{j,t}^{0} = \lambda_{j,t}$ $\qquad\qquad\qquad\qquad \forall j, t.$

This constraint makes sure that $W_{j,t}^{0}$, the number of patients entering queue *j* at the beginning of time period *t*, is equal to $\lambda_{j,t}$, the demand for care for queue *j* at the beginning of time period *t*.

$W_{j,t}^{n} = W_{j,t-1}^{n-1} - C_{j,t-1}^{n-1}$ $\qquad\qquad\qquad \forall j, t, n > 0.$

This constraint updates the waiting list variables at the beginning of each time period *t* by subtracting $C_{j,t-1}^{n-1}$, the number of patients in queue *j* that had been waiting *n* time periods and were served during the previous time period, from $W_{j,t-1}^{n-1}$, the number of patients who were waiting *n* time periods in queue *j* at the beginning of the previous time period.

$C_{j,t}^{n} \leq W_{j,t}^{n}$ $\qquad\qquad\qquad\qquad \forall j, t, n \geq 0.$

This constraint makes sure that no more patients are served then the number of patients waiting in queue.

$C_{j,t} = \sum_{n=0}^{\infty} C_{j,t}^{n}$ $\qquad\qquad\qquad\qquad \forall j, t.$

This constraint calculates $C_{j,t}$, the total number of patients in queue *j* that are served during time period *t*.

$$\sum_{j} s_{j,r}^{1} * C_{j,t} + \sum_{j} \sum_{p} s_{j,r}^{2} * C_{j,p} + \sum_{j} \sum_{q} s_{j,r}^{3} * C_{j,q} + \sum_{j} \sum_{s} s_{j,r}^{4} * C_{j,s} \leq \varphi_{r,t} + E_{r,t}$$

$\forall r, t$, where

$p \geq t - k_j + 1,$

$q = t - 2i \wedge q \geq t - k_j + 1 \wedge i \in \mathbb{N},$

$s = t - 3i \wedge s \geq t - k_j + 1 \wedge i \in \mathbb{N},$

$k_j =$ the treatment duration of patients in queue *j*,

$E_{r,t} \geq 0.$

This constraint makes sure that $s_{j,r}^{1}$, the resource requirement from discipline *r* that is required only once (in the first treatment week), plus $s_{j,r}^{2}$, the resource requirement from discipline *r* that is required weekly (from the first week of the treatment until the end of the treatment), plus $s_{j,r}^{3}$, the resource requirement from discipline *r* that is required every two weeks (from the first week of the treatment until the end of the treatment), plus $s_{j,r}^{4}$, the resource requirement from discipline *r* that is required every three weeks (from the first week of the treatment until the end of the treatment), for the patients who are served during time period t, does not exceed $\varphi_{r,t}$, the available resource capacity of discipline *r* during time period t. If necessary, the resource requirement can exceed the available resource capacity by $E_{r,t}$. For this a punishment is imposed in the objective function.

$$E_{r,t} \leq e_r * \varphi_r \qquad \forall r, t.$$

This constraint makes sure that the required resource capacity of discipline *r* during time period *t* cannot exceeded φ_r, the available resource capacity of discipline *r* during normal weeks (i.e. outside holiday periods), by more than a certain percentage, e_r.

$$B_t - \sum_{j \in J^I} C_{j,t} \geq 0 \qquad \forall t.$$

This constraint makes sure that the number of inpatients who are served during time period *t* does not exceed b_t, the number of beds that is available at the beginning of time period *t*.

$$B_t = B_{t-1} - \sum_{j \in J^I} C_{j,t-1} + \sum_{j \in J^I} C_{j,t-k_j} \qquad \forall t.$$

This constraint updates the number of beds that is available at the beginning of time period *t* by adding $\sum_{j \in J^I} C_{j,t-1}$, the number of inpatients who were served during the previous time period, to the number of beds that was available at the beginning of the previous time period, and subtracting $\sum_{j \in J^I} C_{j,t-k_j}$, the number of inpatients who is discharged at the beginning of time period *t*.

$$W_{j,t}^{N} = \sum_{m=N-1}^{N} \left(W_{j,t-1}^{m} - C_{j,t-1}^{m} \right) \qquad \forall j, t.$$

This constraint makes sure that $W_{j,t}^{N}$, the number of patients who are not served during time period $(t-1)$ and are waiting N time periods, remain on the waiting list at the beginning of time period *t*.

$$C_{j,t} \in \mathbb{N} \qquad \forall j, t.$$

This constraint is an integrality constraint for the total number of patients in queue *j* that are served during time period *t*.

6 Experimentation

This chapter describes the experiments that we performed in order to measure the effect of the proposed planning model on the performance of the SIR care unit. Hereby, the MILP is implemented in AIMMS 4.9 and solved using the built-in CPLEX solver. Section 6.1 describes the input data, section 6.2 describes the verification and validation of the model, section 6.3 describes the different scenarios and section 6.4 describes the results.

6.1 Input data

This section describes the input data for the starting situation.

Sets

Table 6.1 gives an overview of the queues and table 6.2 gives an overview of the disciplines of the therapists that we consider. Currently, the SIR care unit decides each week which patients to admit. Because a planning horizon of one week takes a lot of computation time and tactical planning problems in hospitals typically have a planning horizon of four to eight weeks, our model considers a planning horizon of six weeks. We run the model for three years. Since our model starts with an empty waiting list and no patients who are currently in treatment, we determined the warm-up period of the model using Welch's method. Figure 6.1 shows that the model has a warm-up period of approximately 52 weeks.

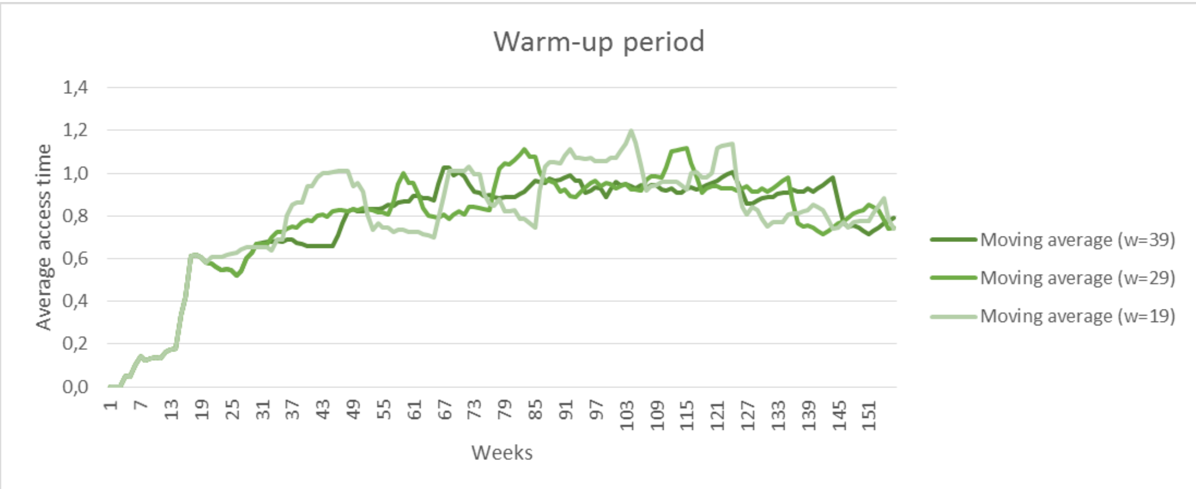

Figure 6.1. Warm-up period using Welch's method for three different windows (w=19, w=29, w=39)

Table 6.1. Overview of queues

Inpatient and outpatient queues	
Inpatient	Spinal injury T6 and higher
Inpatient	Spinal injury T7 and lower
Inpatient	Spinal injury other
Inpatient	Guillain Barré
Inpatient	Oncology
Inpatient	Baclofen Pump
Inpatient	Bolus Baclofen
Inpatient	Decubitus
Outpatient	Arm/hand function screening
Outpatient	Outpatient continuation
Outpatient	Standard outpatient
Outpatient	Sports desk
Outpatient	Sitting advice

Table 6.2. Overview of disciplines of therapists

Discipline of therapists	
BAG	Movement therapist
ET	Occupational therapist
FT	Physiotherapist
MW	Social worker
PS	Psychologist

Weight factor α

When minimizing the access time ($\min \sum_{j\in J} \sum_{n=0}^{\infty} \sum_{t\in T} \beta_j^n * W_{j,t}^n$), the best situation would be to admit all patients immediately when they arrive. In that case, $Best_A = 0$. The worst situation would be to admit none of the patients who arrive. In that case, all the patients remain on the waiting list and $Worst_A = 4702290$. When minimizing the excess use of therapist capacity ($\min \sum_{r\in R} \sum_{t\in T} E_{r,t}$), the best situation would be to never use any excess therapist capacity. In that case, $Best_E = 0$. The worst situation would be to use all the therapist capacity that is needed to admit all patients once they arrive. In that case, $Worst_E = 378705$.

α is used in the objective function to indicate the importance of minimizing the access time of patients relative to minimizing the excess resource capacity that is used. We assume $\alpha = 0.85$.

Weight factor $\boldsymbol{\beta_j^n}$

β_j^n is used in the objective function to prioritize patients who are waiting in queues *j* in order to deploy resources where they are most effective. β_j^n depends on the care pathway (i.e. queue) of the patient and the number of time periods that the patient has been waiting. We distinguish five priority groups of care pathways, based on the standards for the access time and the maximum allowed access time, as indicated by the management of the SIR care (Table 6.5). Table 6.3 provides an overview of the care pathways (i.e. queues) per priority group. Based on this, we determined the values for β_j^n. Hereby, β_j^n with *n* smaller than the standard is 1, β_j^n with *n* between the standard and the maximum allowed access time is 2, and β_j^n with *n* larger than the maximum allowed access time is 10 for the first value for *n* and increases with 2 every time *n* increases with 1 (Appendix IV).

Table 6.3. Overview of care pathways in each priority group

Priority 1	**Priority 2**	**Priority 3**	**Priority 4**	**Priority 5**	**Priority 6**
Outpatient continuation Spinal injury other Spinal injury T6 and higher Spinal injury T7 and lower Sports desk	Guillain Barré	Decubitus Oncology	Standard outpatient	Arm/hand function screening Sitting advice	Baclofen Pump Bolus Baclofen

Arrival rates

We determined the arrival rates of patients for all queues, based on the orders that are registered in the Hospital Information System (HIS). We identified all orders for a new care pathway or a continuation of the care process with another care pathway in 2013 and 2014. Based on these orders, we determined the arrival rate by calculating the average number of patients who arrived per week for each care pathway, i.e. queue (Table 6.5). The number of patients who arrive in each queue is then determined by using a Poisson distribution with the arrival rates as input.

Therapist resource capacity

In the decision which patients to admit, we included the availability of therapist of the disciplines BAG, ET, FT, MW, and PS. The availability of therapists is determined by calculating the available direct patient time per discipline per week, according to the standard for direct patient time and the current available capacity in FTE (Table 6.4).

Since we excluded patients whose care pathway is unknown, we reserve part of the therapist resource capacity for these patients. For this purpose, we determined the amount of care the excluded patients received in 2013 and 2014 and subtracted this from the available direct patient time of the therapists. Table 6.4 gives an overview of the percentage of direct patient time we reserved for patients with an unknown care pathway.

For the disciplines ET, FT, MW, and PS we assume that 50% of the therapists is absent during the summer holiday and Christmas period. For the discipline BAG, we assume that the therapist is replaced during the summer holiday and Christmas period. Public holiday, trainings, sick leave etc. are subtracted from the average available direct patient time per week.

Table 6.4. Overview of therapist capacity per discipline

Discipline	FTE	Available direct patient time (in min/week)	Direct patient time reserved for excluded patients (%)	Max % by which capacity may be exceeded (e_r)
BAG	0.38	600	35%	15%
ET	3.53	5568	17%	12.5%
FT	5.69	8984	31%	17.5%
MW	1.11	1754	11%	15%
PS	1.00	1578	21%	15%

Resource requirements

For the resource requirements of the patients, we consider the resource requirements per discipline per week as prescribed in the care pathway. For group therapy sessions, we divided the prescribed therapy time by the average number of patients in the type of the group therapy session and multiplied it by the average number of therapists that is needed for the type of the group therapy session.

Treatment duration

For the treatment duration of the patients, we consider the treatment duration as prescribed in the care pathway (Table 6.5).

Number of beds

We consider 28 beds, which is the total number of available beds of the SIR care.

Table 6.5. Overview of the arrival rate, treatment duration and standard and maximum for the access time per queue per week

Care pathway	Arrival rate (per week)	Treatment duration (in weeks)	Standard for access time (in weeks)	Maximum allowed access time (in weeks)
Arm/hand function screening	0,02	1	6	8
Baclofen Pump	0,09	2	8	12
Bolus Baclofen	0,04	1	8	12
Decubitus	0,16	12	3	5
Guillain Barré	0,03	24	2	4
Oncology	0,05	6	3	5
Outpatient continuation	0,05	12	1	2
Sitting advice	0,16	1	6	8
Spinal injury other	0,03	18	1	2
Spinal injury T6 and higher	0,41	24	1	2
Spinal injury T7 and lower	0,33	18	1	2
Sports desk	0,01	1	1	2
Standard outpatient	0,34	18	4	6

6.2 Validation of the model

Since the way patients are currently admitted to the SIR care unit is different from the way patients are admitted in the model, we could not use the current performance of the SIR care unit to validate the model quantitatively. Therefore, we validated the model qualitatively by discussing the input data and formulating the constraints and weight factors in consultation with the SIR care unit.

In addition, we ran the model with different input data to validate the output of the model. First we ran the model with a large resource capacity (i.e. five times the current resource capacity of the SIR care unit). As expected, this resulted in an average access time of 0 weeks, since all patients could be admitted to the SIR care unit immediately. Second, we ran the model with a small resource capacity. This resulted in a high average access time and a growing waiting list. Furthermore, we changed the values of the weight factors. A higher value for α resulted in a larger number of admitted patients and a lower value for α resulted in a smaller number of admitted patients. Beside, patients with a higher value for β_j^n had shorter access times than patients with a lower value for β_j^n.

6.3 Scenarios

We composed four scenarios to measure the effect of changes in the available resource capacity and the standards for the access time on the performance of the SIR care unit. In scenario 1, we use the current situation of the SIR care unit with the input data as described in section 6.1. In the second scenario, we adjust the resource capacity such that all patients can be treated according to the care pathway and the standards for the average access time. In the third scenario, we use the same resource capacity as in scenario 2, but we adjust the standards for the access time of the patients such that there are in line with the standards of the government. In the fourth scenario, we adjust the resource capacity such that 25% more inpatients can be treated according to the care pathway and the standards for the average access time. Table 6.6 provides an overview of the scenarios that we consider. For each scenario we performed four independent runs, using different seeds (i.e. random numbers) for the Poisson distribution. We describe the changes in the input data in scenario 2 to 4 compared to the input data in scenario 1.

Table 6.6. Overview of the scenarios

	Resource capacity	**Standards for the access time**
Scenario 1	Current resource capacity	Current standards
Scenario 2	Sufficient resource capacity for current patients	Current standards
Scenario 3	Sufficient resource capacity for current patients	Government standards
Scenario 4	Sufficient resource capacity for 25% extra inpatients	Current standards

Scenario 2

By means of several simulations with different values for the therapist capacity, we determined how much therapist capacity is needed to treat all current patients according to the care pathway and the standards for the average access time. Table 6.7 shows the values we use for the therapist capacity in scenario 2. We increased the capacity of BAG with 0.75 FTE, the capacity of ET with 0.25 FTE and the capacity of FT with 2.25 FTE.

Table 6.7. Therapist capacity in scenario 2

BAG	**ET**	**FT**	**MW**	**PS**
1784	5963	12536	1754	1578

Scenario 3

In scenario 3 we use the same therapist capacity as in scenario 2 (Table 6.7), but we differ the values for β_j^n (the weight of patients in queue *j* who have been waiting *n* time periods). As described in section 6.1, the values for β_j^n are determined based on the standard for the access time and the maximum allowed access of the priority group of patients in queue *j*. In scenario 3, we use the standard for the access time and the maximum allowed access time as set by the Dutch government (Table 6.8).

Table 6.8. Standard for the access time and maximum allowed access time in scenario 3

	Inpatients	**Outpatients**
Standard for access time	5	3
Maximum allowed access time	7	4

Scenario 4

In 2016, the SIR care unit expects to treat 25 extra inpatients on top of the ca. 100 inpatients who are currently treated each year. By means of several simulations with different values for the therapist capacity, we determined how much therapist capacity is needed to treat 25% extra inpatients according to the care pathway and the standards for the average access time. We use this therapist capacity in scenario 4 (Table 6.9). We increase the capacity of BAG with 1 FTE, the capacity of ET with 1.25 FTE, the capacity of FT with 5 FTE, the capacity of PS with 0.25 FTE and the bed capacity with 9 beds.

Table 6.9. Therapist capacity and bed capacity in scenario 4

BAG	ET	FT	MW	PS	Number of beds
2178	7542	16876	1754	1973	37

6.4 Results

This section discusses the results of the experiments per scenario. Since our model has a warm up period of approximately one year, we do not consider the result of the first year.

Scenario 1

Scenario 1 represents the current situation of the SIR care unit. Figure 6.1 shows the number of inpatients and outpatients on the waiting list at the beginning of each week, before patients are admitted, for one run. The figure shows that if there is not sufficient resource capacity to treat all patients, the waiting list will continue to grow up to infinity.

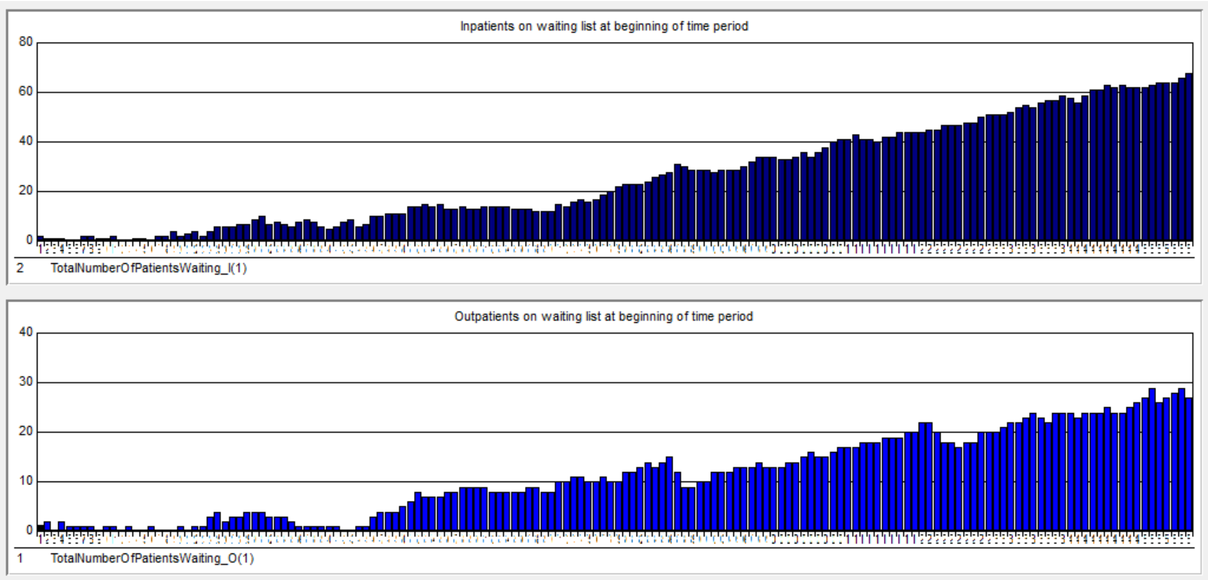

Figure 6.1. Number of inpatient and outpatients on the waiting list at the beginning of each week for scenario 1

Figure 6.2 shows the average access time in weeks per priority group. Hereby, we took the average of all five runs. The figure shows that the average access time of patients with priority 1, 2 and 4 is much higher than the standard of the SIR care unit. This can be explained by the fact that patients with priority 1,2 and 4 require a lot of therapy. Therefore, these patients have to wait for a long time, before enough resource capacity comes available to treat the patient. Since patients with priority 3, 5 and 6 require less therapy, it takes less time before enough resource capacity comes available to treat the patient. This means that with the current design of our model, in some situations a patient with priority 3, 5 or 6 who has been waiting for a shorter period of time than a patient with priority 1,2 or 4 is admitted first. Figure 6.2 shows the situation after 3 years; as more time elapses the access times will get even higher.

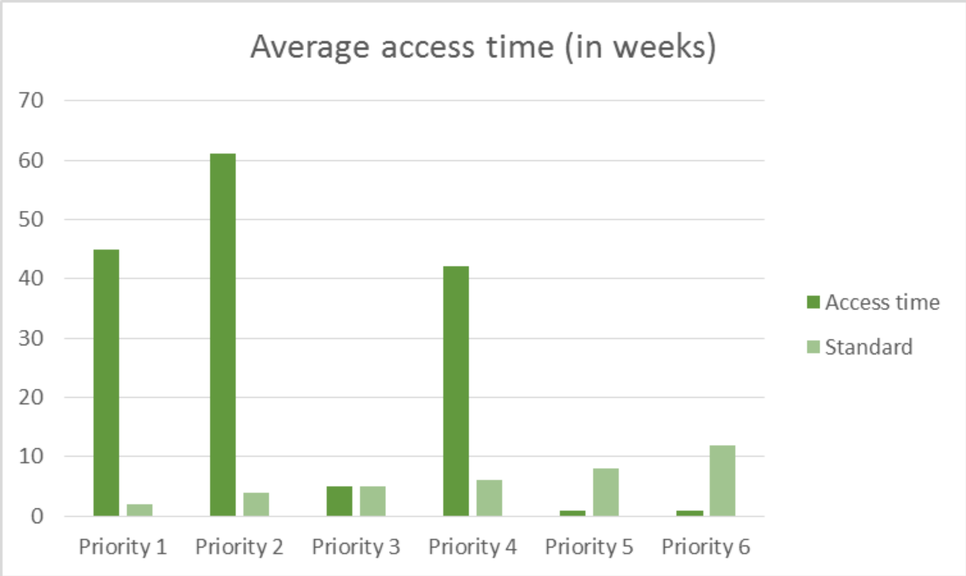

Figure 6.2. Average access time in weeks per priority group for scenario 1 (for year 2 & 3)

Figure 6.3 shows the allocated therapist capacity (in minutes per week) and the allocated bed capacity (in number of beds per week) per run relative to the available resource capacity. The figure shows that the capacity of BAG currently is the bottleneck in patient admissions, resulting in a low utilization of the other disciplines and a low bed occupancy. The low amounts of allocated resource capacity in the first weeks are caused by the warm-up period.

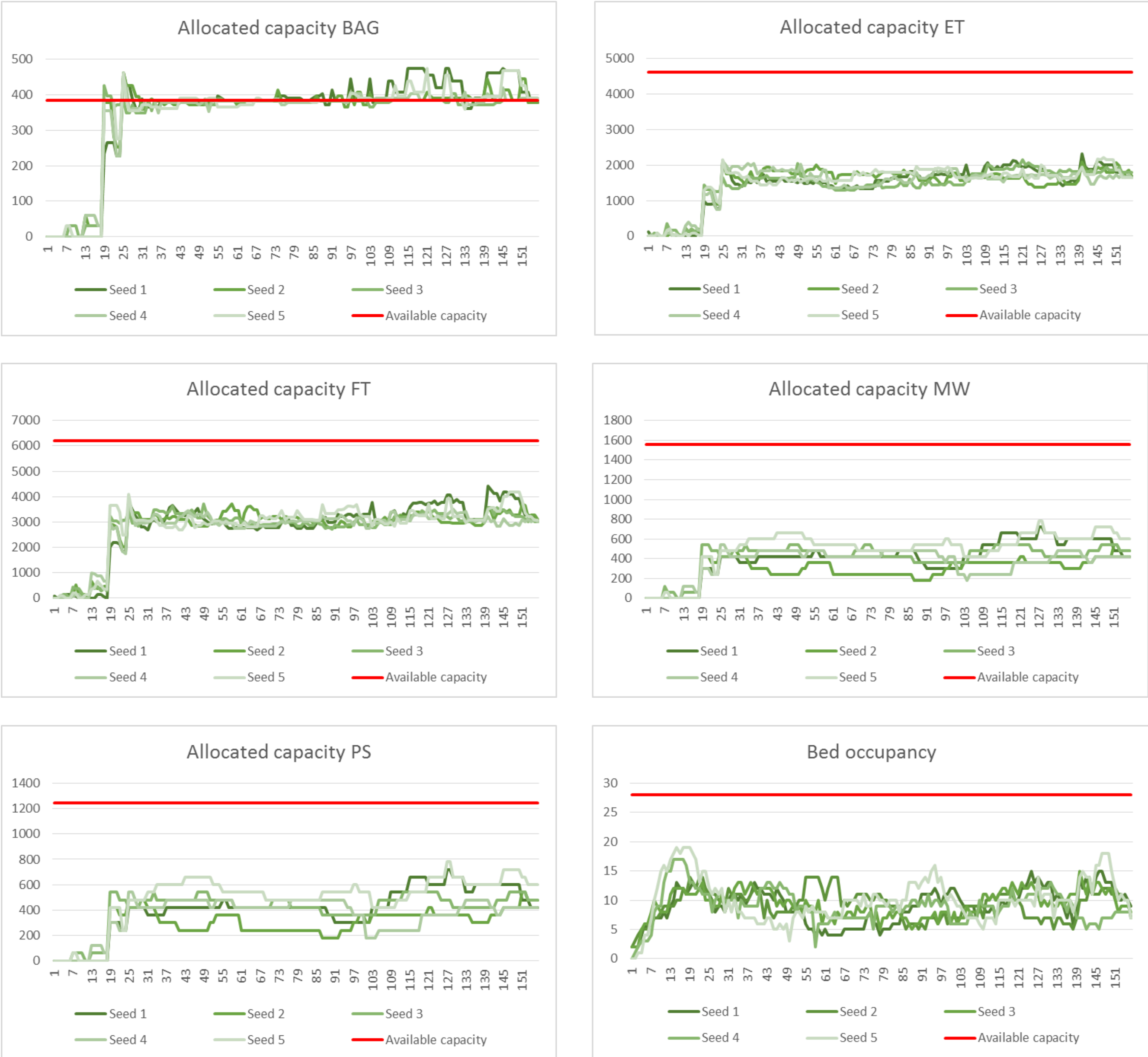

Figure 6.3. Allocated and available resource capacity (in minutes per week and number of beds per week) for scenario 1

Scenario 2

In scenario 2, we adjusted the resource capacity such that all patients can be treated according to the care pathway and the standard for the average access time, as described in section 6.3 (p.40). Figure 6.4 shows the number of inpatients and outpatients on the waiting list at the beginning of each week, before patients are admitted, for one run. The figure shows that if there is sufficient resource capacity to treat all patients, the waiting list does not to grow up to infinity, but fluctuates over the weeks.

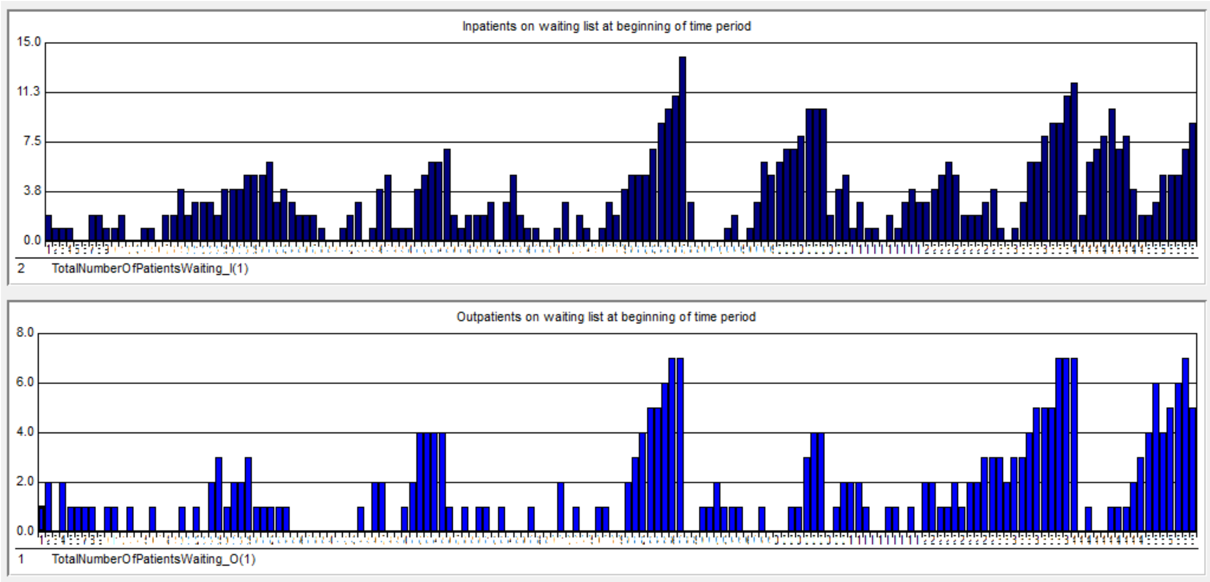

Figure 6.4. Number of inpatient and outpatients on the waiting list at the beginning of each week for scenario 2

Figure 6.5 shows the average access time in weeks per priority group. Hereby, we took the average of all five runs. The figure shows that the average access time of all patients is within the standard of the SIR care unit. Because patients with priority 5 and 6 require the least amount of therapy, it takes less time before enough resource capacity comes available to treat these patient than for the other patients who require more therapy. For this reason, patients with priority 5 and 6 have the lowest access time.

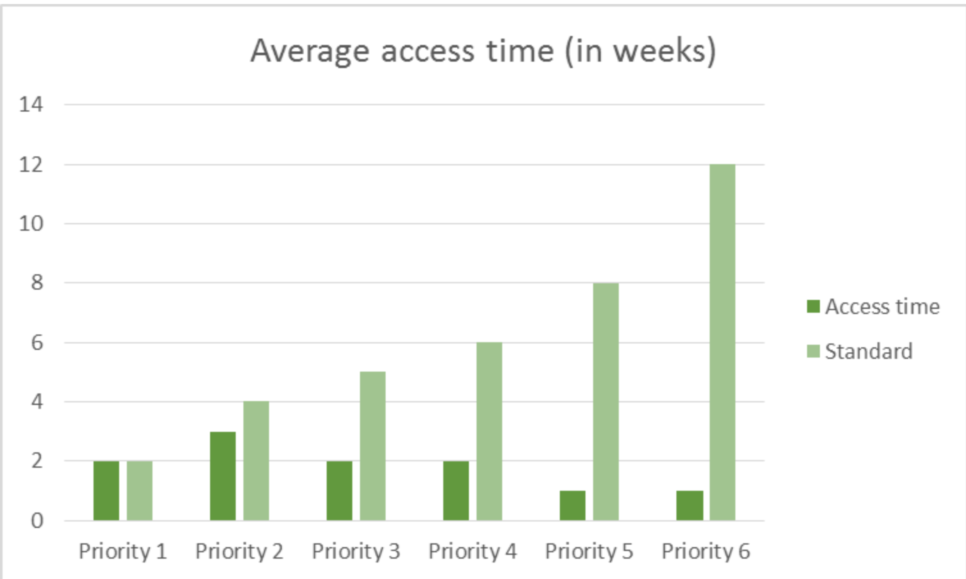

Figure 6.5. Average access time in weeks per priority group for scenario 2 (for year 2 & 3)

Figure 6.6 shows the allocated therapist capacity (in minutes per week) and the allocated bed capacity (in number of beds per week) per run relative to the available resource capacity. The figure shows that the allocated resource capacity differs per run depending on the arrival of the patients. Also, the figure shows that the utilization of the discipline MW is relatively low compared to the other disciplines, even though we did not increase the capacity of MW.

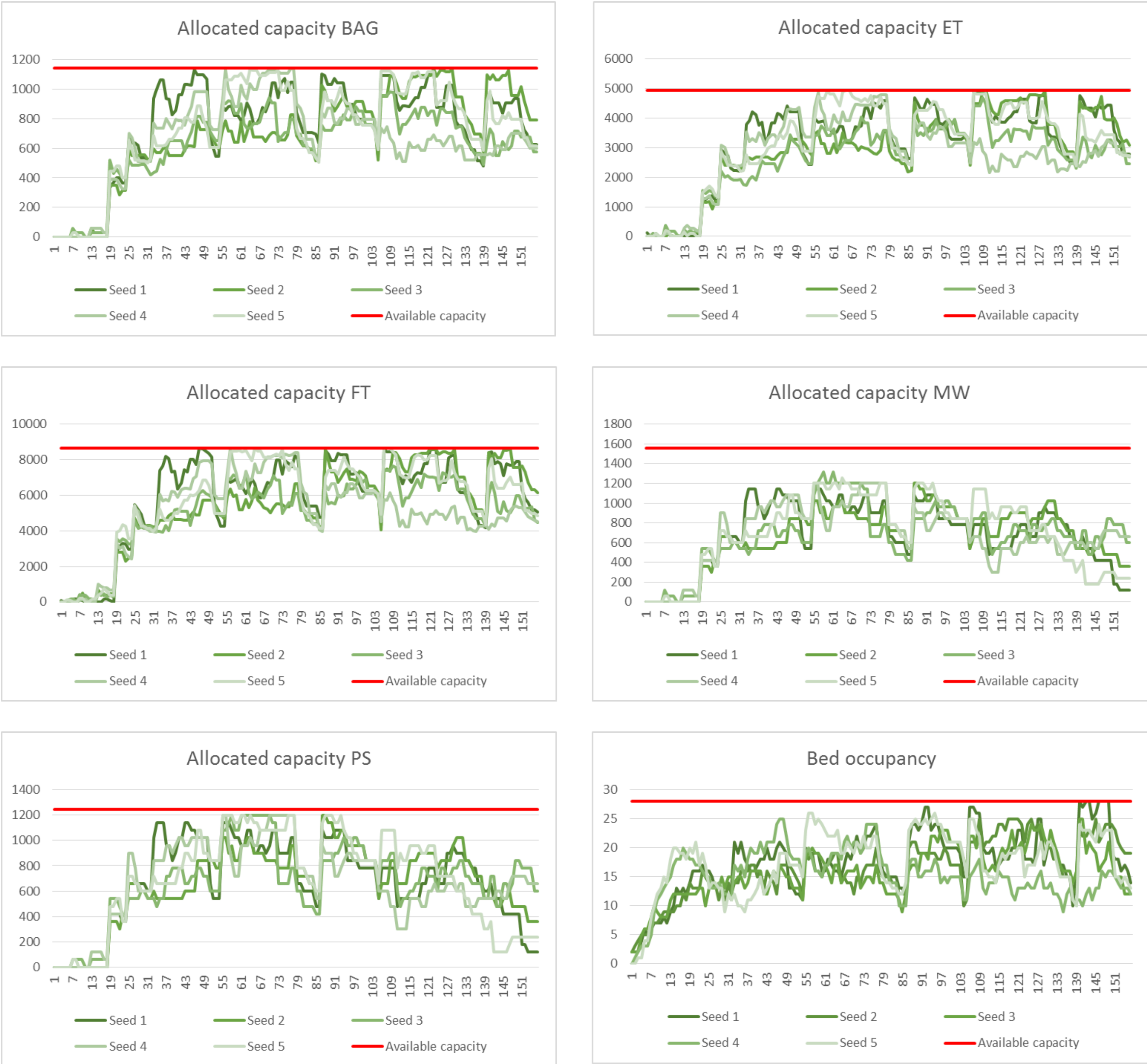

Figure 6.6. Allocated and available resource capacity (in minutes per week and number of beds per week) for scenario 2

Scenario 3

In scenario 3, we used the same resource capacity as in scenario 2, but we adjusted the standards for the access time, and thus the values for β_j^n, such that they are in line with the standards of the government (in Dutch: treeknormen). Figure 6.7 shows the average access times in weeks for inpatients and outpatients. Hereby, we took the average of all five runs. The figure shows that the average access time of both inpatients and outpatients is within the standard of the government (in Dutch: treeknormen).

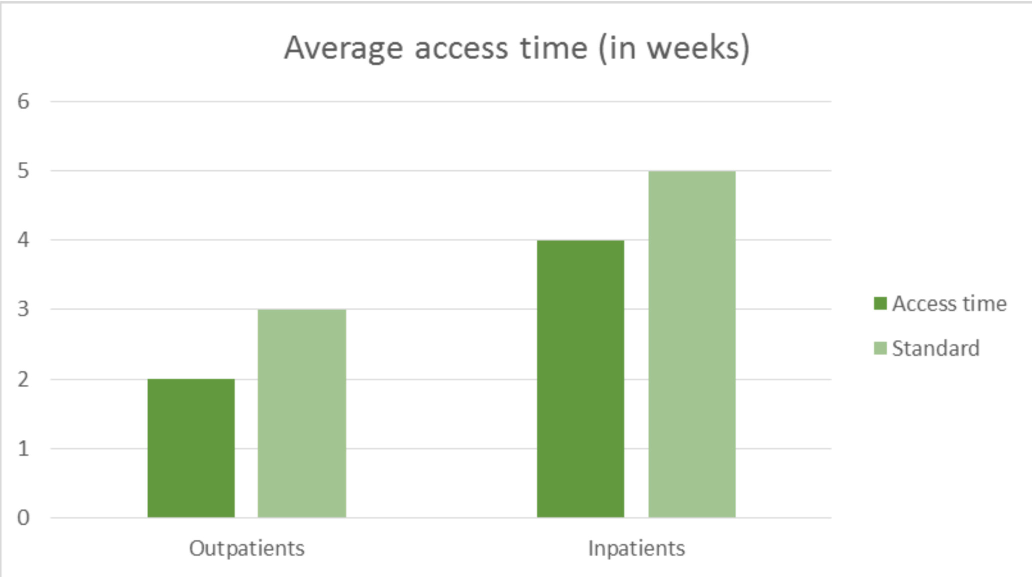

Figure 6.7. Average access time in weeks for outpatient and inpatients for scenario 3 (for year 2 & 3)

Figure 6.8 shows the allocated therapist capacity (in minutes per week) and the allocated bed capacity (in number of beds per week) per run relative to the available resource capacity. The figure shows that the allocated resource capacity differs per run depending on the arrival of the patients. Also in this case, the figure shows that the utilization of the discipline MW is relatively low compared to the other disciplines, even though we did not increase the capacity of MW.

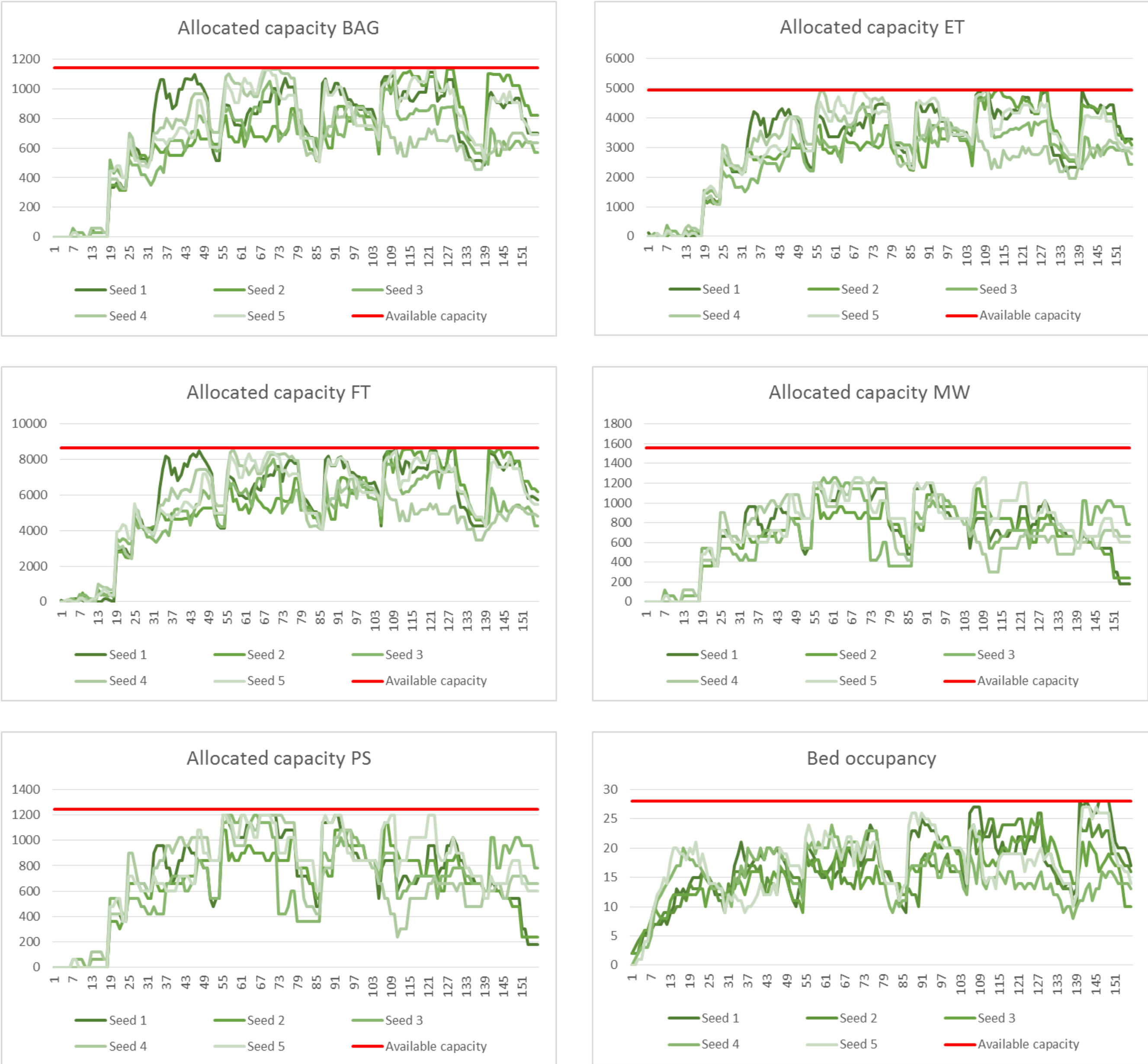

Figure 6.8. Allocated and available resource capacity (in minutes per week and number of beds per week) for scenario 3

Scenario 4

In scenario 4, we adjusted the resource capacity such that 25% more inpatients can be treated according to the care pathway and the standard for the average access time, as described in section 6.3 (p.41). Figure 6.9 shows the average access time in weeks per priority group. Hereby, we took the average of all five runs. The figure shows that the average access time of all patients is within the standard of the SIR care unit.

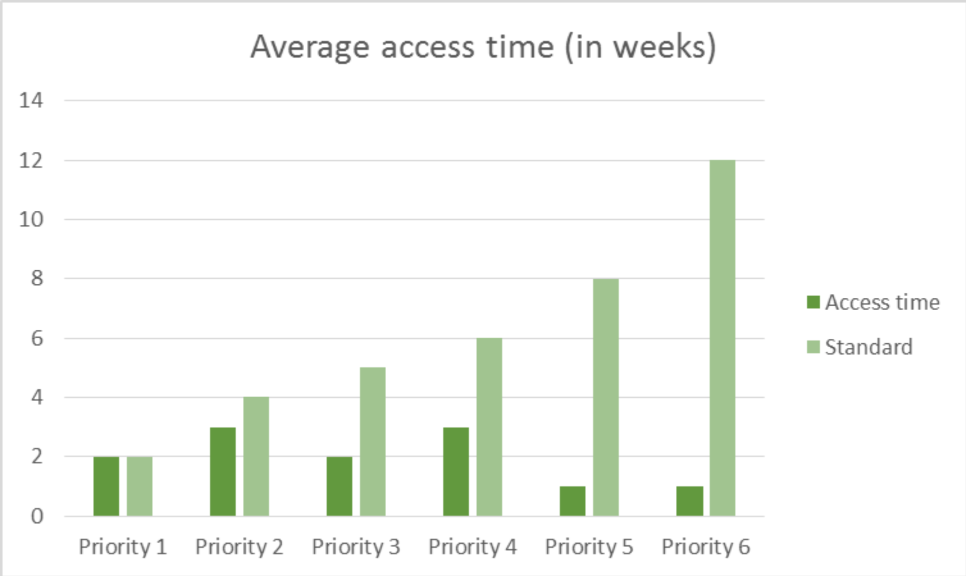

Figure 6.9. Average access time in weeks per priority group for scenario 4 (for year 2 & 3)

Figure 6.10 shows the allocated therapist capacity (in minutes per week) and the allocated bed capacity (in number of beds per week) per run relative to the available resource capacity. The figure shows that the allocated resource capacity differs per run depending on the arrival of the patients. In this case, the figure shows that the utilization of the discipline MW is similar to the utilization of the other disciplines.

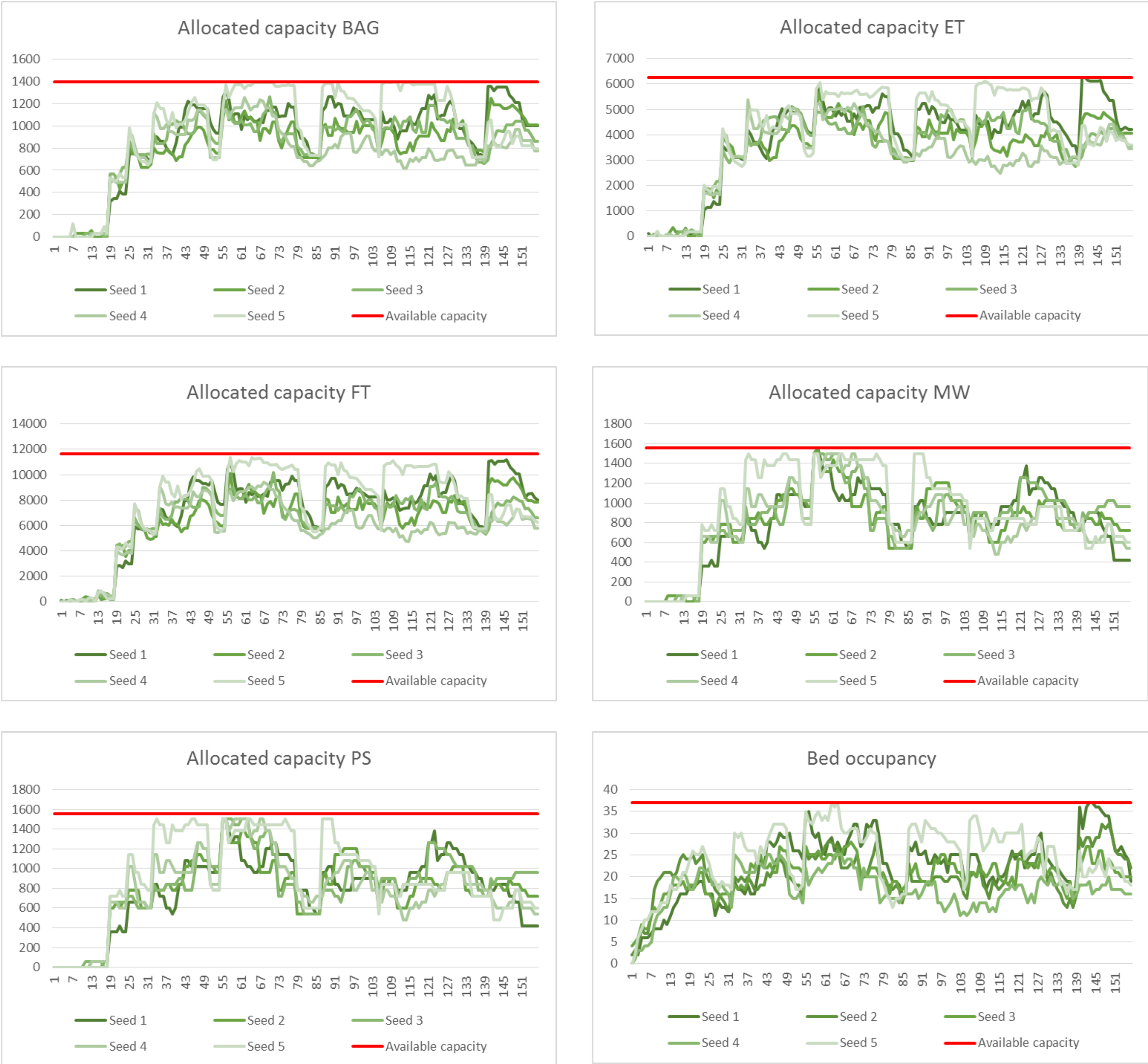

Figure 6.10. Allocated and available resource capacity (in minutes per week and number of beds per week) for scenario 4

The next chapter (section 7.1) contains the conclusion of the experiments.

7 Conclusion and recommendations

This chapter contains the conclusion of our research and recommendations for SMK. Section 8.1 contains the conclusion, section 8.2 gives an overview of the limitations of our research and section 8.3 discusses the recommendations.

7.1 Conclusions

The objective of this research was to:

Develop a prototype planning model in order to meet access time standards, while controlling labor costs.

The Dutch government has set standards for the access times of inpatients and outpatients. Based on a measurement of the current performance of the SIR care unit (section 3.3), we conclude that the access time of inpatients is within the standard, but the access time of outpatients is far above the standard. Besides, a large number of patients receive either more or less therapy than prescribed in the care pathway.

We have developed a patient admission planning tool for rehabilitation patients, based on the patient admission planning model by Hulshof et al. (2013), which is suitable for long-term rehabilitation treatments. The model develops a patient admission plan and allocates resource capacity, whereby the objective is to meet access time standards and minimize excess use of therapist capacity. The decision that is made every week is how many and which patients from the waiting list to admit for treatment starting one week later. Hereby, the model takes into account the type of the patient (inpatient or outpatient), the care pathway of the patient, the standards for the access time of the patient, the time the patient has already been waiting, the available therapist capacity, and the available bed capacity. We performed experiments with four different scenarios in order to measure the effect of changes in the resource capacity and the standards for the access times on the performance of the SIR care unit.

The results of the experiments (section 6.4) show that, when using the current resource capacity, the waiting list will continue to grow up to infinity, resulting in high access times. Also the experiments show that the therapist capacity of the discipline BAG currently is the bottleneck for patient admission. Furthermore, the experiments show that if we increase the capacity of BAG with 0.75 FTE, the capacity of ET with 0.25 FTE and the capacity of FT with 2.25 FTE, then all patients can be treated according to the care pathway and the standards for the average access time. If we increase the capacity of BAG with 1 FTE, the capacity of ET with 1.25 FTE, the capacity of FT with 5 FTE, the capacity of PS with 0.25 FTE and the bed capacity with 9 beds, then 25% more inpatients can be treated.

Based on these results, we conclude that our patient admission planning model helps to identify when there is insufficient resource capacity to treat all the patients according to the care pathway. In case there is sufficient resource capacity to treat all patients according to the care pathway, without continuously increasing waiting lists, our model helps to decide when to admit which patients such that the standard for the access times of as many patients as possible is met.

7.2 Limitations of the research

This research has several limitations, which will be discussed below.

- Due to a lack of data, we were not able to perform a reliable measurement of the current performance of the SIR care unit. As a result, the current performance of the SIR care unit should be interpreted carefully.
- In determining the arrival rates of the patients, we had to exclude patients whose care pathway is unknown. As a result, the number of patients that arrive in our planning model, and their care pathway, might differ from the patients that arrive in reality. Therefore, the results of the experiments should be interpreted carefully.
- In our planning model, we made several assumptions that might cause differences between the results of the experiments and the results in practice:
  - We reserve part of the therapist capacity for patients who were excluded, based on the realized amount of care for these patients. However, the realized amount of care might differ from the amount of care in the treatment plan. This means, that we might reserve either too much or too little resource capacity for patients who were excluded. This could result in deviations in the amount of resource capacity that is needed to treat all patients according to the care pathway in reality compared to the amount of resource capacity that is needed in the experiments.
  - We assume that patients are treated according to the care pathway, whereas in practice, the treatment of patients differs from the treatment as prescribed in the care pathway.
  - We assume that all patients with the same care pathway have the same urgency when they arrive. However, in practice for example the treatment of some patients

with the care pathway decubitus is much more urgent then the treatment of other patients with the same care pathway.

- In determining which patients to admit, we only take into account the therapist capacity and the bed capacity. We do not take into account the capacity of nurses or the costs of an empty bed.
- In our model, sometimes a patient who requires little therapy and has a low priority is admitted before a patient who requires a lot of therapy and has a high priority, because there is sufficient resource capacity available to treat the second patient but there is sufficient resource in case there
- In case there is not sufficient resource capacity available to treat a patient who requires a lot of therapy, but there is sufficient resource capacity available to treat a patient who requires less therapy, in our model, the patient who requires less therapy is admitted first. In this case, the patient who requires a lot of therapy might have to wait even longer.

7.3 Recommendations

This section contains recommendations for the SIR care unit.

Improve data registration

First of all we recommend the SIR care unit to improve the registration of patient characteristics. It is important that the arrival date of the patient, the care pathway of the patient and the treatment phase are correctly registered. Currently, in a lot of cases, the care pathway of the patient is registered as “other” or the diagnosis of the patient is registered as the care pathway, which is not the same. Also, when a patient switches from the diagnosis phase to the treatment phase or from an inpatient care pathway to an outpatient care pathway, this is not always correctly registered. This makes it impossible to measure the current performance of the SIR care unit reliably.

Take measure to improve congruence

Since the current care pathways are outdated, we recommend the SIR care unit to revise the current care pathways and to take measures to enable that appointments can be scheduled according to the care pathway. In this way, there will be fewer deviations between the realized care and the care as prescribed in the care pathway.

Increase resource capacity

To make sure that all patients can be treated according to the care pathway and the standards for the average access time, we recommend the SIR care unit to increase the capacity of BAG with 0.75 FTE, the capacity of ET with 0.25 FTE and the capacity of FT with 2.25 FTE. After the resource capacity has been increased, data registration has been approved and the current care pathways have been revised, the SIR care unit can use the proposed planning model as a decision support tool for the admission of patients.

Adjust therapist's shifts

In the context analysis (section 1.1) we found that therapist's shifts start between 7:30 and 8:30, but most patients are not available for therapy until 9:00 or 10:00. Therefore, we recommend the SIR care unit to adjust therapist's shifts to the availability of the patients and to consider providing therapy in the evening for patients who prefer to have therapy later on the day.

7.4 Further research

This section discusses topics for further research.

- In determining which patients to admit, our model takes into account the therapist capacity and the bed capacity. However, the availability of nurses also is an important factor in the decision whether or not to admit an inpatient for treatment. In order to extend the model with the availability of nurses, further research is needed.
- Our model allocates therapist capacity on a weekly basis. This means that the therapists still have to be allocated to the days of the week and to specific patients. Further research is needed in order to optimally allocate resource capacity to the days of the week and to the admitted patients. Also, methods to adjust resource capacity to temporary increases or decreases in demand for care, would be an interesting topic for further research.
- In the decision whether or not to admit a patient, the cost of an empty bed relative to the cost of therapists/nurses working in overtime could be taken into account. This would be an interesting topic for further research.
- Further research is needed to decrease the access time of outpatients between the referral of the patient to SMK and the first appointment with the rehabilitation specialist.

- In order to improve patient satisfaction, it would be interesting to investigate the effects on the quality of the patient planning of the possibility of determining the starting date of the treatment when the patient arrives at the SMK.

8 Implementation of the model in the SMK

This chapter describes how the results of this research can be implemented in practice. We have developed a prototype planning model that can be used to decide how many patients of which type to admit on a weekly basis. Here we describe how the prototype planning model and the results of this research can be implemented.

When to admit which patient from the waiting list to the SIR care unit is a complex decision, whereby the availability of therapists, the availability of beds and the access time of the patient play an important role. The patient admission planning model that we have developed can be used as a decision support tool for the management of the SIR care unit. The management can indicate the standards for the access times of different types of patients and the importance of meeting the access time standards compared to excess use of resource capacity. Based on this, the tool can determine an optimal patient admission plan. The output of the planning tool includes an overview of the admitted patients per care pathway, the patients who are on the waiting list, the access time per type of patient (inpatient or outpatient) and the allocated resource capacity (therapists and beds). Figure 7.1 and 7.2 show an example of two output screens of the planning tool. In addition, it is possible to analyze the output data (for example the access times per care pathway) in Excel.

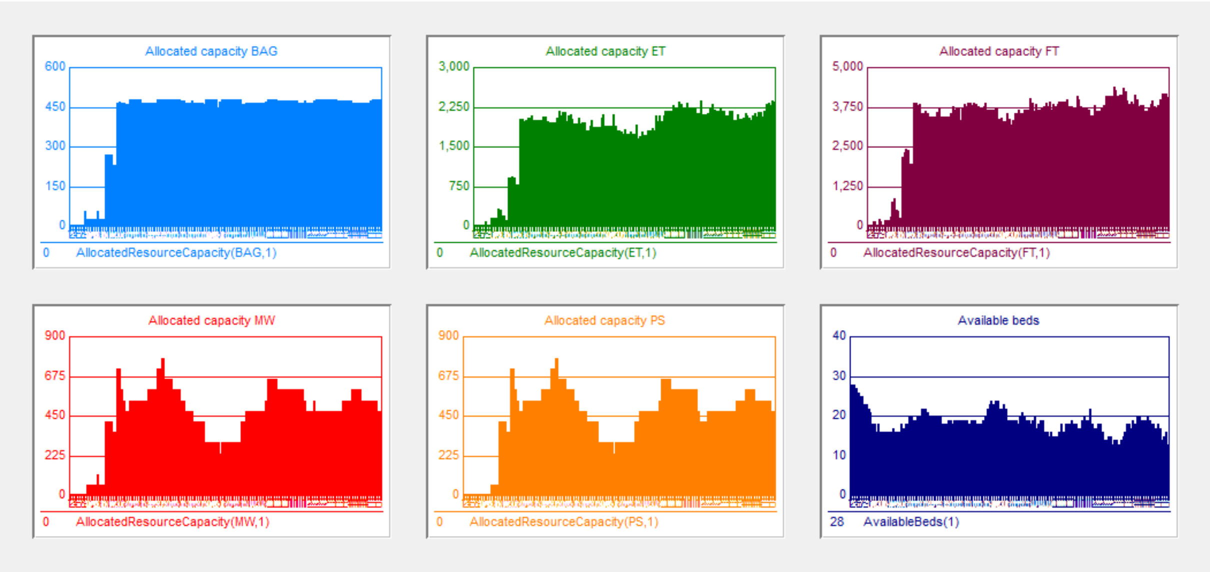

Figure 7.1. Output screen of the planning tool showing the allocated resources

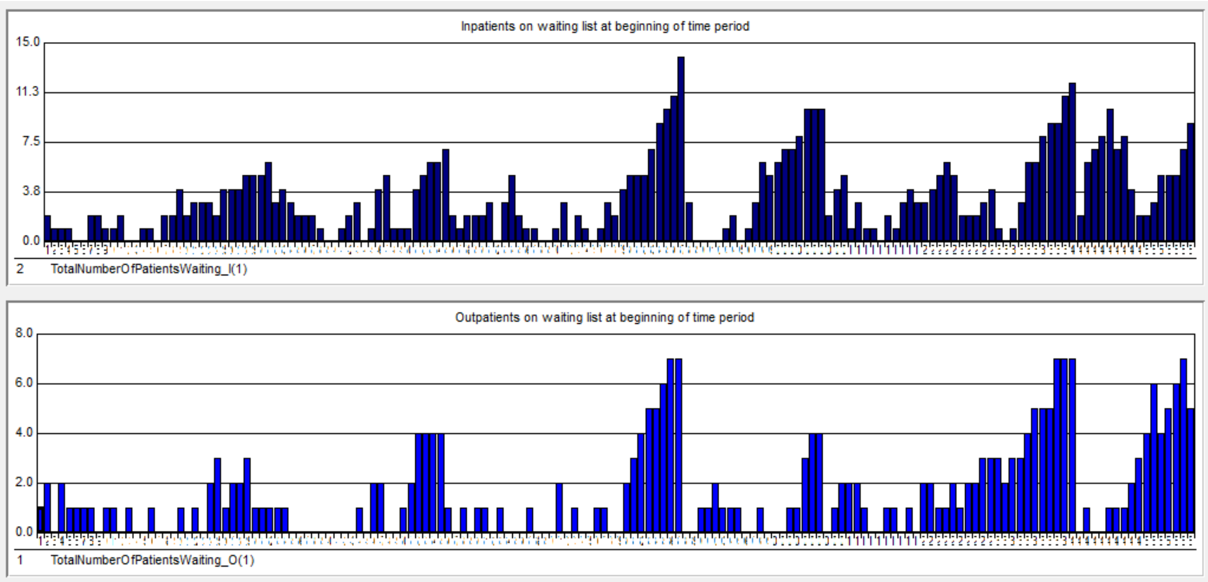

Figure 7.2. Output screen of the planning tool showing the patients who are waiting at the beginning of each time period

The care pathways and arrival rates of the patients can easily be changed and loaded into the model. Also, the disciplines and number of therapists and the number of beds can easily be adjusted. This makes it possible to use the model for other departments than the SIR care unit.

To obtain a reliable patient admission plan, it is important that data about the arrival of patients and patient characteristics (inpatient/outpatient, diagnosis/treatment, care pathway) are structurally and correctly registered. Furthermore, in order to use the model as a decision support tool, the SMK will need to purchase a license for a solver, such as CPLEX or Gurobi. A license for Gurobi approximately costs $48.000. An alternative would be to formulate the MILP in Excel or R Studio, and use the CPLEX cloud service for $10 per hour or the Gurobi cloud service for $15 or $25 per hour (depending on the usage) to solve the MILP.

Another alternative would be to formulate a simplified set of decision rules that state which patient should be admitted in which situation, based on the results of the planning model. These decision rules can be used as a guideline in patient admission planning.

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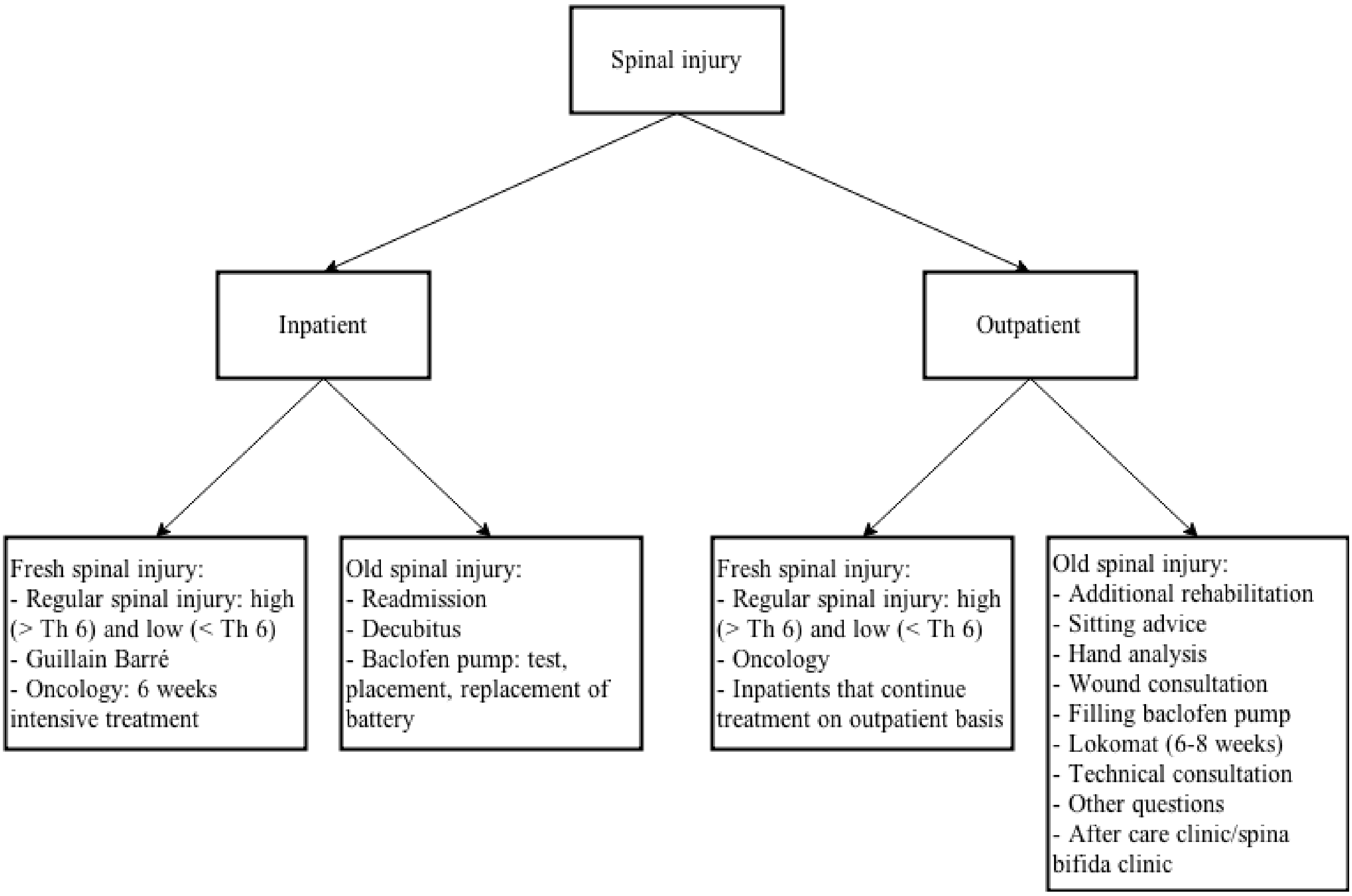
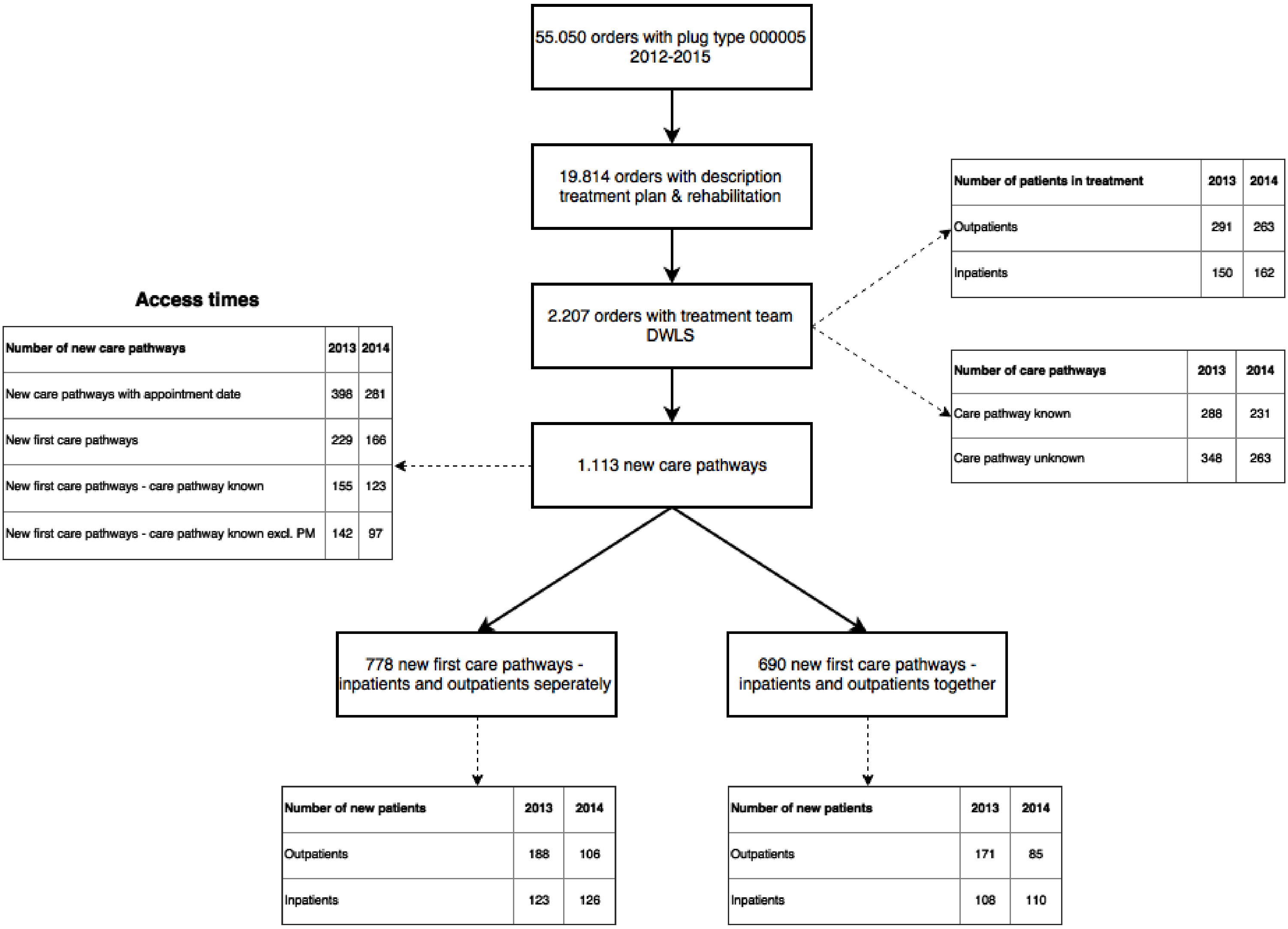
Appendix I: Diagnosis groups



Appendix II: Number of care pathways and patients in HIS



Access times

Number of new care pathways	2013	2014
New care pathways with appointment date	398	281
New first care pathways	229	166
New first care pathways - care pathway known	155	123
New first care pathways - care pathway known excl. PM	142	97

Number of patients in treatment	2013	2014
Outpatients	291	263
Inpatients	150	162

Number of care pathways	2013	2014
Care pathway known	288	231
Care pathway unknown	348	263

778 new first care pathways - inpatients and outpatients seperately:

Number of new patients	2013	2014
Outpatients	188	106
Inpatients	123	126

690 new first care pathways - inpatients and outpatients together:

Number of new patients	2013	2014
Outpatients	171	85
Inpatients	108	110

Appendix III: Literature search

We searched for articles about resource capacity planning, patient admission planning and planning/scheduling in rehabilitation care. For this purpose we used the search engine Scopus. Since we used the article by Hulshof et al. (2012) as a starting point for our literature search, we also searched for articles in their references. Table III provides an overview of the search terms we used, the number of articles we found and the articles we included.

Table III. Overview of search terms and included articles

Search engine	Search terms	Number of articles	Included articles
Scopus	ALL(“Resource capacity planning”)	22	Hulshof et al. (2013) Hulshof et al. (2015)
Scopus	ALL(“Patient admission planning”)	38	Hulshof et al. (2013) Hulshof et al. (2015)
Scopus	TITLE(“Patient scheduling”)	286	-
Scopus	TITLE(“Admission scheduling”)	213	Garg et al. (2010)
Scopus	TITLE(“Rehabilitation planning”)	79	-
Scopus	TITLE(“Rehabilitation scheduling”)	9	-
References of Hulshof et al. (2012)	-	-	Elkhuizen et al. (2007) Hans et al. (2011) Nunes et al. (2009) Zonderland et al. (2010)

Appendix IV: overview of weight factor β_j^n in the starting situation

n	Arm/hand function screening	Baclofen Pump	Bolus Baclofen	Decubitus	Guillain Barré	Oncology	Outpatient continuation	Sitting advice	Spinal injury other	Spinal injury T6 and higher	Spinal injury T7 and lower	Sports desk	Standard outpatient
0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	2	1	2	2	2	2	1
3	1	1	1	1	2	1	10	1	10	10	10	10	1
4	1	1	1	2	2	2	12	1	12	12	12	12	1
5	1	1	1	2	10	2	14	1	14	14	14	14	2
6	1	1	1	10	12	10	16	1	16	16	16	16	2
7	2	1	1	12	14	12	18	2	18	18	18	18	10
8	2	1	1	14	16	14	20	2	20	20	20	20	12
9	10	2	2	16	18	16	22	10	22	22	22	22	14
10	12	2	2	18	20	18	24	12	24	24	24	24	16
11	14	2	2	20	22	20	26	14	26	26	26	26	18
12	16	2	2	22	24	22	28	16	28	28	28	28	20
13	18	10	10	24	26	24	30	18	30	30	30	30	22
14	20	12	12	26	28	26	32	20	32	32	32	32	24
…	…	…	…	…	…	…	…	…	…	…	…	…	…
155	302	294	294	308	310	308	314	302	314	314	314	314	306