Thesis M-IEM

Improving the weekly blueprint plan of the pediatric rehabilitation department, using mixed integer linear programming on a tactical level of control

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Improving the weekly blueprint plan of the pediatric rehabilitation department of the St. Maartenskliniek, using mixed integer linear programming (MILP) on a tactical level of control

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Management Summary

Introduction
This study focuses on the improvement of the current procedures used to construct a weekly blueprint plan for the pediatric rehabilitation department of the St. Maartenskliniek (SMK), Nijmegen. The pediatric rehabilitation department is characterized by children requiring both education and therapeutic treatment. To satisfy demand in terms of therapy and education, the SMK constructs a weekly blueprint schedule where appointments between individual patients and therapists are captured, as well as moments that a school class receives education. The goal of this research is three-folded:

1. To identify and quantify current difficulties in the P&S processes of the pediatric rehabilitation department
2. To develop a tactical method in which the resource capacity allocations of therapists, teachers, and physicians are assigned in such a way that flexibility of the rosters increases, whilst satisfying all planning restrictions
3. To experiment with a prototype of the developed method

Problem description
Currently, the weekly blueprint schedule that is used to match demand with capacity takes 5 months to construct, consuming vital capacity of both planners and therapists. During the construction process, information is gathered and stored using dated methods, e.g. E-mail and Word documents. Also, the blueprint is constructed on an individual level and fixed for one year. This results in therapists feeling little ownership of their agendas and planners complaining about little flexibility/robustness whenever operational deviations in capacity or demand occur. Such deviations cause a lot of last-minute re-scheduling of appointments. We also observed that no clear strategic goals are formulated to allow easy cooperation between the school and the clinic. Moreover, there are no KPIs to measure the current performance of the weekly blueprint.

Approach
To tackle the problems, we first introduce strategic objectives (Quality of Education, Quality of Care, Quality of Labor, Quality of Service and Productivity) that need to be considered while making managerial decisions. Using these strategic perspectives, we formulated possible KPIs to quantify our performance on the strategic metrics. These KPIs quantify the performance of blueprint plans, but also the strategic course of the entire pediatric rehabilitation department.

We conduct a literature study to gather more information on commonly used methods to construct blueprint plans. In literature, we find that blueprint planning is a promising method to solve planning problems in this context. Mixed Integer linear programming (MILP) is an often-used method for constructing such plans (Bikker et al., 2015, Griffiths et al., 2012, Leeftink et al., 2019, van der Velde et al., 2012). We look to find a weekly plan and do not experiment with other time horizons, because the children of the St. Maartenschool require repetitiveness in their weekly rosters. To obtain the planning rules that can be converted to linear constraints, we conduct interviews with expert planners and therapists. During the construction of the model, we create a tiny problem instance to allow quick verification of newly added constraints. Also, we used a continuous validation and improvement cycle, where therapists and planners could validate intermediate versions of the model. This allowed us to implement initially forgotten constraints/planning rules. We model the week as a 5 by 20 grid (days, periods) and aim to find the optimal combination of appointments, given a certain objective. After completion of the model, we conducted a

what-if-analysis to gain insights into the effects on the performance of the blueprint when making certain decisions on a managerial level.

Results

During the course of this research, we organized for the representatives of the three stakeholder perspectives to meet for the first time during an advisory group meeting. During such a meeting, we presented a mnemonic that was developed during this research, which enables management to weigh the impact of a decision over all five strategic objectives at a glance. The mnemonic is called the rehabilitation turtle and is illustrated in Figure 1 on the next page. The turtle was received with much enthusiasm. Because of the strategic pillars (and the turtle), better communication and cooperation between the planning department, the therapists and the school is enabled.

This research applies the hierarchical levels of control, first introduced in the healthcare setting by Hans et al. (2012), and applies it in a practical setting. We introduce a currently non-existent tool that functions as a means to translate strategic objectives to a robust tactical plan, which in turn can be used to construct an operational plan. Robustness in the tactical plan ensures easy translation from a tactical plan to an operational plan. The result is a tactical weekly plan that provides flexibility on an operational level.

From the experimental results, we observe that the current problem is infeasible due to the high demand of very constraining multi-disciplinary meetings. By reducing the demand of these meetings, the problem became feasible but still resulted in large optimality gaps (around 50%) after 28.000 seconds of solver run time. Because of the large optimality gap, we need to be cautious with interpreting the results, therefore, we do not present key results in this summary but refer to our extensive discussion.

Conclusion & Recommendations

This research provides a road map to synergize the strategic, tactical and operational levels of control. The developed model can be used in similar (pediatric) rehabilitation centers (in the Netherlands), but can also be adjusted to be applicable to other settings where demand is assigned to capacity, given a pre-known availability per actor or machine. This research provides the organization with a shared strategic vision for all stakeholders in the pediatric rehabilitation department of the SMK. The tactical plan provides therapists with more ownership over their agenda. We save time for planners, due to a decrease in the number of requests for rescheduling appointments. Lastly, teachers and therapists will enjoy more pleasant communication with each other due to a decrease in the number of linked therapists per class.

We recommend undertaking the following:

- For SMK, we advise implementing a tactical level of control, using the developed model of this research as a supportive tool.
- For SMK, we advise reevaluating the ascription of multi-disciplinary meetings with the goal to reduce the demand for these meetings, as these meetings are the main bottleneck that causes infeasibility and a large optimality gap.
- For SMK, we advise reevaluating the moments at which classes have gym, animal care, hydrotherapy and block times, as a different distribution of these moments over the week can result in an increased solution quality.
- For Rhythm, we advise integrating the model as part of a yearly service contract that is scalable to other pediatric rehabilitation departments (in the Netherlands).
- For Rhythm, we advise exploring the possibilities of solving the blueprint plan by using a heuristic approach, as this will likely increase the quality of the solution and consume less solver time.

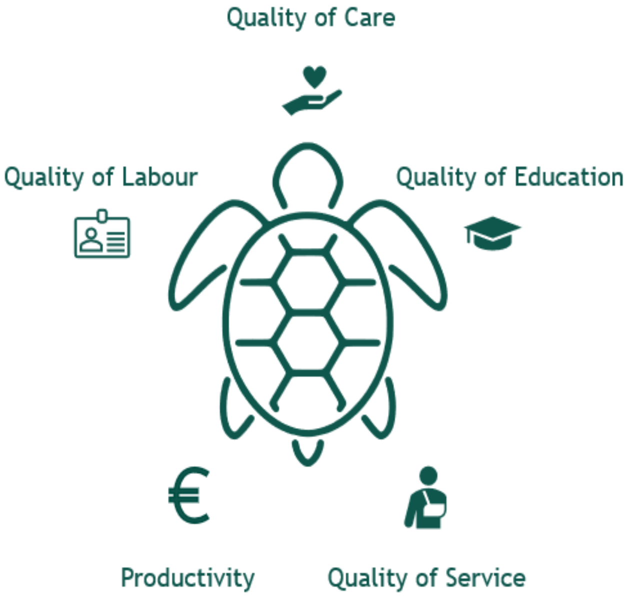

Figure 1: Rehabilitation turtle

Contents

Preface

Dear reader,

This master thesis: "Improving the weekly blueprint plan of the pediatric rehabilitation department of the St. Maartenskliniek, using mixed integer linear programming on a tactical level of control" marks the end of my student time and my master Industrial Engineering & Management at the University of Twente.

I would like to thank Rhythm B.V. and the St. Maartenskliniek for this opportunity and, especially, Bas Kamphorst, Jordi van Heeswijk, Linda Sluijter and Bart Bogers for their guidance during my research. I appreciate the time (often time off) and effort you have put in supporting me to finish this research.

Furthermore, I would like to express my gratitude to Erwin Hans and Daniela Guericke as my supervisors from the University of Twente for providing valuable input during this research. Erwin, I really enjoyed the atmosphere during our meetings. There was a nice balance between personal subjects and diving into the MILP formulations. I will never forget the airy meeting where we talked more about Croatia than the research.

Finally, I would like to thank my family and friends for the support they gave me during my research.

I hope you enjoy reading this thesis.

Stef Huttinga, Enschede, November, 2022

Glossary & Accronyms

Term (Eng)	Term (NL)	Definition
Year plan	Jaarplanning	A blueprint planning on patient-level, static for an entire schoolyear (Sept - Aug).
Blueprint schedule	Blauwdruk planning	Refers to the year plan, or any other cyclic schedule.
Block times	Bloktijden	Times (often hours) in which a class, or a child, is not available for therapy. This could be due to medical conditions or educational factors. Blok-times can further be categorized as: child-specific blok-times and class-specific blok-times.
Classes	Schoolklas	A Class is a group of children with the same characteristics. Most important are: 1. Cognitive capability, 2. Social-emotional capabilities, 3. Medical condition and 4. Over-all behaviour
Units	Units	A unit is a group of classes that share the same characteristics of children in that class
Products	Producten	A product is a fixed treatment-procedure with predictable outcome in terms of therapeutic development
Basic-treatment	Basis behandeling	Basic-treatment is the set of all specifically targeted therapeutic treatments, that are not available as a product
Planning-bureau	Planbureau	Team of planners, working for the Planning-department of the SMK
ELF-moments	ELF-momenten	Indirect time for a group of therapeuts, treating the same specific child, or children
EKEP	EKEP	Treatment vision, in which all facets of development of a child are balanced. This includes social-emotional development, cognitive development and medical therapy (balance between school and therapy)
CKB	CKB	CKB is a meeting between a doctor, therapist(s), teacher(s) and parents, to establish strategic goals for a single child. During this meeting therapists, teachers, doctors and the parents come together to decide the general direction of treatment vs school, for a single child. This is the only formal, pre-planned, possibility for parents to steer the directed path and influence the focus points of the EKEP-treatment. The CKB often precedes an MDO

Concept (Eng)	Concept (NL)	Definition
MDO	MDO	MDO is a meeting between a doctor and therapists, to establish a specific treatment-procedure for a single child. During the MDO, the details concerning the 'how' of the therapy are decided. An MDO often follows a CKB
ELF	ELF	ELF is a short way to converse about the three therapeutic disciplines operating in child rehabilitation
Productivity	Productiviteit	Refers to efficiency, costs, utilization
Quality of Care	Kwaliteit van verzorging	Is considered to be everything that improves the quality and effectiveness of therapy
Quality of Service	Kwaliteit van service	Refers to the experienced degree of service from a patient's perspective (what is the patient's experience, undergoing care?)
Quality of Education	Kwaliteit van onderwijs	Is considered to be everything that improves the quality and effectiveness of education
Quality of Labor	Kwaliteit van werknemers	Is considered to be everything that makes work easier or more pleasant for our employees
Conflicts	Agenda conflicten	Multiple appointments, for one actor, at the same time
Influx	Instroom	Refers to the influx of demand over the year when more children register

1 Introduction

Rehabilitation care focuses on preventing, reducing and curing diseases or injuries. During rehabilitation treatment, patients see a range of therapists with varying expertise. Therapists work closely together in a multidisciplinary team, headed by a rehabilitation physician. In Dutch healthcare, rising healthcare expenditures have led to the introduction of a performance-based reimbursement system, which increases the importance of providing high quality of care efficiently. The Dutch association of rehabilitation centers recognizes the importance to improve logistical efficiency and indicates that the logistical organization of rehabilitation centers can be improved (Revalidatie Nederland, 2010). The organization of rehabilitation care differs from regular hospital care. For example, planning in hospitals is regularly focused on material resources such as operation rooms, while human resources are the focus in rehabilitation care (Raschendorfer and Hamacher, 2014). The multidisciplinary character of rehabilitation care makes it difficult to efficiently deploy these resources, while quality of care is guaranteed.
In this research, we introduce KPIs to quantify the performance of the pediatric rehabilitation care unit of the St. Maartenskliniek in general as well as the blueprint in specific. Moreover, we introduce a model which enables the planners to efficiently and effectively deploy resources on a tactical level in a multidisciplinary character, whilst maintaining quality of care.
Chapter 1 is structured as follows: Section 1.1 describes the hospital and department where the study is performed as well as a brief introduction to the problem owner. Section 1.2 discusses the motivation for this research and gives the problem description. Section 1.3 defines the research objective and demarcates the scope and lastly, Section 1.4 describes the research questions, including an outline of the report.

1.1 Problem context

The Sint Maartenskliniek (SMK) is a Dutch hospital specialized in musculoskeletal and neuromuscular conditions and offers orthopedic, rehabilitation and rheumatism care. SMK has locations in Nijmegen, Woerden, Boxmeer, and Tiel, all in the Netherlands. In addition, it has outpatient clinics in Panningen and Mijdrecht. SMK describes itself as a 'leading hospital in treating conditions in movement and posture (Sint Maartenskliniek, 2022)'. In 2017, the hospital realized a turnover of €169 million and had 1.117 fte (Sint Maartenskliniek, 2017).
The rehabilitation center at the hospital in Nijmegen offers inpatient and outpatient care and consists of four care units. The pediatric rehabilitation care unit offers treatment to children with conditions in motion and posture. As of 2014, there are three care units for adults. At the neurologic rehabilitation care unit patients recover after a nervous system injury, such as a cerebrovascular accident. Moreover, the unit treats patients with cerebral palsy and several neuromuscular conditions. The chronic pain, amputation and orthopedic rehabilitation care unit involves, among other things, rehabilitation after amputation and orthopedic interventions. Finally, patients with a spinal injury and several other related conditions, such as Guillain-Barre, rehabilitate at the spinal injury rehabilitation care unit (Sint Maartenskliniek, 2017).
The pediatric rehabilitation care unit works closely together with the St. MaartenSchool (SMS) to coordinate the intensity of the treatment with the educational needs of a child. The protocol that centralizes the needs of a child is called the EKEP (One Child One Plan) protocol. The St. Maartenschool is a school for students with physical or multiple

disabilities and children with long-term illnesses. The students have an intensive need for support, requiring rehabilitation treatment to help them further in their development (St. MaartenSchool, 2022). Over 200 children between the age of 4-12 years are registered at the school and divided over 20 classes. The throughput of the school is around 25 children per year.

1.1.1 Problem Owner(s)

This research knows three stakeholders: the University of Twente, Sint-Maartenskliniek (SMK) and Rhythm B.v. In this section, we explain the relationship between these stakeholders to one another. The SMK is the problem owner. The research is conducted by Rhythm B.V., which is a spin-off of CHOIR (Centre for Healthcare Operations Improvement and Research of the University of Twente) and Ortec. It can be considered a technological consultancy firm that operates in the healthcare sector. The SMK outsources process optimization support to Rhythm B.V. As a result, Rhythm B.V. functions as a technological policy consultant on efficiency improvements. In other words, Rhythm B.V. conducts integral capacity management for the SMK.

1.2 Motivation

The focus of this research is on improving the planning and scheduling (P&S) processes of child rehabilitation treatment. The SMK observed that notable time and resources are wasted in these processes. Therefore, SMK requested research in which potential improvements in these processes can be identified and solved. Besides the identification of potential solutions, SMK expects to be guided and assisted with the implementation of found solutions.

Child rehabilitation P&S processes are complex due to two main factors. First, the children require intensive, individual, specialized treatment and are of school age (compulsory education). A balance has to be found between school (representing social-emotional- and cognitive development) and treatment (representing rehabilitation development). Second, the system harbors many involved actors and facilities such as therapists from multiple disciplines, teachers, physicians, a swimming pool, riding stables, rooms, and expensive treatment tools such as the C-MILL [1].

Currently, planners are not able to develop a roster that perfectly satisfies agenda restrictions from both fields of tension. In turn, this leads to dissatisfied physicians, therapists, teachers, planners, and patients. This research focuses on the field of tension between integrating school and treatment (and the accompanying problems that arise for the involved actors and facilities as a consequence) of rehabilitating children in the SMK.

1.3 Objective and Scope

This section covers a brief statement of the research goal. As mentioned in the Introduction, this research focuses on the P&S problems that arise in the child rehabilitation department of the SMK due to the field of tension between school and treatment.

We analyze the system in Section 2.3 and identify the objective of the research in Section 2.5. In Section 2.5 we identify the rigidity of the current rosters and the presence of divergent objectives in the construction process of the year plan as the main problems.

[1] https://www.motekmedical.com/solution/c-mill/

In Section 2.3, we make a hierarchical analysis of the system and observe that no clear method is integrated for the tactical P&S procedures.

The two analyses led us to the following objectives for this research:

1. To identify and quantify current difficulties in the P&S processes of the child rehabilitation
2. To develop a tactical method that optimizes the resource capacity allocations of therapists, teachers, and physicians in such a way that flexibility of the rosters increases, whilst satisfying all planning restrictions and guarantying stability.
3. To test a prototype of the developed method

Definitions of plannings-restrictions, flexibility- and stability of the rosters can be found in the Glossary. In Section 2.7 we elaborate on the intended performance of the company and further quantify the objectives introduced above.

The scope of the research is limited to the P&S processes of the child rehabilitation department. More specifically, we focus on children that are registered in the St. Maartenschool and have an age between 4-12 years. The perspectives of all actors in the system are taken into account.

The pediatric rehabilitation department provides two types of therapy. Regular therapy, such as occupational therapy, speech therapy and physiotherapy, but also 'products'. Regular therapy is an appointment between one therapist, of a certain specialty, and one patient. Products are a series of appointments between a patient and several therapists, of multiple specialties. Appointments in a product can be on an individual level but are often in groups of patients and groups of therapists. Also, in some products physicians are part of a series of appointments. In general, a patient receives a fixed amount of regular therapy on a weekly base and can receive additional therapy in the form of a product when this is deemed necessary by the therapists and physician. During this research we focus on planning the regular therapy, assuming that products are already planned by hand.

1.4 Research Design & Reading Guide

In this section, we describe the approach to solve the previously described problem. We make use of the plan for managerial problem-solving, introduced by Heerkens and van Winden (2021). The approach can be summarized in the following steps:

1. Identify the core problem by conducting a problem analysis, where we identify the observable problems and deduce the causes of these problems
2. Analyse the current situation and acquiring additional knowledge through literature and data analysis
3. Formulate alternative solutions and select the alternative which best fits the problem context
4. Develop and test the solution best suited to the case

To briefly repeat, the main objective of the research is:

"To develop a method which provides the (near) optimal resource capacity allocation of therapists, teachers, and physicians in such a way that flexibility and stability of the roster can be guaranteed".

To deliver the objective(s), we propose research questions to guide the research. Each research question covers a certain aspect of the research. The research can be conducted by subsequently answering the research questions. We structure the research questions per chapter of the research. The chapters are presented in bold, the research questions are indicated with the letters of the alphabet and the sub-research questions (to structurally answer research questions, if needed) are indicated with Roman numerals. Below the research questions, we provide a brief explanation of the approach that is used to answer the question.

2. **Context analysis**
   (a) How are the child rehabilitation planning and scheduling processes currently organized?
      i. How do the different concepts and actors of the system relate to one another?
   (b) How do the planning and scheduling processes currently perform?
      i. How does one quantify the planning performance of the child rehabilitation planning?
   (c) Which difficulties/problems can currently be observed in the pediatric rehabilitation system?

   The context is analyzed in depth through observations and interviews with employees within the child rehabilitation system, this includes physicians, therapists, teachers, and planners. The employees provide insight into the tasks performed within their department and the methods used. Besides that, data analysis is done to obtain quantitative information about the current performance P&S processes.

3. **Literature**
   (a) Which problem-solving approach is best suited for the identified problem?
      i. In what manner can we classify the identified problem?

   A literature review is conducted to identify research in which similar challenges are tackled. We aim to provide a theory-ingrained base for our solution design.

4. **Solution approach**
   (a) What model optimizes the resource capacity allocation of therapists, teachers, and physicians in such a way that flexibility and stability of the roster can be guaranteed?

   We use the findings from our literature review to design a model that is able to construct a weekly plan that adheres our objectives. In this phase we test the model on a toy problem to verify correct functioning. We involve the advisory group to validate intermediate results and balance objectives.

5. **Experiments**
   (a) How does the developed method work compared to currently used methods?
   (b) In what manner can managerial interventions increase the performance of the pediatric rehabilitation plan?

   In agreement with the advisory group, we formulate potential managerial interventions. With the managerial interventions as a base, we introduce experiments that quantify the impact of each intervention. A table with experimental parameters is presented in combination with a table of experimental results.

6. **Implementation plan**
   (a) How can the model be adapted and used for future research?

   This chapter is intended for integral capacity management consultants and describes the functioning of the model in a practical sense. For example, the sheet of input parameters and several data-processing tools are introduced.

7. **Conclusions and recommendations**
   (a) What are the managerial implications of the proposed model?
   (b) Which recommendations for future research can we make?
   (c) What are the limitations of this research?
   (d) Contributions to theory and contributions to practice?
      i. Contribute to practice: How can we apply the proposed model to the SMK child rehabilitation setting, such that flexibility and stability of the roster are acquired?
      ii. Contribute to theory: In what manner can this problem be applied to other cases?

We use this chapter to draw conclusions from the experimental results and to reflect on the body of our research. We regard our own work critically and point out limitations, future improvements and possibilities. Also, we interviewed the lead therapists to identify other potential applications for the model. We end this chapter with a list of key points to take away from this research.

2 Current situation

This chapter focuses on explaining the pediatric rehabilitation system in detail. The Chapter start with an overview of the systems characteristics in Section 2.1. Section 2.2 is used to introduce the involved actors. The patient journey and the P&S procedures that are currently in place are described in Section 2.3 and 2.4 respectively. In Section 2.5, we analyze observable problems, per actor, in the problem analysis. Section 2.6 introduces KPIs which enables us to quantify the performance of the pediatric rehabilitation (planning). We close the Chapter by comparing the intended performance of the plan to the actual performance of the plan in Section 2.7. Page viii provides an overview of the jargon that is used in the chapter.

2.1 System characteristics

The system that we are analysing is the pediatric rehabilitation department. Table 2.1 provides an overview of the size of the system in 2022 by introducing characteristics per actor. We observe that many part-time therapists are operating in occupational therapy (ot) and speech therapy (st) and less so in physiotherapy (pt). Table 2.2 provides the distribution of patients over classes and the generated demand of therapy sessions (Direct demand) and indirect time (IDR demand). IDR is the administration time associated with a therapy sessions. CP indicates the cumulative number of patients in a class. Ot, St and Pt refers to the specialties that are introduced above. The letter in front of the class represents the unit of a class. E.g. 'A helikopter' (ENG = helicopter) is the name of a class situated in unit 'A'. We observe that classes in unit B have a relatively low number of children. Children in unit B have the greatest limitations in terms of physical movement and cognitive development. Therefore, these children require more individual attention of teachers, which explains the lower number of children in these classes.

Figure 2.1 shows the characteristics of the units plotted against age and cognitive development. 'Route' indicates the level of cognition in a respective Unit. We see that children in unit A are mixed in terms of cognitive development (route 2 to 7) and grouped per age (only ages 4 to 7). Units C, D and E contain children that have progressed from unit A and are grouped in terms of cognitive capability. Progression is indicated with the grey arrows. In this figure, we also see that children in Unit B remain (generally speaking) in Unit B through the years. This is because children in unit B show little progression in terms of physical movement and cognitive development.

Table 2.1: Overview of actors in 2022

Actor	**Count**	**FTE (40 h)**	**Specialty**
Physicians	5	3.8	-
Patients	213	-	-
Classes	20	-	-
Therapists	21	11.7	Occupational therapy (ot)
	23	12.2	Speech therapy (st)
	14	12.75	Physiotherapy (pt)
Grand total therapists	58	36.65	

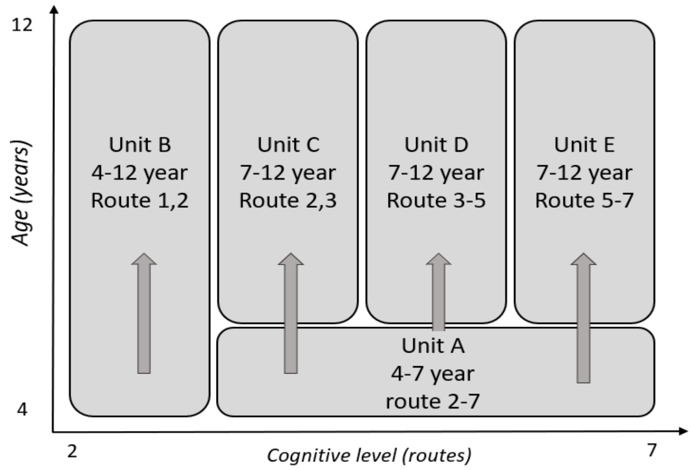

Figure 2.1: Unit characteristics

From Table 2.2 we also observe that direct demand of classes in the same unit can fluctuate significantly. For example, 'B dahlia' has an Ot demand of 2 and 'B madelief' has an Ot demand of 11. Another example is 'D berk' with an Pt demand of 26 and 'D linda' with a Pt demand of 6. We see the same of IDR. For example, 'D berk' with an St. IDR demand of 0,7 and 'D linde' with an St. IDR demand of 7,0. Another example is 'A luchtballon' and 'A straaljager' whom both have a relatively high Ot. IDR demand. To better show the dispersion of the direct- and IDR demand of classes in a unit, we introduce Tables 2.3 and 2.4.

Table 2.2: Class characteristics

		Direct			**IDR**		
Class	**CP**	**Ot**	**St**	**Pt**	**Ot**	**St**	**Pt**
A helikopter	12	18	22	20	5,2	3,3	1,2
A luchtballon	8	16	17	15	1,0	2,0	0,0
A raket	10	13	14	12	1,7	1,3	2,3
A straaljager	11	19	21	19	6,3	2,7	2,0
A vlieger	12	24	23	23	1,3	1,0	0,0
A zeppelin	12	22	21	21	2,0	4,0	2,7
B dahlia	7	2	7	4	0,0	3,3	1,3
B klaproos	7	10	13	14	1,0	1,3	0,7
B lavendel	7	8	12	17	0,3	3,7	4,0
B madelief	7	11	11	11	1,3	1,7	0,7
C dolfijn	10	6	12	6	2,3	6,7	2,3
C schildpad	9	7	17	8	0,3	8,7	1,0
C zeepaardje	8	11	19	9	3,7	8,0	0,0
D berk	13	13	5	26	2,3	0,7	2,3
D kastanje	13	20	18	17	5,3	3,0	2,3
D linde	12	15	22	6	4,7	7,0	2,0
D wilg	13	9	5	16	2,7	0,7	3,3
E beren	15	7	6	8	1,3	0,0	0,0
E dassen	14	13	8	9	2,0	4,3	1,3
E vossen	13	13	14	13	1,7	3,3	1,3
Average	10,7	12,9	14,4	13,7	2,3	3,3	1,5
Std.dev	2,6	5,6	5,9	6,0	1,8	2,5	1,1
Sum Total	213	257	287	274	46,5	66,7	30,8

Table 2.3 shows the mean (μ), standard deviation (σ) and the relative standard deviation (RSD) per unit. The RSD is defined as the ratio of the standard deviation to the mean, $RSD = \frac{\mu}{\sigma}$. RSD provides an indication of dispersion with which we can compare units per demand category and therapy specialty. Table 2.4 presents the same information for IDR demand. In 2.3 we observe that primarily Unit B and Unit D cope with a large dispersion of demand over classes. In Table 2.4 we observe large dispersion of IDR demand over all units. In the context of this research we assume the large dispersion of demand over the classes as a given and do not alter this information. For future research it might be worthwhile to experiment with different distributions of children over classes as this parameter highly influences the performance of the plan.

Table 2.3: Mean (μ) and standard deviation (σ) of direct demand per unit

	Od			**St**			**Pt**		
Unit	μ	σ	**RSD**	μ	σ	**RSD**	μ	σ	**RSD**
A	18,7	3,6	0,19	19,7	3,1	0,16	18,3	3,7	0,20
B	7,8	3,5	0,45	10,8	2,3	0,21	11,5	4,8	0,42
C	8,0	2,2	0,27	16,0	2,9	0,18	7,7	1,2	0,16
D	14,3	4,0	0,28	12,5	7,6	0,61	16,3	7,1	0,44
E	11,0	2,8	0,26	9,3	3,4	0,36	10,0	2,2	0,22

Table 2.4: Mean (μ) and standard deviation (σ) of IDR demand per unit

	Od			**St**			**Pt**		
Unit	μ	σ	**RSD**	μ	σ	**RSD**	μ	σ	**RSD**
A	2,9	2,1	0,70	2,4	1,1	0,44	1,4	1,1	0,78
B	0,7	0,5	0,79	2,5	1,0	0,41	1,7	1,4	0,82
C	2,1	1,4	0,65	7,8	0,8	0,11	1,1	1,0	0,86
D	3,7	1,3	0,34	2,8	2,6	0,91	2,5	0,5	0,20
E	1,7	0,3	0,16	2,6	1,9	0,72	0,9	0,6	0,71

2.2 Actors

The pediatric rehabilitation treatment processes has six main actors. The following list states each actor and provide a brief descriptions of their responsibilities and role in the pediatric rehabilitation system.

1. **Physicians**
   Each child is assigned one physician. A physician has ultimate responsibility for the rehabilitation of the child. The physicians are not responsible for cognitive, or social-emotional, development of a child. Physicians allocate around 50% of their total available hours to the pediatric rehabilitation department. Of all actors, the physician has the least contact with every child, receiving most information from therapists, teachers, and parents. Although a physician has the ultimate responsibility for rehabilitation treatment, all actors influence the treatment procedure together. This is done in a central child discussion (NL = Centrale Kind Bespreking, CKB).

2. **Therapists**
   Each child can have multiple therapists. Therapists deliver the therapy and can be specialized in one of three specialties: occupational therapy (NL = ergotherapy),

speech therapy (NL = logopedie), and physiotherapy (NL = fysiotherapie). Often, the acronym ELF (from the Dutch: Ergotherapy, Logopedie, Fysiotherapie) is used to describe the three specialties. This report also uses ELF to refer to the three specialties and multidisciplinary meetings between therapists of different specialties. These multidisciplinary meetings are called ELF-moments. Whenever a therapists provides therapy to a child, situated in a class, that therapist is linked to that class. All linked therapists need to consult with each other and the teacher of that class. To reduce communication difficulties the planning department focuses on reducing the number of linked therapists to one class.

3. **Teachers**
   Each child is placed in a school class with around eleven children, led by one teacher (sometimes two, if teachers work part-time). The teacher is responsible for delivering the cognitive- and social-emotional development of the children in the class. A child is placed in a certain class according to four criteria: cognitive capabilities, social-emotional capabilities, medical ability, and overall behavior. The class in turn is grouped in units, as depicted in Figure 2.1.

4. **Planners**
   The planners deliver the planning & scheduling services to accomodate treatment in combination with school for all children of the St. Maartenschool.

5. **Caretakers/Parents**
   The caretaker's voice the children's (and their own) interests concerning cognitive, medical, and social-emotional development.

6. **Children**
   The children are arguably the most important actor, because as a patient they are subject to all decisions made during the planning processes in the pediatric rehabilitation department. Children are considered too young to voice their own concerns. Therefore, we assume that the teachers represent their interests concerning cognitive- and social-emotional development and therapists their rehabilitation interests. The caretakers represent their overall interest, including the treatment vs school field of tension.

2.3 Patient journey

The care pathway for every child is unique, therefore the SMK introduced the EKEP (one child one plan) principle, which strives to find a balance between all facets of the development of a child. In practise this means that every child receives a different intensity and frequency of treatment, next to education. Whenever a patient is registered at the St. Maartenschool, the care pathway starts. The average care pathway of children on the St. Maartenschool spans on average 8 years, assuming children are registered at an age of 4 and leave school at an age of 12. Figure 2.2 visualises the patient journey. After registration, the patient receives a screening. During the screening the patient is observed on current physical performance and cognitive ability. Subsequently, the treatment for a child and the class is decided in the CKB, using the information obtained from the screening. CKB is the central child discussion and is attended by teachers, a physician, therapists and the parents. Following the CKB, an MDO takes place. The MDO is only attended by therapists and a physician. In short, the CKB sets goals in terms of treatment and the MDO specifies which procedures are needed to achieve set goals. During the CKB, a patient (in this case a child of age between 4-12) is also placed in a class (school class). The placement/classification of a class is based on four aspects: cognitive development, social-emotional development, therapeutic demand, and behavior. All classes are grouped per unit. As age is not named as a placement criterion, it is important tof note that children of different ages can be grouped in the same class and unit. Halfway through a school year, another round of CKBs and MDOs are planned to determine whether adjustments in treatment need to be made. Every year, educational needs are adjusted (just like in a normal elementary school). At the age of 12, the child leaves elementary school.

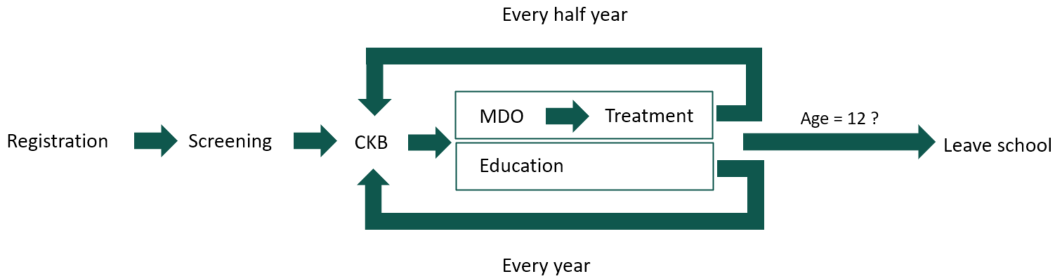

Figure 2.2: Visualization of patient journey of children of the St. Maartenschool.

2.4 Planning procedures

To make the described patient journey possible, a collection of planning procedures are adopted by the Planning Bureau of the SMK. In this section, we describe the procedures currently in place and categorize them per organizational level, as described by Hans et al. (2012): strategic, tactical, and operational planning procedures (definitions are also found in the glossary). The procedure with the largest impact on the P&S tasks is the year plan. Therefore, we explain the impact of the year plan as a product of the clinic, but also elaborate on the current constructing process of the year plan.

2.4.1 Strategic planning procedures

Year plan as a product

To deal with the complex task of creating a weekly schedule for the pediatric rehabilitation treatments, the SMK introduced a planning tool called the year plan (NL = jaarplanning). The year plan is a weekly repeating blueprint of all appointments, for every actor, on an individual level. This means that every weekly repeating appoint between a therapists and a child is fixed for one year. We classify the year plan as a strategic planning tool because it focuses on achieving the pediatric rehabilitation department's mission for a year.
In other words, the year plan forces the organisation to match demand (number of children to treat) and capacity (the number of therapists required) for a year. Although the year plan is a strategic planning tool, it incorporates the specificity of operational offline planning due to appointments at individual actor level, resulting in rigid blueprint plan for a full year. *Note, every single appointment for the upcoming year is planned before the start of September.* Moreover, the year plan, is continuously changed and tweaked by planners throughout the year to accommodate for operational fluctuations in demand and/or capacity. This is a tedious job, as every change in the year plan affects multiple actors, which in turn affects multiple appointments. As we will see in the Section 2.5, this leads to several problems.

Year plan construction process

The drafting process of the year plan starts approximately 6 months prior to September (in March) and demands extensive collaboration between two different organizations (St. Maartenschool and St.MaartensKliniek) and over 10 actors (e.g. therapists, teachers and planners). The goal is to gather information relevant for constructing the year plan. Examples of information that is collected are the number of children registered at the SMS from 1 September, hours of available capacity per therapist, the distribution of children over classes, the total demand of treatment per child etc. Also, the wishes and restrictions of all actors in the system are collected. Examples are part-time working therapists with a wish to be available on days 1,2,3 and not on days 4, and 5. Or, a child is never available for lessons or therapy between 12:30 and 14:00 due to a catheter change. The gathering of information is referred to as collecting input and the gathered data is referred to as input data.
One person has the ultimate responsibility to gather all input data for the construction of the year plan. Usually, this is a planner or therapists with affinity for project management. The input data is used to construct the year plan. Although a lot of effort and harmonization is put into the construction of a year plan that satisfies all wishes and restrictions, this has never been realized. In theory the blueprint should reflect a balance between school and therapy, dividing the available hours of children evenly over the two points of attention. In practice, planners often prioritizes therapy over the school.

2.4.2 Tactical planning procedures

The tactical planning processes are not well captured and unstructured. At irregular time intervals, the coordinating therapists of each specialty meet in a multi-disciplinary meeting together with the head of the rehabilitation department. During this meeting they discuss the balance of capacity versus demand on a time horizon of the upcoming three months. We classify this multi-disciplinary meeting as a tactical planning procedure, because they decide how therapists dedicate their time. Often, capacity is switched from A to B. For example, whenever a product (serie of therapeutic appointments, as explained in Section 1.3), has less demand for a given period the therapists that are responsible to provide that product can use their time to provide regular therapy instead. They may also decide that schedule overtime on several therapists or hire extra staff for several months.

2.4.3 Operational planning procedures

We distinguish between offline operational and online operational planning procedures. The offline operational planning procedures consist of scheduling appointments in advance with a known demand and a known capacity for a given horizon. The online operational planning procedures consist of dealing with unforeseen, or stochastic, events at the moment. The most important difference is that in online operational planning, demand is not known in advance and mostly urgent. An example of online operational stochastic demand is an emergency patient who needs treatment right know (urgent and unforeseen). An example of offline operation demand is a patient who requires four sessions of speech therapy over the course of two months (not urgent and known).

Online operational

The nature of the pediatric rehabilitation system doesn't allow for daily, unforeseen events like an emergency patient. However, planning mistakes and daily fluctuations in both capacity and demand need to be dealt with at the moment and are unforeseen. Examples are double-booking (e.g. a therapist that needs to be at 2 locations at the same time), absence of a child (loss in demand) or employee (loss in capacity). Events like these are solved by contacting the affected actor(s) and rescheduling their missed appointment(s). On the spot, agendas need to be adjusted, such that the idle time of therapists and physicians is minimized.

Offline operational

The offline operational planning procedures in the SMK consist of making adjustments to the year plan. The difference is that requested changes are known in advance. Examples are appointment requests (e.g. an extra appointment, incidental cancellation of an appointment), re-scheduling requests (e.g. seeing child A on Wednesday instead of Monday). Most of these requests allow planners at least a time window of two working days.

2.5 Problem analysis

In this section, we analyse the problem and present the observable problems in the current system and categorize them per actor, indicated with −. Below each problem we state the root cause of each problem, presented with ◦. Many IEM thesis present the relation of problems in a problem cluster. Due to the large body of problems and the many actors involved, we decide to present the problems in a list format. Moreover, in this format the actors in the system can easily navigate, relate and add problems to the list.

2.5.1 Identified problems and root-causes

Therapists

- Therapists regularly work during their breaks (e.g. to converse about patients with other therapists).
  - Often, therapists linked to a class, can not attend ELF-moments with other linked therapists, forcing therapists to converse about patients during their breaks. ELF-moments are multi-disciplinary meetings between therapists providing therapy to the same class.
  - Whenever a therapist decides to sacrifice a break (expecting to have this break later during the day), the current blueprint doesn't allow therapists to make small changes to their own agenda.
  - Often, appointments for passings are not included in the blueprint of the year plan.
- Therapists, do not feel ownership over their agenda (their roster is constantly subject to changes and enjoy little freedom to allocate their own time).
  - The planning bureau changes appointments at will, often without conversing or providing clear explanations as to why a change is made.
  - Because the weekly plan is monitored, as a whole, by the planning department, only planners oversee the impact of changes in the individual agenda of therapists.
- Therapists experience annoyance when planning mistakes (e.g. conflicts) occur.
  - Planning-mistakes occur, because it is relatively hard for planners to identify conflicts in agendas of the actors of the pediatric rehabilitation system. SAS (a system that can generate a list of conflicts), provides unpractical output, forcing planners to spend hours to find conflicts.
- Therapists experience troublesome, and delayed, communication when conversing with the planners.
  - Therapists expect a first-time-right process, where they request an appointment and do not have to invest additional effort. The planners receive agenda

orders with incomplete details (e.g. the duration of the order is not stated) or receive orders which lead to conflicts. The planners recontact the therapists, often via e-mail, to clarify details or conflicts, thus not meeting the expectations of the therapists. Moreover, due to the delay in communication some agenda requests are never scheduled.

- Therapists sometimes experience periods with a low workload.
    - Non-structured capacity management of therapeutic resources.
- Therapists experience periods with a high workload (also related to working during breaks).
    - Non-structured capacity management of therapeutic resources.

Teachers

- Teachers have to iterate their classical explanations.
    - Planners are not able to find a 'perfect' roster, satisfying all restrictions. Therefore, planners are forced to negate some restrictions. At the moment planners always favor therapy over classical block times (education), resulting in the absence of children during essential classical activities. This in turn leads to teachers having to explain the same material multiple times to different children.
- Teachers miss moments to coordinate treatment/education with therapists.
    - Currently, teachers are not expected to be present during ELF-moments. Teachers are not incorporated in the year plan. This leaves them with a feeling of missing out on relevant information.
- Teachers spend a lot of time coordinating/dealing (treatment/education) with a lot of therapists (often more than 6)
    - A lot of therapists work part-time, thus to meet the demand of a single class, several therapists, per specialty, are required to be linked to a class to match capacity with demand.
    - At the moment, at the start of the year, as few as possible therapists are linked to a class, closely matching the total demand of a class with the total capacity of a group of therapists. However, a class is subject to an influx of new children, which increases the demand for a class. Whenever demand surpasses the capacity of the group of therapists, an additional therapist is linked to the class. Because the new therapists can not be idle for a big portion of the time, the capacity of the additional therapist is fragmented over several classes that encounter influx. This process repeats itself throughout a school year, as an influx occurs during the entire year.

Planners

- Planners receive orders with unclear, or in-complete, details.
    - No clear framework/template structuring the required information to schedule an order is integrated, thus every therapists writes a unique order request, sometimes forgetting essential details.
- Planners spend a lot of time checking a list of conflicts.
    - The system, generating a list of all conflicts in child rehabilitation, is not user friendly, as a lot of irrelevant information is printed as well.
- Planners need to re-schedule a lot of appointments.
- Planners experience difficulties in completing orders, due to full rosters (e.g. swapping two appointments can be a major task).
    - There is little room for ad-hoc agenda orders, or changes, because the entire blueprint is rigid for a year. Therefore, when one appointment is

    - changed, a lot of other appointments need to be changed as well. This makes (re-)scheduling appointments a tedious task.
- Planners receive orders that lead to conflicts and do not know which appointments should be prioritized.
    - Therapists do not always check for possible conflicts in advance when requesting an appointment. Whenever a conflict occurs due to a new request, planners do not have clear guidelines as to which appointment to prioritize.

Physicians

- Physicians regularly have to travel a significant distance from appointment to appointment, losing precious time/capacity.
    - Planners do not incorporate walking time of consecutive appointments on different locations. Planners are often not able to cluster appointments that take place on the same location.
- Physicians regularly have to switch from subject A to subject B (often every half hour). Switching between subjects is considered tiresome and requires several minutes.
    - Different subjects of appointments are not taken into account while constructing the planning for a physician. No effort is made to cluster appointments with the same subject.
- Physicians sometimes miss last-minute appointments whenever those appointments are planned on the same half-day
    - Whenever an appointment is canceled on the same day, a new appointment is scheduled by the planners. During the day, a physician is often not able to check updates in their day roster (via e-mail) and is not notified of the change via e.g. telephone. This results in a physician being absent, or late, at the newly planned appointment.
- Physicians are not enabled to see a patient on short notice, although this is desirable.
    - The agenda of a physician is very rigid and full for the upcoming 2 to 3 weeks. Therefore, a physician is incapable of seeing a patient on short notice when e.g. that patient happens to require just one additional appointment to finish their series of treatments.
- Physicians often encounter double-bookings. The double-bookings are sometimes even planned on purpose, burdening the physician to choose which appointment is more important.
    - Planners are not able to find a schedule that satisfies all actors. This happens most often in the agendas of physicians, as those agendas are the most rigid. Planners are not able to independently prioritize certain appointments over others, because they do not have clear guidelines as to which appointment is currently deemed more important. Planners solve this problem by scheduling conflicting appointments, burdening the physician with the decision as to which appointment is deemed more important.

Patients (children & parents

- Not all children receive the rest and play-time they deserve/need.
    - As planners are not able to find a schedule to satisfy all restrictions, they need to make compromises. At the moment, planners feel the need to prioritize therapy over block times and breaks.

2.5.2 Categorizing the problems

We identify six main classes in which the causes can be categorized: A.) rigidity of rosters, B.) the absence of children during block times, C.) communication, D.) sub-optimal clustering of orders, E.) objectives in the year plan and F.) Other. Table 2.5 presents a systematic approach in which we tally the cause of a problem per category. The 'objective of the year plan' category is tallied whenever a problem is caused by the objective, or missing objective, of the year plan. An example is problem 2., which is primarily caused because we do not focus on providing a feeling of ownership over a therapists agenda when constructing the year plan. Problems 2.i and 7.i are effects of the corresponding numbered problem without an "i" and problem 12.i is comparable to problem 12. To prevent redundant tallying we exclude the problems with an "i" from the SumTotal row.

2.5.3 Conclusion on Problem Analysis

The SumTotal row of Table 2.5 shows that the objectives of the year plan is tallied the most, followed closely by communication and the rigidity of the rosters. Also, we observe that the absence of children during essential block times is only considered a problem for the teachers and that only physicians complain about the sub-optimal clustering of appointments. The problems in 'other' are caused by a tedious computer program and by the inability of equalizing workloads over a longer period of time. In conclusion, the main problems that we are going to focus on are the divergent objectives of the year plan (E.) and the rigidity of the rosters (A.). To limit our scope, we do not focus on the communications category (C.) in this research.

The problems related to the objectives of the year plan (E.) are addressed in Section 2.6, where we provide strategic guidelines and KPIs to quantify the performance of the planning. During the modelling phase we focus mainly on solving the rigidity of the year plan (E.) by introducing a year plan on a tactical level and adhere to the objectives stated in Section 2.6.

Table 2.5: Tally problems per category

		Cause category:					
	Therapists	A.	B.	C.	D.	E.	F.
1.	Therapists regularly work during their breaks (e.g. during a passing, or have to converse about patients with other therapists).	1					
2.	Therapists, do not feel ownership over their agenda (their roster is constantly subject to changes and have enjoy little freedom to allocate their own time).	1				1	
2.i	Therapists experience annoyance when planning mistakes (e.g. conflicts) occur.						
3.	Therapists experience troublesome, and delayed, communication when conversing with the planners.			1			
4.	Therapists sometimes experience periods with a low workload.						1
5.	Therapists experience periods with a high workload (also related to working during breaks).						1
	Teachers						
6.	Teachers have to iterate their classical explanations.		1	1		1	
7.	Teachers miss moments to coordinate treatment/education with therapists.					1	
7.i	Teachers spend a lot of time coordinating/dealing (treatment/education) with a lot of therapists (often more than 6)						
	Planners						
8.	Planners receive orders with unclear, or in-complete, details.			1			
9.	Planners spend a lot of time checking a list of conflicts.						1
10.	Planners need to (re-)schedule a lot of appointments (e.g. swapping two appointments can be a major task)	1					
11.	Planners receive orders that lead to conflicts and do not know which appointments should be prioritized.	1		1			
	Physicians						
12.	Physicians regularly have to travel a significant distance from appointment to appointment, losing precious time/capacity.				1	1	
12.i	Physicians regularly have to switch from subject A to subject B (often every half hour). Switching between subjects is considered tiresome and requires several minutes.						
13.	Physicians sometimes miss last-minute appointments whenever those appointments are planned on the same half-day			1			
14.	Physicians are not enabled to see a patient on short notice, although this is desirable.	1				1	
15.	Physicians often encounter double-bookings. The double-bookings are sometimes planned on purpose, burdening the physician to choose which appointment is more important.			1		1	
	Children						
16.	Not all children receive the rest and play-time they deserve/need.					1	
	SumTotal	5	1	6	1	7	3

2.6 Key Performance Indicators (KPIs)

In this section, we focus on identifying relevant KPIs that enable us to measure the performance of the pediatric rehabilitation planning system. Hans (2020-2021), proposes to group KPIs according to four strategic objectives: Quality of Care, Quality of Service, Quality of Labour, and Productivity. These four objectives generally cover every point of view in a system. However, in this system, a fifth objective can be identified: Quality of Education. For each strategic objective, we provide a definition and list identified KPIs. The KPIs are identified via non-structured interviews with actors in the system. The '+' indicates that increasing the KPI is favorable for the objective, a '-' indicates a decrease is favorable and '∘' marks other KPIs.

- **Quality of care** (QoC) is considered to be everything that improves the quality and effectiveness of therapy. This excludes a patient's experience (happy vs not happy). QoC can be improved by e.g:

  + \+ % of provided pre-described appointments
  + \- Total number of therapists linked to a class. This KPI also improves the quality of labor for teachers and therapists, because coordinating with less therapists is more easy/pleasant.
  + \+ % of therapy that can be planned in quick succession [1] (thus reducing the chance of deterioration of a patient's progress)
  + \+ Nr of times a half-year MDO and CKB meetings take place, per child, with all relevant linked actors

- **Quality of Service** (QoS) refers to the experienced degree of service from a patient's perspective (what is the patient's experience, undergoing care?). QoS can be improved by e.g.:

  + \- Nr of times multiple appointments of a single actor are scheduled on the same slot (i.e. conflicts taking place)
  + \+ Nr of weeks that a (repeating) appointment is kept on the same slot (thus ensuring tranquility for children)

- **Quality of Education** (QoE) is considered to be everything that improves the quality and effectiveness of education. QoE be be improved by e.g.:

  + \+ % of therapy not planned during a block times
  + \+ % of ELF-moments that can be planned with one therapists of every specialty, linked to that class

- **Quality of labor** (QoL): is considered to be everything that makes work easier or more pleasant for our employees. The QoL for every actor in the system is different, therefore we split this objective per labor-actor.

  Therapists
  + \- Nr of time periods a therapist is scheduled to work over-time (either after 17.00, or during breaks)
  + ∘ *See also: reduction of therapists per class, ELF-moments with all specialties, weekly repeating appointments, no agenda conflicts*

  Teachers
  + ∘ *See also, reduction of therapists per class, weekly repeating appointments*

  Planners
  + \- % of available hours spent checking for conflicts, per planner

[1] We define 'quick succession' as having no more than two weeks between consecutive appointments.

- ◦ *Clear guidelines to decide on conflicts (not a real KPI, but relevant for recommendations)*
- ◦ *Increase clear communication of order requests (not a real KPI, but relevant for recommendations)*

Physicians

- Nr of times a physician has to change from location each week
- Nr of times a physician has to switch from subject, per week
- Nr of last-minute (on the same day-part, e.g. afternoon) changes to agenda
- Access-time, per physician, to (re)plan a new appointment

• **Productivity** refers to efficiency, costs, utilization. Productivity can be improved by e.g.:

- Nr of hours spent re-scheduling appointments
+ % of daytime that facilities/assets (e.g. swimming pool) are productive
◦ % of available hours dedicated per productive task (providing therapy, indirect time, ELF-moments and other)

2.7 Intended performance vs actual performance

2.7.1 Intended performance of the company

In this section we select the most meaning full KPIs of each strategic objective introduced in Section 2.6. This allows us to quantify the intended performance and current performance of the company for each respective problem. Table 2.6, provides an overview of the selected KPIs, the intended performance, and the current performance. The intended performance and current performance of each strategic objective is obtained in a meeting with the advisory group. The advisory group can be considered an expert panel and consists of 5 experts: the head of the planning department, the head of the rehabilitation department, the principal of the St. Maartenschool, two integral capacity management consultants and a delegate to represent all involved therapists. To cover the interests of the physicians, an individual interview with one physician is executed. The most important take away from the meeting is the intention to evenly distribute attention (weights) over the five strategic objectives. In Table 2.6 this is indicated with a weight of 20% (intended perf.). The current performance (current perf.) of the strategic objectives is an estimate of the advisory group. From Table 2.6 we observe that QoC enjoys preference at the cost of primarily QoE. The current performance of the selected KPIs is obtained by conducting a data analysis and the intended performance is again set by the advisory group.

To enable the advisory group follow-up what they have agreed upon with respect to the five strategic objectives, we introduce the rehabilitation turtle in Figure 2.3. The turtle is a mnemonic to remember every perspective in decision making. This helps to identify deviation from intended performance in an early stage. Before making a decision, the question: 'What impact will this decision have on all five strategic objectives?' will greatly improve the balance between the performance of the system and the well-being and happiness of patients and employees. The turtle was first presented during an advisory group meeting and was received with great enthusiasm.

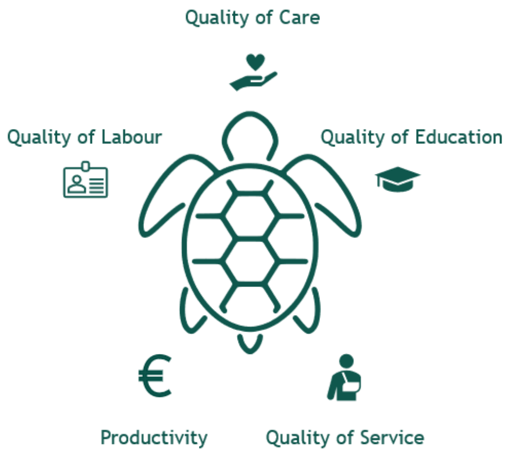

Figure 2.3: Rehabilitation turtle

Table 2.6: Comparison of performance between manually drafted plan versus current performance

KPIs and strategic objectives		Intended perf.		Current perf.	
Quality of Care		20%		30%	
Average number of therapists linked to a class		±5		5,55	
% of predescribed appointments planned		100%	Therapy	100%	Therapy
		100%	IDR	100%	IDR
		100%	ELF	100%	ELF
		100%	Blocktimes	100%	Blocktimes
Quality of Service		20%		25%	
Nr of times per month that conflicts occur (i.e. multiple appointments of a single actor are scheduled on the same slot) (i.e. conflicts taking place)		Never		NA	
Average number of weeks that repeating appointment are kept on the same slot (thus ensuring tranquility for children)		NA		NA	
Quality of Education		20%		10%	
% of total blocktimes without interruptions		100%		$\leq$ 15%	
Quality of Labour		20%		20%	
Doctor	Nr of times per month a doctor has to switch from subject A to subject B, or walk more than 3 minutes between appointments, per week	NA		NA	
Therapists	Nr of time periods per month a therapist is scheduled to work over-time	Never		0	
Planners	% of available hours spend checking for conflicts	NA		NA	
Productivity		20%		15%	
Nr of times per month an unique order-ID is re-scheduled		NA		NA	
% of daytime that facilities/assets (e.g. swimmingpool, therapists, physicians) are productive		NA		NA	

3 Literature study

This chapter describes literature related to resource capacity planning (RCP) in health care. The goal of the chapter is to create a theory-ingrained base for our solution design. The chapter is structured in three parts. Section 3.1 covers the introduction of taxonomy and classification of this research. Section 3.2 provides an overview of techniques used in literature to make RCP decisions. Section 3.3 goes into more detail on Blueprint scheduling, the most promising technique for this problem instance, according to the found literature in the previous section. Section 3.4 finalizes the chapter with conclusions on the best-suited problem-solving approach for this context.

3.1 Taxonomy & Classification

Chapter 1 uses the managerial framework of Hans et al. (2012) to classify the objective in terms of hierarchical levels of control. To repeat briefly, our focus lies on the tactical level of RCP. This includes (a) block planning, (b) capacity allocation (facilities, therapists to link to a class), and (c) staff shift scheduling (availability of employees over days and hours, such that patient demand can be satisfied). These subjects are further discussed in the next section.

Due to the multi-disciplinary nature of the system we are dealing with, we follow the definition of a multi-disciplinary care system, as defined by Leeftink et al. (2018):

> *A multi-disciplinary care system is a care system in which multiple interrelated appointments per patient are scheduled, where health care professionals from various facilities or with different skills are involved.*

The care system has similarities to machine scheduling: one could model the care of a patient as a job that can be scheduled on an actor (e.g. a therapist), or needs to be scheduled on multiple actors (e.g. the patient needs to visit multiple therapists). Graham et al. (1979) was the first to classify machine scheduling problems. Cardoen et al. (2010) later applied a similar classification method to health care. Although the latter is specifically developed for classifying problems related to operating room planning and scheduling problems, we see similarities between the subject of this research and the operating room planning research field. A resemblance is found in repetitively constructing schedules (or performing re-scheduling tasks), which is a time-consuming, tedious, and complex task. Although our system has different characteristics and challenges, the modeling approach is comparable. For example, in operating room specific cases, operating types are planned over operating rooms, whereas in our case classes can be planned over therapists. By applying the Graham notation, as proposed by Cardoen et al. (2010), our problem can be classified as:

$$\alpha_1 = \text{el} \mid \beta_1 = \text{pat, disc, other} \; ; \; \beta_2 = \text{date, time, cap} \; ; \; \beta_3 = \text{iso} \mid \gamma_1 = \text{stoch (arr)} \mid \delta_1 = \text{multi} \; ; \; \delta_2 = \text{util, pref, other.}$$

Here α_1 is modeled as elective patients, as the children of the SMS are normally available during working hours, although with restrictions. β_1 *disc* refers to the disciplines of the therapists and *other* refers to the doctors. β_2 *date* and *time* refer to the days of the week and periods during a day. γ_1 = stoch (arr) is chosen to cover the stochastic arrival process of elective patients over the year (i.e. influx of children). δ_1 *multi* refers to the weighted average of performance indicators (explained later in the chapter) and δ_2 refers to the focus of the performance indicators (util = utilisation of resources and pref = preferences of therapists). We use the classification as a guide to find relevant literature, which is discussed in the following sections.

3.2 Resource capacity planning

In this section, we focus on the Tactical level op RCP. In Section 3.2.1 we discuss the earlier introduced subjects (a), (b) and (c), as introduced by Hans et al. (2012). Subsection 3.2.2 discusses the pros and cons of analytical vs statistical methods for RCP.

3.2.1 Tactical level of RCP

Capacity allocation (a) & Block planning (b)

Leeftink et al. (2018) and Hulshof et al. (2012) describe the tactical level of RCP as capacity planning and capacity allocation respectively. Both studies state that capacity allocation considers the division of resource capacity into specialties, patient groups, or time slots. Leeftink et al. (2018) introduces three means to execute capacity allocation:

(i) Blueprint scheduling (block planning). A blueprint schedule describes the amount of capacity on a day or particular time slots that can be used for specific patient types in the operational scheduling.
(ii) Patient admission planning (admission control). Patient admission planning considers the design of an admission policy that describes how many and which patients should be admitted from the waiting list.
(iii) Temporary capacity changes. Temporary capacity changes relate to developing guidelines for temporary capacity changes in case of demand peaks and drops.

Below, we discuss the introduced means in the context of our problem description to determine if in-depth research on this topic should be included in this literature review.

(i) Hans et al. (2012) describes the term 'block scheduling' as 'block planning', but the same definition is used. In the remainder of this research, both terms are used interchangeably. van Oostrum et al. (2006) introduces the (cyclic) block schedule (i.e. MasterSurgicalSchedule (MSS)) as a tool to deal with earlier described problems such as repetitively constructing schedules. Note that the MSS is a type of blueprint schedule. van Oostrum et al. (2006) also focuses on operating room-specific modeling challenges such as the leveling of capacity in subsequent departments and accounting for the uncertain duration of an operation by introducing slack. For an extensive literature review on existing papers in the field of operating rooms p&s, we refer to Cardoen et al. (2010).

(ii) Patient admission planning is not further researched as the subject is out of scope in our context: the number of children in the school and the prescribed therapies for these children are considered a given. In the 'discussion' we will further elaborate on the possibilities when this is not a given.

(iii) Temporary capacity changes are not preferred, as the staffing pool is considered constant. In the 'discussion' we will further elaborate on the possibilities when this is not a given.

Staff-shift scheduling (c)

It is essential to align staff schedules, with for example a blueprint schedule, to ensure that members of a multi-disciplinary team have enough options to deliver combined care or to attend joint meetings (Mutlu et al., 2015). Staffing levels per discipline need to be such that feasible operational plans can be generated and shifts for various disciplines need to be synchronized to facilitate interdisciplinary team meetings(Benzarti et al., 2013). Hulshof et al. (2012) and Leeftink et al. (2018) both state that little research is conducted on this topic.

3.2.2 Analytical vs simulation

Models for resource planning described in the literature can be broadly categorized as analytical or simulation-based (VanBerkel and Blake, 2007). The simulation-based models often focus on waitlist management, throughput optimization, and the testing of operational scheduling policies or tactical planning tools.

The strength of simulation models lies in the fact that they are well equipped to capture the broad scope of complex systems, while analytical methods have a limited capacity to capture the complexity of these systems (Vanberkel et al., 2010). A possible weakness of simulation-based optimization is that these models are inexact and require a great deal of time to develop (Vanberkel et al., 2010).

Researchers have overcome the disadvantages of both methods, by developing techniques to combine the strengths of both approaches or using local search heuristics and approximations when exact problems get computationally intractable. Combining the two enables us to evaluate an optimal solution in a realistic, dynamic environment (van Dijk and van der Sluis, 2008).

Also, simulation methods are not suitable for constructing blueprint schedules, but are important tools for testing and validating designed blueprints. Blake et al. (1995) for example, presents a simulation model that uses the patient flow of a certain department to test the impact of an MSS.

3.3 Blueprint scheduling (i)

As stated in Chapter 1, Section 1.3, the scope of this research is limited to the design of a method, or tool, that supports the construction of a tactical roster. Therefore, we focus on literature that introduces methods to construct cyclic block schedules (i.g. blueprint scheduling or MSS). We observe that blueprint scheduling occurs primarily in operating room departments and radiotherapy departments. Therefore, we discuss approaches primarily used by these departments. We also discuss approaches used in multi-disciplinary settings, such as rehabilitation departments. We start by introducing the objectives and characteristics in the next section.

3.3.1 Objectives & Characteristics

Leeftink et al. (2018) found that blueprint scheduling is a widely studied research field that applies to many healthcare areas (among others the operating room department). They identify four objectives in the field of blueprint scheduling: aggregating consultation appointments on one day, minimizing waiting time on a day, or minimizing access time or throughput time. Hulshof et al. (2012) states amongst other things that the objectives of capacity allocation are to trade off patient access time and the utilization of resources, maximize the number of patients treated, level workload and minimize staff overtime. Both researchers observe that the majority of operation research in health care contributions focus on a single facility or department, while an integrated approach concerning multiple departments or stages in the care process may lead to better results. Hulshof et al. (2012) describes the process of block scheduling in three steps:

1. *Patient groups are identified.*
   In our problem context, the patient groups can be classified in two dimensions: in terms of therapy discipline demand and in cognitive capability (school classes). The division of patients into groups over the two dimensions is considered a given, as the therapy discipline demand is determined in the CKB and the classes are formed by the teachers and therapists.

2. *Resource capacities, often in the form of operating time capacity, are subdivided over the identified patient groups.*
   Resource capacity can be interpreted as a form of capacity allocation (b). The division of classes over therapists can be compared to the machine scheduling problem described by (Gademann and Schutten, 2002) and in theory, be compared to scheduling problems of the operating room theatre.

3. *Blocks of assigned capacity are scheduled to a specified date and time (defined as block scheduling).*

3.3.2 Multi-disciplinary settings

Leeftink et al. (2019) propose a stochastic integer linear program (ILP) to design a blueprint schedule in a multi-disciplinary setting while taking open access requirements into account. The open-access requirement of the model makes the resulting blueprint schedule more robust as it takes into account the uncertainty of operational fluctuations (in this case patient arrival). The objective is to minimize the weighted average waiting time of a patient, clinician idle time, and clinician over time. A sample average approximation algorithm is used to approximate the objective value. Braaksma et al. (2014) tackles the online scheduling task of outpatients in rehabilitation treatment. They use an ILP to model find the optimal match between a therapist and patient in combination with the date and time for the corresponding sequence of appointments. The objective is to minimize the sum of the weighted penalty costs - focusing on penalization for undesirable situations and rewarding performance gains on KPIs. Griffiths et al. (2012) proposes a three-stage heuristic approach to construct a schedule for an offline operational inpatient physiotherapy setting. Chien et al. (2008) model an open access rehabilitation center as an ILP and deal with large instances by proposing a generic algorithm approach. van der Velde et al. (2012) construct a day schedule for a multi-disciplinary, offline operational using an ILP. They use the output of the ILP as input for a simulation study to compute the capacity of the center, given the designed day schedules. They also formulate a queuing model to predict the access time distributions based on the simulation outcomes under various demand scenarios.

3.3.3 Operating room departments

Pinedo (2009) states that the challenge of scheduling multiple operating rooms can be regarded as either a parallel machine scheduling problem, or as a bin packing problem. They formulate the construction of an MSS as a set packing problem using ILP, providing both a deterministic and a stochastic example. Bikker et al. (2015) propose a method that constructs a cyclic MSS, also using an ILP model. They minimize the expected access times of all patient types in the care process and that matches the number of consultation time slots with demand. The quality of the MSS is studied via a discrete event simulation model. Results of a case study indicate that considerable access time reductions may be obtained when implementing the designed schemes. van Oostrum et al. (2006) also uses an ILP-modelling approach to construct an MSS. They use column generation to deal with the high computational running times. Column generation is an often-used approach to solve complex optimization problems with a large number of variables (e.g. cutting stock, capacity planning, and crew scheduling, e.g., (Barnhart et al., 1970, Pinedo, 2009)). Fügener et al. (2014) take the downstream effects of the MSS into account. They use the branch-and-bound method (Ross and Soland, 1975) to solve small problem instances optimally. Larger instances are solved by taking the existing MSS of a hospital and applying several improvement heuristics, such as incremental improvement, 2-opt, and simulated annealing. Agnetis et al. (2014) also model the problem as an ILP. To deal with the NP-hardness of the problem, they propose a very fast decomposition heuristic approach, which generates near-optimal solutions. They state that in offline planning situations the computation time of the NP-hard problem may not be an issue.

3.3.4 Radio therapy departments

Vieira et al. (2020) introduce a mixed-integer linear program (MILP) to construct a weekly schedule of a linear accelerator in radiotherapy. Small instances are solved optimally, for larger problems they propose a heuristic method that pre-assigns patients to linacs to decompose the problem in subproblems (clusters of linacs) before using the MILP model to solve the subproblems to the optimality in a sequential manner. Later, Vieira et al. (2021) propose a MILP to generate a weekly radiotherapy treatment schedule, which is implemented in two clinical centers. Iterative model adaptations performed in small steps, early engagement of stakeholders, and constant communication proved to facilitate the implementation of the models into clinical practice. Validation of the proposed weekly schedule is done by the qualified staff of the department. Pham et al. (2021) and Burke et al. (2011) also use linear programs to construct weekly schedules in radiotherapy. Both researchers use simulation to validate their results. Pham et al. (2021) breaks the problem down into two phases to allow faster computations while ensuring near-optimal solutions.

3.4 Conclusions from literature

In this section we will briefly repeat the most important aspects of our literature research and place our findings in context of the research topic.

Block planning (a), also referred to as blueprint scheduling (i), strongly coincides with the problem description of our case. We deduce that constructing a (cyclic) tactical roster is best done with an (M)ILP. As we are not able to apply changes in patient admission (ii) and temporary capacity changes (iii), we save further elaboration on these two topics for the Conclusion and Recommendations chapter.

Besides block planning, staff-shift scheduling (c), is also an important factor in our problem context, as the therapists have multi-disciplinary meetings and provide therapies where multiple disciplines are required. In blueprint scheduling, we can incorporate the allocation of staff shift scheduling at the same time. When staff shifts are a given, we can conduct experiments by relaxing the constraint that staff shifts are given.

In literature, we find that the objective function of (M)ILP's, applied to blueprint scheduling, is often a combination of multiple factors. Often, a trade-off has to be made. In our problem context, this is also the case, as we identified five strategic objectives that need to be translated into a tactical plan.

When problem instances get too big, or models to complex literature refers to heuristics (construction heuristics and improvement heuristics). Think about established heuristics like simulated annealing and tabu search. Besides heuristics, column generation can be applied to an (M)ILP if the problem becomes intractable. Incremental improvement algorithms are used to apply a few changes to an initial schedule. Incremental improvement algorithms can be of help when an initial schedule is generated and we want to update the rosters when the input parameters have changed due to for example operation fluctuations in demand and/or capacity. Literature also shows that large problem instances can be split into several phases - solving every phase optimally.

As of now, we have no clear indication whether a heuristic approach is necessary, because of intractability. Because an exact approach is generally speaking preferred and can yield a guaranteed optimal solution, we decide to explore the possibilities of approaching the presented problem using exact methods.

Take-aways:

- Block planning (a) is best approached following the steps by Hulshof et al. (2012): (1.), (2.), (3.).
- Literature shows that an (M)ILP is best suited to construct a block schedule (3.) or allocate resource capacity (2.).
- Literature recommends to split complex problems into multiple phases. For example, the phases, as indicated by Hulshof et al. (2012).
- Incorporate staff-shift scheduling (c) in the (M)ILP, or conduct experiments by varying this parameter, is important for this problem context.
- Objective functions of (M)ILPs in a comparable context are often composed of a combination of factors.
- Column generation can be used when the (M)ILP gets intractable and incremental improvement algorithms can be used to update an initial roster.

4 Solution approach

This chapter explains the modeling approach to the described problem. As concluded in Chapter 3, we focus on modeling the system as a MILP. Before modeling, we introduce requirements and the underlying assumptions in Section 4.1. The model notation is described in Section 4.2. Section 4.3 proposes a visualization of the output variables. The chapter is concluded with model verification, model validation and feasibility in Section 4.4.

4.1 Model requirements and assumptions

This section briefly summarizes the global assumptions that are made while defining the problem. In Section 4.2 more explicit assumptions, per constraint are mentioned when applicable.

- Appointments are scheduled at the start of a time slot of 30 minutes
- There are no transition times between appointments.
- There are no precedence relations between appointments.
- All therapists are equally valuable in terms of resources.
- Therapy of every child, and every class, are equally valuable.
- Demand for all activities over all actors needs to be met
- Demand that can not be met is stored in the excess variable $np_{c,s}$

To better understand the model Table 4.1 provides an overview of the possible activities that every actor of the system can engage in.

Table 4.1: Possible activities that the modeled actors of the system can be engaged in

Actors	**Activities engaged**	**Explanation**
Therapists	Direct time	Providing therapy
	Indirect time (IDR)	Executing administrative work related to direct time
	ELF-moment	Multi-disciplinary meeting between therapists linked to the same class
	Break small	A break at either 10:00, 10:30 or 11:00
	Break large	A break at either 12:00, 12:30 or 13:00
Classes	Therapy	Receiving therapy
	Play break 1 (& 2)	Enjoying a play break
	Eating break	Dedicated time to eat
	Gym	Physical education
	Hydrotherapy	Type of physical education in the water
	Animal care	Type of physical education involving horses
	Block time	Dedicated time for rest, education or any other activity initiated by the teacher

4.2 Model description

This section provides the reader with the notation used in the model, introduces the main decision variables and explanation of each constraint. The section ends with the formal problem formulation.

4.2.1 Notation

This subsection provides the reader with the notations that are used in the formal problem description. Table 4.2 introduces the notation of sets and indices.

Table 4.2: Notation of sets and indices.

Index and set	Definition
$d \in D \quad (1, 2, 3, 4, 5)$	Days in a week, where $d = 1$ represents Monday and $d = 5$ represents Friday.
$h \in H \quad (1, 2, 3, ..., 20)$	Time periods in a day
$p \in P \quad (1, 2, 3, ..., 200)$	Patients
$c \in C \quad (1, 2, 3, ..., 20)$	Classes
$t \in T \quad (1, 2, 3, ..., 60)$	Pediatric rehabilitation therapists
$s \in S \quad (1, 2, 3)$	Specialties, or discipline, of therapists.
$u \in U \quad (A, B, C, D, E)$	Units (clusters of classes) of the Maartenschool.
$sy \in SY \quad (1, 2, 3, 4)$	Schoolyards

Table 4.3 and Table 4.4 provide an overview of the parameters and variables respectively. All parameter names are abbreviated with uppercase letters, while variables are written in lowercase letters. The variables are split into three sets. Set1 contains all variables concerning planning decisions. Set2 envelops auxiliary variables that provide insights into the performance of the model and can be seen as KPIs. Set3 contains all remaining auxiliary variables.

Table 4.3: Notation of parameters

Parameter	**Full name in AIMMS**	**Definition**
$CELFD_{c,s}$	ClassELFDemand	Demand of multidisciplinary meetings per class c, per specialty s
$CFA_{c,d}$	ClassFysioAvailability	1 if therapy of specialty 3 (physio) may be planned on day d, for class c, 0 otherwise (these are the days where no physiotherapy may be planned)
$CID_{c,s}$	ClassIndirectDemand	Indirect demand (required administrative work) per class c, per specialty s
$CA_{c,d,h}$	ClassAvailability	1 if class c is available on day d, at time period h
$CTD_{c,s}$	ClassTherapyDemand	Therapy demand per class c, per specialty s
$CUL_{c,u}$	ClassUnitLink	1, if class c in part of unit u
FC_s	FacilityConstraint	Maximum number of therapy sessions, per specialty, that can be provided at the same time
HCB_h	HoursClassBreak	Time periods h that breaks for classes may be planned
HEI_h	HoursELF_In	Time periods h between 9:00 and 14:00
HEO_h	HoursELF_Out	Time periods h not between 9:00 and 14:00
$HTBL_h$	HoursTherapistBreakLarge	Time periods h that the large break of therapist t may be planned
$HTBS_h$	HoursTherapistBreakSmall	Time periods h that the small break of therapist t may be planned
MTC	MaximumTherapistsToClass	Maximum cumulative number of therapists assigned to a class
$PA_{p,d,h}$	PatientAvailability	1 if patient p is available in school on day d, at time h
$PCD_{p,c}$	PatientClassDistribution	1 if patient p is linked to class c
$PLTC_{t,c}$	PreLinkTherapistClass	1 if therapist t is mandatory to treat class c
$PTAT$	PatientTherapyAvailability-Threshold	Minimum fraction of therapy sessions of a class, attended per patient in that class
$TA_{t,d,h}$	TherapistAvailability	1 if therapist t is available on day d, at time h, to provide therapy
$TBDL_{t,d}$	TherapistBreakDemandLarge	Demand of large breaks per therapist t, per day d
$TBDL_{t,d}$	TherapistBreakDemandSmall	Demand of small breaks per therapist t, per day d

Parameter	Full name in AIMMS	Definition
TC_t	TherapistCapacity	Total capacity of therapist t, per week
$TSM_{t,s}$	TherapistSkillsMatrix	1 if therapist t is capable of providing specialty s
$UBD_{u,d}$	UnitBreakDemand	Demand of breaks per unit u, per day d
$ULSY_{sy,u}$	UnitLinkSchoolYard	Distribution of units u over schoolyards sy

Table 4.4: Notation of decision variables

Planning decisions	**Full name in AIMMS**	**Definition**
$pt_{t,s,c,d,h}$	PlannedTherapy	1 if therapist t provides therapy of specialty s to class c, on day d, at time h, else 0
$ptbs_{t,d,h}$	PlannedTherapistBreakSmall	1 if therapist t has a small break on day d, at time period h, else 0
$ptbl_{t,d,h}$	PlannedTherapistBreakLarge	1 if therapist t has a large break on day d, at time period h, else 0
$pidr_{t,d,h}$	PlannedTherapistIDR	1 if therapist t executes IDR on day d, at time period h, else 0
$ptelf_{t,s,c,d,h}$	PlannedTherapistELF	1 if therapist t participates in an ELF-moment of specialty s for class c on day d at time period h
$usyu_{u,sy,d,h}$	UnitSchoolYardUtilization	1 if unit u has schoolyard time on schoolyard sy, on day d, at time period h
$fba_{u,d,h}$	FoodBreaksUnitA	1 if unit a has a food break, on day d, at time period h
Performance auxiliary		
$cnpt$	CountNotPlannedTherapy	Total number of therapy sessions that are not planned
$cnpelf$	CountNotPlannedELFMoments	Total number of ELF-moments that are not planned
$cnptb$	CountNotPlannedTherapist-Breaks	Total number of breaks for therapists that are not planned
$cnpi$	CountNotPlannedIDR	Total number of IDR that is not planned
$cltc$	CountLinkedTherapistsClass	Total number of links between therapists and classes
$cacdb$	CountAvailableClassesBreaks	Total number of classes that participate in class breaks over the week
$ctdb$	CountTherapyDuringBlock-times	Total number of times that a therapy session takes place during a block time
cbd	CountBreakDeviations	Total number of time that breaks of therapists deviate from the ideal time period
tu_t	TherapistUtilization	Fraction of time a therapist t is performing an activity
$cpelfi$	CountPlannedELF_In	Total number of ELF-moment planned between 9:00 and 14:00 (time at which children are in school)
$cpelfo$	CountPlannedELF_Out	Total number of ELF-moments planned outside 9:00 - 14:00
Remaining auxiliary		
$npt_{c,s}$	NotPlannedTherapy	Total not planned therapy demand of class c, per specialty
$npidr_{c,s}$	NotPlannedIDR	Total not planned IDR demand of class c, per specialty
$npelf_c$	NotPlannedELF_Class	Total not planned ELF demand per class

Remaining auxiliary		
$nptbs_{t,d}$	NotPlannedTherapistBreakSmall	Total demand of small breaks of therapist t not satisfied on day d
$nptbl_{t,d}$	NotPlannedTherapistBreakLarge	Total demand of large breaks of therapist t not satisfied on day d
$ltc_{t,c}$	LinkTherapistClass	1 if therapist t provides any therapy to class c, or participates in any ELF-moment of class c
$ptdb_{t,s,c,d,h}$	PlannedTherapyDuringBlock-times	1 if therapist t provides therapy of specialty s to class c on day d at a time period h on which a class has schoolyard time or has a food break, 0 otherwise
$celf_{c,d,h}$	PlannedClassELF	1 if therapists linked to class c have an ELF-moment on day d at time period h, 0 otherwise
$acb_{u,sy,d,h}$	AvailableClassesBreaks	Number of classes available during the moment that unit u receives a break on schoolyard sy on day d, at time h

4.2.2 Decision variables

Decision variable, $pt_{t,s,c,d,h}$ (PlannedTherapy) is the basis of the model, as it contains all information as to how and when therapy demand is satisfied for all classes. Equation a. shows the mathematical interpretation of this variable. The other planning decisions (set of planning decision variables) are comparable in notation, but assign either breaks, IDR or ELF-moments to therapists, or breaks and therapy to classes. All planning decision variables are binary variables, taking only values of either 0 or 1. Auxiliary variables tu_t, $ltc_{t,c}$, $ptdb_{t,s,c,d,h}$, $celf_{c,d,h}$ and $t1a_t$ are also binary variables. All other auxiliary variables are positive integers.

$$pt_{t,s,c,d,h} = \begin{cases} 1, & \text{Therapist t provides therapy of specialty s to class c at a given} \\ & \text{moment in the week d, h} \\ 0, & \text{otherwise} \end{cases} \tag{a.}$$

4.2.3 Constraints

To determine the value of planning decision variables, we need to adhere to certain constraints. For example a therapist may not conduct more than one activity at a time, or else that therapist would have super-human abilities. Constraints like these are called hard constraints and may never be violated by the model.

In addition to hard constraints, we introduce soft constraints. Soft constraints are preferably complied with but can be violated if necessary. Whenever a soft constraint is violated, the violation is stored in an excessive/slack variable. We define planning decisions and organizational goals as soft constraints to ensure feasibility of the model. An example of a hard constraint is: ELF-demand of every class needs to be satisfied. However, we know that due to the multidisciplinary characteristics of ELF-moments that they are hard to plan. Therefore, the chance exists that not all ELF-demand can be satisfied. Rewriting this hard constraint to a soft constraint allows us to satisfy as much of the ELF-demand as possible while storing the ELF-demand that is not satisfied in an excessive variable and ensuring feasibility. In turn, for every ELF-moment that is not planned, we could penalize the model in the objective function.

This subsection (4.2.3 Constraints), focuses on explaining the reasoning behind the modeled constraints and objective function. As the total number of constraints is 48, we go into detail on the constraints that are very restricting or harder to interpret without explanation. All constraints are summarized in Tables 4.6 and 4.7 by a notation in words. The formal mathematical formulation of the constraints and the objective is presented on page 39.

Constraint 3: A therapist may perform at most one action at a time. The sum of all actions that a therapist t can perform (therapy, break small, break large, ELF-moments and IDR) over all classes c, and specialties s on every moment d, h, must be less than 1.

$$ptbs_{t,d,h} + ptbl_{t,d,h} + \sum_{c}\sum_{s}(pt_{t,s,c,d,h} + ptelf_{t,s,c,d,h} + pidr_{t,s,c,d,h}) \leq 1 \quad \forall t,d,h \tag{3.}$$

Constraint 4: A therapist t may only perform therapy of specialty s, if that therapist can perform therapy s. Note that in reality, currently, a therapist can only have one specialty. However, in the past there have been therapists that were able to provide therapy of multiple disciplines). Moreover, defining a therapist's specialty helps in planning the ELF-moments and accommodates the user of the model to add therapists who can perform therapy of multi specialties in the future.

$$pt_{t,s,c,d,h} \leq TSM_{t,s} \quad \forall t, s, c, d, h \tag{4.}$$

Constraint 14: Link Therapist to Class. This constraint allows the user of the model to pre-define a link between a therapist and a class, thus ensuring a therapist conducts therapy for a certain class. Therefore, we transform the values from the parameter to a decision variable. Note that the model is free to determine all other instances of $ltc_{t,c}$. Also, restricting the model too much can easily result in infeasibility of the model.

$$ltc_{t,c} \geq LTC_{t,c} \quad \forall t, c \tag{14.}$$

Constraint 18: Maximum therapist class. Each class can have at maximum MTC therapists linked to that class. Thus, the maximum number of therapists that are allowed to provide therapy to class c is limited by MTC. The lowest possible number that can be set is three, as every class requires at least one therapist of each specialty. Note that the parameter MTC is extremely useful and powerful: by setting a low value (i.e. between 3 and 6), the model will have a drastically reduced running time. One should be wary that certain combinations of input parameters will require a higher value of MTC for the model to remain feasible.

$$\sum_t \sum_s ltc_{t,c} \cdot TSM_{t,s} \leq MTC \quad \forall c \tag{18.}$$

Constraints 19 and 20: Satisfy therapy demand, per class. As mentioned in the model requirements and assumptions, the model needs to satisfy all therapy demand of a class. To ensure feasibility and allow easy comparison of objective functions, we add a slack variable ($npt_{c,s}$) to count the number of times that the program is not able to satisfy demand. Constraint 20 is similar to constraint 19 but focuses on therapy of specialty 3 (physiotherapy). The constraint ensures that the physiotherapy of class c can only be planned on days d that class c does not have either horse riding or physical education on that same day. The times that a class receives horse riding or physical education are stored in the parameter $CFA_{c,d}$.

$$\sum_t \sum_d \sum_h (pt_{t,s,c,d,h}) + npt_{c,s} = CTD_{c,s} \quad \forall c, s \neq 3 \tag{19.}$$

$$\sum_t \sum_d \sum_h (pt_{t,s,c,d,h} \cdot CFA_{c,d}) + npt_{c,s} = CTD_{c,s} \quad \forall c, s = 3 \tag{20.}$$

Constraint 24: Time between unit breaks. There need to be at least 3 time periods between the break moments of a unit.

$$usyu_{u,sy,d,h} + usyu_{u,sy,d,h+1} + usyu_{u,sy,d,h+2} + usyu_{u,sy,d,h+3} \leq 1 \quad \forall u, sy, d, h \leq |h| - 3 \tag{24.}$$

Constraints 33 to 39: Planning of ELF-moments. Repeating briefly, an ELF-moment is an interdisciplinary meeting between therapists of different specialties to discuss the treatment of a single child. To plan ELF-moments with therapists that are linked to

classes (determined primarily by the model), we need to find a series of linear equations to prevent the model from becoming quadratic.
An extra variable is introduced: variable $celf_{c,d,h}$ is a dummy variable to set ELF-moments for each class. The planning decision variable $ptelf_{t,s,c,d,h}$ stores the therapists that attend a specific ELF-moment for a class.

Constraint 33: Satisfy ELF-demand on the classical level. Constraints 33 and 35 force the model to satisfy ELF-demand of a class.

$$\sum_d \sum_h (celf_{c,d,h}) + npelf_c = CELFD_{c,s} \quad \forall c, s \tag{33.}$$

Constraint 34. is used to count the number of ELF-moments planned during school times and after school hours, but doesn't constrain the model.

Constraint 35: Satisfy ELF-demand on therapist level.

$$CELFD_{c,s} - npelf_c = \sum_t \sum_d \sum_h telf_{t,s,c,d,h} \quad \forall c, s \tag{35}$$

Constraint 36: ELF-moment for therapists linked to a class can only occur during ELF-moments of a class. We force $celf_{c,d,h}$ and $ptelf_{t,s,c,d,h}$ to be at the same moment for each class.

$$ptelf_{t,s,c,d,h} \geq celf_{c,d,h} \quad \forall t, s, c, d, h \tag{36.}$$

Constraint 37: ELF-moment, at most one therapist per specialty. It limits the required number of specialties per ELF-moment to one, assuming that a therapist participating in an ELF-moment will cover therapy demand for a certain specialty of that child.

$$\sum_t ptelf_{t,s,c,d,h} \leq 1 \quad \forall s, c, d, h \tag{37.}$$

Constraint 38: ELF_RightSpecialty. Only therapists with corresponding specialties are allowed to satisfy ELF-demand of that specialty.

$$ptelf_{t,s,c,d,h} \leq TSM_{t,s} \quad \forall t, s, c, d, h \tag{38.}$$

Constraint 39: ELF_Minimum amount of therapy. Constraint 38 limits the model in assigning only therapists who provide sufficient therapy to a given class. For example, we want to prevent a therapist from providing a total of one therapy session to a class, but participating in more than one ELF-moment. This would be very impractical on an operational level, as this therapist will see one child in therapy, but will participate in the ELF-meetings of more than one child. Besides the restriction on ELF-moments, the same goes for IDR demand: we do not want the sum of IDR and ELF-moments to be higher than the total amount of therapy provided to a certain class.

$$\sum_d \sum_h (pidr_{t,s,c,d,h} + ptelf_{t,s,c,d,h}) \leq \sum_d \sum_h pt_{t,s,c,d,h} \quad \forall t, c, s \tag{39.}$$

Constraint 44: Count break Deviation Penalty (soft constraint). Parameters $HTBS_h$ and $HTBL_h$ can accommodate a set of consecutive hours (in our case, $|HTBS_h| = 3$ and $|HTBL_h| = 3$) per parameter that define the times at which a therapist t can have either a small break, or a large break. In our case for small breaks: *(10:00, 10:30, 11:00)* $\in HTBS_h$. And for large breaks: *12:00, 12:30, 13:00.* The ideal time for a therapist to have a break is the second element. The first and last elements are used for possible deviations from this ideal time. The sum of the deviations, *cbd* is multiplied by the corresponding weight in the objective function to penalize the model. Note that both breaks are planned as separate activities. To prevent introducing additional sets, increase readability and allow fast modeling, we do not use parameters $HTBS_h$ and $HTBL_h$ in constraints, but hard-code the elements of the parameters as be seen in Equation 44..

$$\sum_t \sum_d ptbs_{t,d,"10:00"} + ptbs_{t,d,"11:00"} + ptbl_{t,d,"12:00"} + ptbl_{t,d,"13:00"} = cbd \tag{44.}$$

4.2.4 Objective function

Most constraints that force the model to plan an activity are modeled as soft constraints. This allows the model to remain feasible for a greater range of combinations of input parameters (i.e. this increases the robustness of the model when applied in practice). Per activity, the amount of not planned demand is counted and stored in auxiliary performance variables. Besides variables that count the violation of soft constraints, we introduced auxiliary performance variables that count for example the total number of linked therapists or the total number of therapy sessions planned during block times. All these performance variables are a relevant contribution to our objective function. This coincides with our findings from Chapter 3, where we concluded that objective functions in comparable contexts are often composed of a combination of factors. From all auxiliary performance variables presented in Table 4.4, we select, in consultation with the advisory group, a subset of performance measures to use in the objective function.
To allow easy readability, we copy all relevant auxiliary performance variables, and their definitions, from Table 4.4 to Table 4.5 below. Performance indicators *cnpt* and *cnptb* are the most important, because these values directly influence the QoC, QoS, QoL or productivity. For example, *cltc* influences communication between teachers and therapists, which influences QoC and QoL. A high *cltc* will also result in a decrease in QoS, because children can get upset when to many therapists visit the class. A high number of block time violations for example affect the QoL and the QoE and the QoS as the teachers get interrupted during their lessons. *cbd* influences the QoL of therapists and can be used to make a trade off: 'how many break deviations are allowed if we can reduce the number of linked therapists by one?'. The remaining performance indicators are just a measure for violating soft constraints.
The weight assigned to each performance indicator is subjective. Therefore, we consult the advisory group to assign weights that can be used during the experimentation phase of the research. These weights are introduced in Chapter 5.
Equation 1. describes the objective function in general terms, where $W_i, i \in (1, 2, 3, ..., 7)$ indicates the weight for each KPI. In words: minimize the weighted sum of the total number of linked therapists, therapy sessions during block times, break deviations of therapists and not planned therapy demand, not planned ELF demand, not planned IDR demand, and not planned therapist break demand.

$$\begin{aligned} \min \quad & W_1 \cdot \text{cltc} + W_2 \cdot \text{ctdb} + W_3 \cdot \text{cbd} + W_4 \cdot \text{cnpt} \\ & + W_5 \cdot \text{cnpelf} + W_6 \cdot \text{cnpi} + W_7 \cdot \text{cnptb} \end{aligned} \tag{1.}$$

Table 4.5: Auxiliary performance variables used in the objective function

Auxiliary performance variables		**Definition**
cltc	CountLinkedTherapistsClass	Total number of links between therapists and classes
ctdb	CountTherapyDuringBlock-times	Total number of times that a therapy session takes place during a block time
cbd	CountBreakDeviations	Total number of time that breaks of therapists deviate from the ideal time period
cnpt	CountNotPlannedTherapy	Total number of therapy sessions that are not planned
cnpelf	CountNotPlannedELFMoments	Total number of ELF-moments that are not planned
cnpi	CountNotPlannedIDR	Total number of IDR that is not planned
cnptb	CountNotPlannedTherapist-Breaks	Total number of breaks for therapists that are not planned

Table 4.6: Verbal notation of constraints (a.)

1.	Minimize the weighted sum of the total number of linked therapists, therapy sessions during block times, break deviations of therapists and not planned therapy demand, not planned ELF demand, not planned IDR demand, and not planned therapist break demand.
2.	A therapist t can provide at maximum TC amount of activities in a week
3.	A therapist t can only conduct one action at a time
4.	A therapist t can only perform specialty s type of therapy
5.	A therapist t requires TBDS amount of small breaks on day d
6.	A therapist t requires TBDL amount of large breaks on day d
7.	A therapist t can have small breaks at time periods HTBS
8.	A therapist t can have large breaks at time periods HTBL
9.	A therapist t needs to be available to provide therapy to a class c
10.	A therapist t needs to be available to perform IDR
11.	A therapist t needs to be available to receive a small break
12.	A therapist t needs to be available to receive a large break
13.	A therapist t needs to be available to attend an ELF-moment
14.	Whenever a therapist t is assigned a certain class in advance (parameter) that therapist should be linked to that class (decision variable)
15.	A therapist t may only perform therapy to class c whenever that therapist is linked to class c
16.	IDR demand of every class c must be planned or is stored in not planned IDR
17.	A maximum of FC_s therapy of specialty s may be provided at the same time
18.	The maximum number of therapists t that may be linked to a class equals MTC
19.	Therapy demand, of every class, must be planned or otherwise stored in the slack variable NotPlannedTherapy: $npt_{c,s}$
20.	Physiotherapy demand of every class c must be planned on times that class c is available to receive physiotherapy
21.	Break demand of every unit u needs to be satisfied per day d
22.	A Unit may only take a break on predefined schoolyards
23.	Break demand may only be satisfied during time periods HCB_h
24.	A unit u may not receive a consecutive break within 3 time periods
25.	A unit u requires the break moment to be at the same time for all days d
26.	A class c may only receive breaks whenever that class is available
27.	A class c may receive therapy during a break or eat fruit whenever the violation is stored in the slack variable $ptdb_{t,s,c,d,h}$
28.	A class c may not receive a break and eat fruit at the same time
29.	A class c may only receive therapy whenever that class is available
30.	A schoolyard sy can only contain one unit u of classes at the same time period d, h
31.	A fruit-eating moment of a unit u always occurs the time period before the unit has a break
32.	Minimum fraction of therapy sessions of a class, attended by every patient in that class is equal to PTAT
33.	Every class c requires $CELFD_{c,s}$ ELF-moments, per specialty s
34.	ELF moments of a class may only be planned during specified hours
35.	All therapists t, of specialty s, need to satisfy ELF-demand, per specialty s, per class c
36.	Therapists t may only contribute in satisfying ELF-demand during moments that class c has an ELF-moment

Table 4.7: Verbal notation of constraints (b.)

37.	Only therapists t, with specialty s, may satisfy ELF-demand of specialty s
38.	Only one therapist t of specialty s is required for an ELF-moment
39.	The number of ELF-moments + the number of IDR moments that are assigned to therapists t for class c, may not exceed the total amount of therapy that therapist t provides to class c
40.	$cnpt$ equals the sum of all not planned therapy demand
41.	$cnptb$ equals the sum of all not planned small break demand and large break demand
42.	$cnpti$ equals the sum of all not planned IDR demand
43.	$cnpelf$ equals the sum of all not planned ELF demand
44.	cbd equals the sum of all therapist breaks that deviate from the preferred moment
45.	$ctbt$ equals the sum of all therapy sessions that are planned during block times of a class
46	$cpelfi$ equals the sum of all ELF-moments that take place during schooltimes
47	$cpelfo$ equals the sum of all ELF-moments that take after, or before, schooltimes
48.	The fraction of total available time a therapist is either performing therapy, conducting IDR, attending an ELF-moment or having a break
49., 50., 51.	Sign constraints

4.2.5 Formal problem description

min	$W_1 \cdot \text{cltc} + W_2 \cdot \text{ctdb} + W_3 \cdot \text{cbd} + W_4 \cdot \text{cnpt} +$ $W_5 \cdot \text{cnpelf} + W_6 \cdot \text{cnpi} + W_7 \cdot \text{cnptb}$			1.
$s.t.$	$\sum_d \sum_h (ptbs_{t,d,h} + ptbl_{t,d,h} + \sum_c \sum_s (pt_{t,s,c,d,h} + ptelf_{t,s,c,d,h} + pidr_{t,s,c,d,h}))$	$\leq TC_t$	$\forall t$	2.
	$ptbs_{t,d,h} + ptbl_{t,d,h} + \sum_c \sum_s (pt_{t,s,c,d,h} + ptelf_{t,s,c,d,h} + pidr_{t,s,c,d,h})$	≤ 1	$\forall t, d, h$	3.
	$pt_{t,s,c,d,h}$	$\leq TSM_{t,s}$	$\forall t, s, c, d, h$	4.
	$\sum_h (ptbs_{t,d,h}) + nptbs_{t,d}$	$= TBDS_{t,d,h}$	$\forall t, d$	5.
	$\sum_h (ptbl_{t,d,h}) + nptbl_{t,d}$	$= TBDL_{t,d,h}$	$\forall t, d$	6.
	$ptbs_{t,d,h}$	$\leq HTBS_h$	$\forall t, d, h$	7.
	$ptbl_{t,d,h}$	$\leq HTBL_h$	$\forall t, d, h$	8.
	$pt_{t,s,c,d,h}$	$\leq TA_{t,d,h}$	$\forall t, s, c, d, h$	9.
	$pidr_{t,s,c,d,h}$	$\leq TA_{t,d,h}$	$\forall t, d, h$	10.
	$ptbs_{t,d,h}$	$\leq TA_{t,d,h}$	$\forall t, d, h$	11.
	$ptbl_{t,d,h}$	$\leq TA_{t,d,h}$	$\forall t, d, h$	12.
	$ptelf_{t,s,c,d,h}$	$\leq TA_{t,d,h}$	$\forall t, s, c, d, h$	13.
	$ltc_{t,c}$	$\geq LTC_{t,c}$	$\forall t, c$	14.
	$pt_{t,s,c,d,h}$	$\leq ltc_{t,c}$	$\forall t, s, c, d, h$	15.
	$\sum_{t,d,h} (pidr_{t,s,c,d,h}) + npidr_{c,s}$	$= CID_{c,s}$	$\forall c, s$	16.
	$\sum_t \sum_c pt_{t,s,c,d,h}$	$\leq FC_s$	$\forall s, d, h$	17.
	$\sum_t \sum_s ltc_{t,c} \cdot TSM_{t,s}$	$\leq MTC$	$\forall c$	18.
	$\sum_t \sum_d \sum_h (pt_{t,s,c,d,h}) + npt_{c,s}$	$= CTD_{c,s}$	$\forall c, s \neq 3$	19.
	$\sum_t \sum_d \sum_h (pt_{t,s,c,d,h} \cdot CFA_{c,d}) + npt_{c,s}$	$= CTD_{c,s}$	$\forall c, s = 3$	20.
	$\sum_h \sum_{sy} usyu_{u,sy,d,h}$	$\geq UBD_{u,d}$	$\forall u, d$	21.
	$usyu_{u,sy,d,h}$	$\leq ULSY_{sy,u}$	$\forall u, sy, d, h$	22.
	$usyu_{u,sy,d,h}$	$\leq HCB_h$	$\forall u, sy, d, h$	23.
	$usyu_{u,sy,d,h} + usyu_{u,sy,d,h+1} + usyu_{u,sy,d,h+2} + usyu_{u,sy,d,h+3}$	≤ 1	$\forall u, sy, d, h \leq \|h\| - 3$	24.
	$usyu_{u,sy,d,h}$	$= usyu_{u,sy,d+1,h}$	$\forall u, sy, d \neq 5, h$	25.

$\sum_{c}(CPA_{c,d,h} \cdot CUL_{u,c} \cdot usyu_{u,sy,d,h})$	$= acb_{u,sy,d,h}$	$\forall u, sy, c, d, h$	26.
$pt_{t,s,c,d,h} + \sum_{sy} usyu_{u,sy,d,h} \cdot CUL_{c,u} + fba_{u,d,h} \cdot CUL_{u,c}$	$\leq 1 + ptdb_{t,s,c,d,h}$	$\forall u, sy, t, s, c, d, h$	27.
$usyu_{u,sy,d,h} \cdot CUL_{c,u} + fba_{u,d,h} \cdot CUL_{u,c}$	≤ 1	$\forall u, sy, c, d, h$	28.
$CA_{c,d,h}$	$\geq pt_{t,s,c,d,h}$	$\forall t, s, c, d, h$	29.
$\sum_{u} usyu_{u,sy,d,h}$	≤ 1	$\forall sy, d, h$	30.
$usyu_{u,sy,d,h}$	$\leq fba_{u,d,h-1}$	$\forall u, sy, d, h$	31.
$\sum_{t}\sum_{d}\sum_{h}(pt_{t,s,c,d,h} \cdot PA_{p,d,h})$	$\geq PTAT \cdot CTD_{c,s}$	$\forall p, c, s$	32.
$\sum_{d}\sum_{h}(celf_{c,d,h}) + npelf_{c}$	$= CELFD_{c,s}$	$\forall c, s$	33.
$HEI_{h} + HEO_{h}$	$\geq celf_{c,d,h}$	$\forall c, d, h$	34.
$CELFD_{c,s} - npelf_{c}$	$= \sum_{t}\sum_{d}\sum_{h} telf_{t,s,c,d,h}$	$\forall c, s$	35.
$ptelf_{t,s,c,d,h}$	$\geq celf_{c,d,h}$	$\forall t, s, c, d, h$	36.
$\sum_{t} ptelf_{t,s,c,d,h}$	≤ 1	$\forall s, c, d, h$	37.
$ptelf_{t,s,c,d,h}$	$\leq TSM_{t,s}$	$\forall t, s, c, d, h$	38.
$\sum_{d}\sum_{h}(pidr_{t,s,c,d,h} + ptelf_{t,s,c,d,h})$	$\leq \sum_{d}\sum_{h} pt_{t,s,c,d,h}$	$\forall t, c, s$	39.
$\sum_{c}\sum_{s} npt_{c,s}$	$= cnpt$		40.
$\sum_{t}\sum_{d} nptbs_{t,d} + nptbl_{t,d}$	$= cnptb$		41.
$\sum_{c}\sum_{s} npidr_{c,s}$	$= cnpti$		42.
$\sum_{c} npelf_{c}$	$= cnpelf$		43.
$\sum_{t}\sum_{d} ptbs_{t,d,\text{"10:00"}} + ptbs_{t,d,\text{"11:00"}} + ptbl_{t,d,\text{"12:00"}} + ptbl_{t,d,\text{"13:00"}}$	$= cbd$		44.
$\sum_{t}\sum_{s}\sum_{c}\sum_{d}\sum_{h} ptbt_{t,s,c,d,h}$	$= ctdb$		45.
$\sum_{c}\sum_{d}\sum_{h}(celf_{t,s,c,d,h} * HEI_{h})$	$= cpelfi$		46
$\sum_{c}\sum_{d}\sum_{h}(celf_{t,s,c,d,h} * HEO_{h})$	$= cpelfo$		47
$(\sum_{d}\sum_{h}(ptbs_{t,d,h} + ptbl_{t,d,h} + \sum_{s}\sum_{c}(pt_{t,s,c,d,h} + ptelf_{t,s,c,d,h} + pidr_{t,s,c,d,h})))/\sum_{d}\sum_{h} TA_{t,d,h})$	$= tu_{t}$	$\forall t$	48.
All planning decision variables, $ltc_{t,c}, ptdb_{t,s,c,d,h}, celf_{c,d,h}$	$\in$ 0,1		49.
$npt_{c,s}, npidr_{c,s}, npelf_{c}, nptbs_{t,d}, nptbl_{t,d}, cnpt, cnpelf,$ $acb_{u,sy,d,h}, cnptb, cnpi, cltc, cacdb, ctdb, cbd, cpelfi, cpelfo$	$\in Z^{+}$		50.
tu_{t}	≥ 0		51.

4.3 Model output visualization

This section illustrates a visualized representation of the output of the MILP. A Macro-Enabled Excel file is provided to transform the output tables to a blueprint format that humans can more easily interpret.

The information stored in the variables $pt_{t,s,c,d,h}$, $ptbs_{t,d,h}$, $ptbl_{t,d,h}$, $pidr_{t,d,h}$ and $ptelf_{t,s,c,d,h}$ is combined in a status object with indices t,d,h that can take on the values "Class i" (representing planned therapy for class i), "Break", "ELF-moment", "IDR", "Not Available" and "Idle". This status object in turn is transformed into a visual presentation as shown in Figure 4.1. The same is done for the perspective of Classes and Patients. The therapists that participate in the same ELF-moment can be found in the raw output format. The user of the visualization tool has the option to switch between actors by selecting a different input via the drop-down list on the top right.

Input actor: Therapist1

Time	Day 1	2	3	4	5
08:00	Not available	Not available	Not available	Not available	Not available
08:30	Not available	Not available	Not available	Not available	Not available
09:00	Class1	Class1	Class1	Class1	Class1
09:30	Class1	Class1	Class1	Class1	Class1
10:00	Class1	Class1	Class1	Class1	Class1
10:30	Break	Break	Break	Break	Break
11:00	Not available	Not available	Not available	Not available	Not available
11:30	Not available	Not available	Not available	Not available	Not available
12:00	Break	Break	Break	Break	Break
12:30	Class2	Class2	Class2	Class2	Class2
13:00	Class2	Class2	Class2	Class2	Class2
13:30	Class2	Class2	Class2	Class2	Class2
14:00	Class2	Class2	Class2	Class2	Class2
14:30	Class2	Class2	Class2	Class2	Class2
15:00	Class3	Class3	Not available	Not available	Not available
15:30	Class3	Class3	Not available	Not available	Not available
16:00	Class3	Class3	Class3	Class3	Class3
16:30	Not available	Not available	Class3	Class3	Class3
17:00	Not available	Not available	Class3	Class3	Class3
17:30	Not available	Not available	Not available	Not available	Not available
18:00	Not available	Not available	Not available	Not available	Not available

Figure 4.1: Visualization of model output for Therapist1.

4.4 Model verification, validation and feasibility

Verification

We verify the model by iterative testing new constraints on a toy problem with limited input dimensions. This provides us with instant running times and easy manual verification of results and exceptions. Because we followed this approach we can be certain about the functioning of the model when we increase the problem size and start experimenting with real-world data.

Validation

We used a continuous validation and improvement cycle, where therapists and planners could validate intermediate versions of the model. This allowed us to implement initially forgotten constraints/planning rules. Although a lot of constraints are implemented, probably some are still forgotten. That is why the validation cycle should be continued in the future to refine the model. We will discuss this subject in more depth in Section 6.2.

Feasibility

To ensure feasibility, we introduced several slack variables to store not planned activities: $npt_{c,s}, npelf_c$, $npidr_{c,s}$, $nptbs_{t,d}$, $nptbl_{t,d}$. Although these variables are useful in ensuring the model remains feasible, the solution space is drastically increased. This in turn leads to a slow convergence of the objective value (intractable). To enable faster convergence, we prune the model by removing slack variables and testing the model. The following steps are conducted:

1. **Only slack ELF-moments.** Given that all breaks, all IDR and all therapy needs to be planned, we reason that only including $npelf_c$ should be sufficient. Unfortunately, we find that almost no ELF-moments are planned because all therapists are filled with other activities.

2. **Slack ELF-moments and IDR.** ELF-moments are considered more valuable than IDR, therefore we re-introduce slack IDR. The model is now able to trade IDR (low penalty when not planned) for ELF-moments (high penalty when not planned) whenever it can.
   The model is fast in finding an initial solution, but after 10 hours has just slightly improved. By analyzing the results, we find that almost all IDR has been planned and almost no ELF-moments. IDR is the easiest activity to schedule, as it is very unconstrained. ELF-moments on the other hand are by far the hardest to plan due to their multidisciplinary setting. We hypothesize that because IDR is easier to plan, the model fills available slots of therapists with IDR (easy and quick win in objective value). Now, a large part of all activities is planned and the model seems to have difficulty in 'trading' IDR for ELF-moments. This can be compared with getting stuck in local optima.

3. **Slack ELF-moments.** Therefore, we decide to drop IDR from the model and save a percentage of available slots per therapist to allow IDR to be scheduled after an initial solution is drafted. Now we only plan therapy, breaks and ELF-moments. Even with just one slack variable, the model converges very slowly. After 15 hours, only 22% of all ELF-moments is planned and the number of therapists per class is still very high. We conclude that allowing slack on scheduling ELF-moments is the main cause of slow convergence.

4. **No slack.** The last step is to force the model in scheduling all ELF-demand. This led to infeasible runs and many trials to counter the infeasibility. The parameter settings that seemed to influence feasibility when forcing ELF-moments to be planned were to either increase capacity of therapists, or decrease ELF-demand. After consulting with the therapists it became clear that they have never managed to plan all ELF-demand. Therefore, we chose to tune the ELF-demand parameter. In the experiments section, we initiate experiments with increasing % values of ELF-demand, per class, per specialty, that need to be planned. We decided not to re-introduce IDR-demand (either with slack or without), as the pruning of the model delayed the moment we could start the experimentation phase and the deadline of the research was closing in. We discuss this subject in more depth in the discussion.

The final objective function (without excess variables) is defined by Equation 52.:

$$\min \quad W_1 \cdot \text{cltc} \quad + \quad W_2 \cdot \text{ctdb} \quad + \quad W_3 \cdot \text{cbd} \tag{52.}$$

Concluding the steps taken to construct a feasible and tractable model, we limit a therapist's utilization to leave availability for IDR and proceed with forcing the model to meet all demand presented in the input data. Moreover, we achieve feasibility by decreasing the ELF-demand by a given %.

5 Experiments

This chapter discusses the experiments performed on the MILP model. Section 5.1 provides a general introduction to the experimental approach. In this section, we introduce questions that we use to categorize the experiments and steer toward practical contributions. Section 5.3 describes the experimental setup in terms of parameter settings, intended insights and experimental results. This Section also accommodates a brief analysis and discussion per experiment. In Chapter 6 we reflect on the experimental approach and experimental results. As concluded in Chapter 3, we focus on solving the provided problem with an exact approach.

5.1 General introduction

Before we introduce a list of experiments, we introduce questions that arose during the advisory group meetings. We use these questions to deduce the main body of experiments. With this approach, we aim to provide a practical contribution as well as a theoretical contribution to our experiments. Table 5.1 summarizes the proposed questions and provides the brief reasoning behind the questions. The first column will be discussed after the introduction of the parameters. All parameters that are changed during the experiments are summarized in Table 5.2. The table also introduces abbreviations and indicates which value a certain parameter can take. All other parameters of the model (e.g patient class distribution and class therapy demand) remain constant. Table 5.1 also introduces experiment categories (Exp. cat.). Single experiments are adjustments to the value of one or more parameters. The set of experiments focussing on adjustments of the same parameter(s) is called an experiment category. All questions are related to one experiment category, as presented in Table 5.1. During the chapter, we answer all questions related to an experiment category. Note that parameters n(T) and Util are not translated to an experiment category as Util remains constant throughout the experiments and n(T) provides an easy distinction between the toy problem and the real-world setting. Furthermore, parameters MTC and ELF are grouped into one experiment category because we aim to find a balance between the two parameters. This grouped experiment category is used to answer three of the introduced questions.

Due to the time limitations of this research and practical limitations in implementation, we maintain a fixed run time of 28.000 seconds (around 8 hours) for all experiments. Considering the size of the problem we might still have a large optimality gap after the expiration of the run time. In Section 5.3 we will see that this is indeed the case. We will reflect on this in Chapter 6.

5.2 General experiment setup

Before presenting the experiments, we discuss three parameters that need further explanation: TA, LTC and PTAT.

Parameters TA and LTC

Parameters TA and LTC are complex to systematically alter. In the TA parameter, the number of changes we can make is very large, because we have 62 therapists, 5 days and 20 slots per day. Therefore, it is difficult to formulate general conclusions or exclude the influence of certain settings.

Table 5.1: Questions to obtain insights and reasoning behind them

Exp. cat.	**Question**:
ELF/MTC	How does the blueprint plan of the model perform, compared to the manually drafted blueprint? The gap between the manually drafted blueprint and the output of the model can provide insights into the added value of the model.
ELF/MTC	In what manner does the percentage of ELF-demand influence the solution quality? In what manner does the maximum number of therapists that may be linked to a class influence the solution quality? ELF-demand is the hardest activity to plan. This question will provide an overview of the impact on the solution quality when altering the % ELF-demand to be planned. MTC highly influences the feasible region of the model. A low value will (probably) result in infeasibility, whereas a large value might result in computational intractability. Finding a balanced value for MTC provides the user of the model with relatively fast convergence, given reasonable solution space.
PTAT	In what manner does the value of PTAT influence the balance between robustness versus the solution quality of the model? We hypothesize that an increase in PTAT increases the robustness of the model in terms of the ease with which the tactical plan can be translated into an operational plan. But, the increase of PTAT will probably decrease the solution quality, as fewer and fewer slots of classes remain available to provide therapy in.
TA	How does the objective value change when altering the degree of availability of therapists while keeping capacity constant? This question can help us gain insights into the added value of (partly) controlling the moments at which part-time therapists do not work.
LTC	How does the objective value change when altering the number of pre-linked therapists to classes? This question can provide insights into the effects of constraining therapists to classes before the construction of the blueprint has started.
GAH	How does the objective value change when altering the moments for gym, animal care and hydrotherapy? Facilities for gym, animal care and hydrotherapy are shared with other departments of the hospital. This question can provide the user with an indication of the added value of changing these moments.
BD	How does the objective value change whenever break moments of therapists are fixed? This question can provide the user with an indication of the added value of relaxing or constraining break moments.
UTO	Do we need to use every currently contracted therapist to satisfy demand? Currently, it is assumed that all therapists are required to satisfy demand. By gaining insights into this subject, management might decide to deploy certain therapists for other activities (e.g. to implement, or explore new working methods).
BT	How does the objective value change whenever block times may never be violated? This question provides the user with an indication of the constraining power of block times on the plan.

Table 5.2: Abbreviations and possible values used in the experimental setup.

Parameters:		**Coding**	**Description**
n(T)	Cardinality of set T (therapists)	-	Cardinality
BD	Break deviation	1	Deviation of break moments is allowed for therapists
		0	Deviation of break moments is not allowed for therapists
BT	Block times	0	Therapy is not allowed during block times
		1	Therapy is allowed during block times
UTO	Use therapists once	0	Not mandatory to utilize every therapist
		1	Required to utilize every therapist
MTC	Maximum therapist class	#	Value represents the maximum number of therapists that may be assigned to one class
PTAT	Patient therapy availability threshold	#	The minimum fraction of therapy sessions of a class, attended per patient in that class
ELF	ELF-demand	#	Value represents the fraction of ELF-demand that is planned
		++	Plan as many ELF-moments as possible
TA	Therapists availability	rw	Real-world availability (given the availability of therapists)
		tp	Toy problem availability (manually set availability)
		1	Increase available time slots of one physio from 64 to 80
		2	Increase available time slots from 64 to 80 for one therapist of every specialty
		3	Increase available time slots of one physio from 16 to 32
		4	Increase available time slots from 16 to 32 for one therapist of every specialty
LTC	Link therapist class	0	No therapist is linked to any class
		1	Therapist 1 is linked to a random class from Unit A
		2	Therapist 10 is linked to a random class from Unit A
		3	Therapist 10 is linked to two random classes from Unit A
GAH	Gym/AnimalCare/	0	Given GAH moments from clinic
	Hydrotherapy	1	GAH moments are distributed at random over the week
		2	GAH moments are distributed evenly over the week
Util	Utilisation	#	The maximum fraction of available time slots that may be used, for all therapists

Time	Monday	Tuesday	Wednesd	Thursday	Friday
07:30	0	0	0	0	0
08:00	0	1	0	0	0
08:30	0	1	0	1	0
09:00	0	0	0	1	0
09:30	0	0	0	0	0
10:00	1	0	0	0	0
10:30	1	0	0	0	0
11:00	1	0	0	0	0
11:30	1	0	0	1	0
12:00	1	1	0	1	0
12:30	0	0	0	1	0
13:00	0	0	0	1	0
13:30	0	0	0	1	0
14:00	0	0	0	1	0
14:30	0	0	0	0	0
15:00	0	0	0	0	0
15:30	0	0	0	0	0
16:00	0	0	0	0	0
16:30	0	0	0	0	0
17:00	0	0	0	0	0
17:30	0	0	0	0	0

(a) Tp - 16 available periods

Time	Monday	Tuesday	Wednesd	Thursday	Friday
07:30	0	0	0	0	0
08:00	0	0	0	0	0
08:30	0	0	0	0	0
09:00	0	0	0	0	0
09:30	0	0	0	1	0
10:00	0	1	0	1	0
10:30	0	1	0	1	1
11:00	0	1	0	1	1
11:30	0	1	0	1	1
12:00	0	1	0	1	1
12:30	0	1	0	1	1
13:00	0	1	0	1	0
13:30	0	1	0	1	0
14:00	0	0	0	1	0
14:30	0	0	0	1	0
15:00	0	0	1	1	0
15:30	0	0	1	1	0
16:00	0	0	1	1	0
16:30	0	0	1	1	0
17:00	0	0	0	0	0
17:30	0	0	0	0	0

(b) Tp - 32 available periods

Time	Monday	Tuesday	Wednesd	Thursday	Friday
07:30	0	0	0	0	0
08:00	1	1	0	0	0
08:30	1	1	0	0	0
09:00	1	1	1	0	1
09:30	1	1	1	1	1
10:00	1	1	1	1	1
10:30	1	1	1	1	1
11:00	1	1	1	1	1
11:30	1	1	1	1	1
12:00	1	1	1	1	1
12:30	1	1	1	1	1
13:00	1	1	1	1	1
13:30	1	1	1	1	1
14:00	1	0	1	1	0
14:30	1	0	1	1	0
15:00	1	0	1	1	0
15:30	1	0	1	0	0
16:00	0	0	0	0	0
16:30	0	0	0	0	0
17:00	0	0	0	0	0
17:30	0	0	0	0	0

(c) Tp - 64 available periods

Figure 5.1: Sets of therapists and incrementally increasing availability to target

Time	Monday	Tuesdag	Wednesda	Thursday	Friday
7:30	0	0	0	0	0
8:00	8	4	5	0	4
8:30	9	4	8	0	4
9:00	8	6	9	8	5
9:30	9	6	9	9	6
10:00	9	9	9	11	6
10:30	9	7	9	10	4
11:00	9	9	9	11	4
11:30	9	8	9	11	4
12:00	9	5	7	7	4
12:30	6	5	6	5	4
13:00	6	4	7	5	3
13:30	6	3	5	5	2
14:00	6	2	5	4	2
14:30	5	2	1	1	1
15:00	5	1	2	1	0
15:30	5	1	2	1	0
16:00	0	0	0	0	0
16:30	0	0	0	0	0
17:00	0	0	0	0	0
17:30	0	0	0	0	0

(a) Rw - Ergo

Time	Monday	Tuesdag	Wednesda	Thursday	Friday
7:30	0	0	0	0	0
8:00	5	4	5	0	3
8:30	5	5	4	0	4
9:00	5	7	4	9	5
9:30	6	7	5	8	5
10:00	6	8	4	8	5
10:30	5	8	4	8	5
11:00	6	8	4	9	5
11:30	6	8	4	9	5
12:00	7	8	5	9	5
12:30	6	6	5	9	3
13:00	8	6	6	9	3
13:30	8	8	6	9	3
14:00	8	7	8	9	3
14:30	7	4	5	8	3
15:00	7	4	5	8	3
15:30	5	3	5	6	3
16:00	4	4	5	5	3
16:30	0	1	3	1	0
17:00	0	0	1	0	0
17:30	0	0	0	0	0

(b) Rw - Logo

Time	Monday	Tuesdag	Wednesda	Thursday	Friday
7:30	1	0	0	0	0
8:00	9	6	3	0	5
8:30	9	10	3	0	7
9:00	8	9	5	8	7
9:30	7	9	5	8	7
10:00	6	9	5	10	7
10:30	6	9	5	9	6
11:00	7	10	6	11	6
11:30	7	9	6	10	8
12:00	9	9	2	8	8
12:30	6	5	1	6	4
13:00	8	8	2	8	4
13:30	9	8	2	8	4
14:00	7	6	2	6	3
14:30	3	5	1	4	3
15:00	4	4	1	4	3
15:30	2	4	1	3	2
16:00	2	3	1	2	2
16:30	1	1	1	1	1
17:00	0	0	0	0	0
17:30	0	0	0	0	0

(c) RW - Physio

Time	Monday	Tuesdag	Wednesda	Thursday	Friday
7:30	0	0	0	0	0
8:00	5	3	3	1	1
8:30	5	4	4	3	3
9:00	6	4	5	5	5
9:30	6	6	5	7	5
10:00	7	7	6	7	5
10:30	7	6	6	7	4
11:00	7	6	7	8	4
11:30	7	6	7	8	4
12:00	7	7	7	7	4
12:30	5	6	7	5	4
13:00	4	4	7	5	3
13:30	4	4	5	6	3
14:00	3	2	4	5	3
14:30	3	1	4	3	3
15:00	3	1	3	1	2
15:30	4	2	3	1	1
16:00	0	0	0	0	0
16:30	0	0	0	0	0
17:00	0	0	0	0	0
17:30	0	0	0	0	0

(d) TP - Ergo

Time	Monday	Tuesdag	Wednesda	Thursday	Friday
7:30	0	0	0	0	0
8:00	4	1	3	0	1
8:30	4	3	3	0	2
9:00	4	3	4	3	3
9:30	4	5	4	7	3
10:00	4	7	4	7	4
10:30	4	6	4	7	4
11:00	4	6	5	8	4
11:30	4	7	4	8	4
12:00	5	6	4	8	4
12:30	5	6	6	6	4
13:00	6	5	6	5	3
13:30	5	5	6	6	3
14:00	5	1	5	6	2
14:30	5	1	4	6	2
15:00	6	1	5	4	2
15:30	3	3	5	3	1
16:00	2	1	2	2	0
16:30	0	0	2	2	0
17:00	0	0	1	0	0
17:30	0	0	0	0	0

(e) TP - Logo

Time	Monday	Tuesdag	Wednesda	Thursday	Friday
7:30	0	0	0	0	0
8:00	5	5	3	0	1
8:30	5	8	3	0	2
9:00	7	7	4	6	5
9:30	6	8	4	8	5
10:00	5	8	4	7	6
10:30	5	7	4	7	6
11:00	6	6	4	7	5
11:30	6	8	3	8	5
12:00	7	8	2	8	4
12:30	6	7	3	7	4
13:00	7	6	3	6	3
13:30	5	6	2	7	3
14:00	5	3	1	7	2
14:30	5	2	1	5	2
15:00	6	2	2	4	2
15:30	3	4	1	3	1
16:00	2	2	2	1	0
16:30	0	0	1	1	0
17:00	0	0	1	0	0
17:30	0	0	0	0	0

(f) TP - Physio

Figure 5.2: Comparison between therapist availability distribution of real-world setting versus toy problem.

The impact of the LTC parameter is greatly dependent on the availability of the linked therapists. For example, pre-linking a therapist who is only available on Mondays will have a different impact compared to a therapist who is available full-time. Because parameters TA and LTC are complex to systematically alter, we introduce a tailored approach.

In this tailored approach, we decrease the number of therapists from 62 to 30 and evenly divide the therapists over the three specialties, resulting in 10 therapists per specialty. In each specialty, 3 therapists are available for 64 periods, 3 therapists are available for 32 periods and 4 therapists are available for 16 periods. Examples of rosters are visualized in Figure 5.1. Light green indicates availability, and dark green is explained later. The obtained availability by scaling Figure 5.1 to 30 therapists is called the toy problem (tp). The toy problem uses the same MILP to solve the blueprint plan but differs in the number of therapists and their TA. Other parameters, such as class- and patient availability, are kept constant in the toy problem.

We systematically change the TA parameter by increasing the available periods of a therapist (or for one of each specialty) from either 64 to 80, or from 16 to 32. These alterations are indicated under TA in 5.3, with codes 1, 2, 3 and 4. The alterations are generated by a simple algorithm that incrementally adds one random, adjacent slot of availability to the initial availability until the targeted number of available slots is obtained. Figure 5.1 highlights the adjacent slots that are considered during one iteration of the algorithm in dark green.

By aligning the input of the toy problem in terms of availability heat maps, we aim to generate an output that can be generalized to the real-world case. Figure 5.1 shows a heat map of the therapist's availability of both the real-world setting and the toy problem. We observe comparable regions of availability (green) and unavailability (yellow, orange, red).

Parameter PTAT

During non-systematic experimentation, we observed that CA (class availability) is a very constraining parameter. In other words: a lot of therapy needs to be planned in a brief period of time. CA is largely influenced by the PTAT parameter value. To get a better feeling and understanding of the PTAT parameter value, this subsection contains a small data analysis on historical data for school year 2021-2022.

We reason that a robust value for PTAT will allow the bulk of all patients to be present during therapy. The minimum required PTAT, per patient is depended on their contribution to total class therapy demand. During this research, we work with a shared PTAT value for all patients. Therefore, we show the minimum required PTAT for every patient, aggregated over specialties, in a box plot in Figure 5.3. Note that outliers, who sometimes contribute up to 100% of all class demand, are not illustrated in the plot.

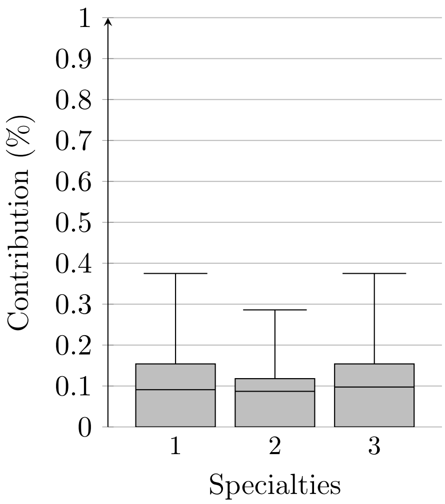

Figure 5.3: Spread of % of contribution to total class demand of all patients, per specialty

The PTAT parameter is only used in constraint 32. (PTAT constraint), which is modeled to ensure robustness in the translation process of the tactical plan to an operational plan. From Figure 5.3 we conclude that a PTAT higher than 0.4 will be unnecessarily constraining, as the vast majority of the patients will probably already be able to attend therapy when required. However, when incorporating outliers, we can conclude that a shared PTAT for all patients might be insufficient due to a lack of robustness. We reason that with a shared PTAT it is easy for patients with a high contribution to total class demand, to be absent during therapy. For example, if the total class demand of physiotherapy consists only of the therapy sessions of one patient (i.e. 100% contribution), a shared PTAT lower than 1 will probably be insufficient.

Due to time limitations, we proceed with a shared PTAT during experimentation. In Section 6.2 we advise altering the shared PTAT value to the minimum required PTAT values on the patient level and altering constraint 32. to accommodate this change.

5.3 Experimental setup and experimental results

In this section, we present the parameter settings and experimental results per experiment category, per experiment. We also provide a brief analysis and discussion per experiment category. All parameter settings regarding the real-world problem are obtained from discussions with experts within the clinic. Experiments are solved using CPLEX 22.1 and performed on an AMD Ryzen 5 5600X 6-Core Processor 3.70 GHz with 48.00 GB RAM. The weights in the objective function are defined in consultation with therapists and planners, and are defined as follows: $W_1 = 100, W_2 = 2andW_3 = 0.1$. We reason that our primary focus is to decrease the number of required linked therapists and want to limit the model in making a trade off.

Per experiment category (i.e. per subject), we first introduce the parameter settings and experimental results. In the parameter settings, light green cells indicate a change in the value of a parameter with respect to the rest of the column. In other words, the parameter is changed to test the influence on the solution quality. 'Subject' corresponds with the most important parameter that is altered. *Note that in some versions of Adobe Acrobat the colored cells overlap with table borders dependent on the level of zoom.* The experimental result tables are indexed by parameters that are subject to change. The remaining 10 columns represent performance measures. All performance measures are introduced in Table 5.3. The tables that present the experimental results also contain "NA" values. These values indicate that the experiment is infeasible for the given parameter settings.

Note that we have a large optimality gap in every experiment ($\geq$ 34%). The large optimality gap imposes us to be cautious with drawing conclusions from the results of the experiments because the found MILP solution can still differ significantly from a near-optimal integer solution. During the remainder of this chapter, we do not mention the large optimality gap in every interpretation of the results. We use Chapter 6 to further explore the limitations of a.o. the experimental approach and the experimental results.

Table 5.3: Abbreviations of performance measures in experimental results

Abbreviation	**Definition**
GAP	Optimality gap
MILP	MILP objective value (i.e. objective value)
LP	Best lower bound
LT	Total number of linked therapists
PELF	% of ELF-moments planned
BTV	Total number of block time violations by therapy
BrTV	Total number of break time violations by therapy
BD	Total number of break deviations of therapists
ELF_Out	Total number of ELF-moments planned during schooltime
ELF_In	Total number of ELF-moments planned after schooltime

Maximum Therapist Class (MTC)

Table 5.4 provides the experimental parameter settings for MTC/ELF. In Table 5.5, MTC ≤ 6 and ELF $= 0$, we observe that at least one class requires a minimum of 6 linked therapists to satisfy all therapy demand. In experiment MTC $= 6$, ELF $= 0.3$, we observe that 30% of ELF-demand can be planned while keeping MTC constant. In the same experiment, we see that we observe that almost 30% of ELF-demand is planned after school times and the MILP value has increased relatively little. Therefore, we can conclude that it is relatively easy to satisfy 30% of ELF-demand without negatively impacting the objective value. By increasing the % ELF-demand to 50% however, we see that the model becomes feasible only when MTC ≥ 8. The absolute number of ELF-moments that need to be planned during school times increases rapidly. We also observe an increase in the number of linked therapists (LT). We reason that whenever ELF-moments during school times increase, therapists participating in ELF-moments are not able to provide therapy at that moment. Therefore, the model needs to compensate for the loss of capacity during school times by linking additional therapists. When MTC is increased and ELF is kept constant, we observe that the model often converges to the same solution it found with lower values of MTC.

The estimated performance of the manually drafted blueprint plan is introduced in Chapter 2, in Table 2.6. We state that comparison is hard, because restrictions used to construct the two plans differ greatly (i.e comparing apples to oranges). For example, the model doesn't allow any ELF-moments to be planned if less than three therapists can be present. This is in contrast to the manually drafted plan, where approximately 90% of all ELF-moments is planned with two participating therapists. We can comment that the model is comparably good at finding ELF-moments with three participating therapists, but lacks the functionality to plan residual ELF-moments with e.g. two participating therapists. Also, the model (in its current state) is not able to incorporate the planning of IDR, whereas the manually drafted plan is a complete all encompassing plan. Due to these differences, we decide not to perform a quantitative comparison on the performance of the two methods of blueprint plan development. We reason that this will most likely lead to a skewed comparison of two different approaches and weak conclusions.

Table 5.4: MTC experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
MTC/ELF	4	0	0.1	1	0	rw	0	0	1	62	0.9
	5	0	0.1	1	0	rw	0	0	1	62	0.9
	6	0	0.1	1	0	rw	0	0	1	62	0.9
	7	0	0.1	1	0	rw	0	0	1	62	0.9
	8	0	0.1	1	0	rw	0	0	1	62	0.9
	6	++	0.1	1	0	rw	0	0	1	62	0.9
	7	++	0.1	1	0	rw	0	0	1	62	0.9
	8	++	0.1	1	0	rw	0	0	1	62	0.9
	6	0.3	0.1	1	0	rw	0	0	1	62	0.9
	7	0.3	0.1	1	0	rw	0	0	1	63	0.9
	8	0.3	0.1	1	0	rw	0	0	1	62	0.9
	6	0.5	0.1	1	0	rw	0	0	1	62	0.9
	7	0.5	0.1	1	0	rw	0	0	1	62	0.9
	8	0.5	0.1	1	0	rw	0	0	1	62	0.9

Table 5.5: MTC experimental results

MTC	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
4	0	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
5	0	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
6	0	44%	7930	4410	78	0%	14	35	38	0	0
7	0	44%	7930	4410	78	0%	14	35	38	0	0
8	0	44%	7930	4410	78	0%	14	35	38	0	0
6	++	34%	9265	6125	108	22%	22	81	93	22	0
7	++	64%	16798	6088	126	17%	42	88	99	17	0
8	++	68%	18689	5931	142	11%	65	93	108	11	0
6	0.3	41%	8647	5090	84	30%	25	15	37	27	6
7	0.3	41%	8647	5090	84	30%	25	15	37	27	6
8	0.3	41%	8647	5090	84	30%	25	15	37	27	6
6	0.5	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
7	0.5	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
8	0.5	51%	9621	4752	98	50%	20	23	48	41	16

Patient Therapy Availability Threshold (PTAT)

In the MTC/ELF category, we conduct two experiments (with PTAT = 0.1) that are also relevant for this category and are copied to enable easy comparison. In this category, we distinguish two groups of experiments where ELF is either kept constant at 0.3 or 0.5. In both groups, we observe that increasing PTAT from 0.1 to 0.2 yields little impact on the objective value. By increasing PTAT from 0.2 to 0.4 and keeping ELF constant at 0.3, we observe an increase in the number of linked therapists (and in the MILP objective value) of over 40%. Increasing PTAT from 0.2 to 0.4 when ELF = 0.5 results in the model becoming infeasible. Increasing PTAT to 0.6 and keeping ELF = 0.3 also results in infeasibility. This shows how constraining the PTAT parameter is at higher values (≥ 0.4). The constraining power of this parameter comes from the fact that it constrains the moments at which a class can receive therapy on a patient level. The degree of constraint coincides with the data analysis presented in Figure 5.3, which showed that the vast majority of patients contribute no more than 20% of total class demand, per specialty. At lower levels of PTAT, the parameter isn't very constraining because many combinations of slots still exist to satisfy class therapy demand on moments when multiple patients are available. Whenever PTAT increases, the number of slots that a class is available drastically decreases. Lastly, we see that the model starts to increase the deviation of therapist breaks at higher PTAT values. The model probably uses the break deviation to accommodate for the restrictions on moments that a class can receive therapy.

Table 5.6: PTAT experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
PTAT	8	0.3	0.1	1	0	rw	0	0	1	62	0.9
	8	0.3	0.2	1	0	rw	0	0	1	62	0.9
	8	0.3	0.4	1	0	rw	0	0	1	62	0.9
	8	0.3	0.6	1	0	rw	0	0	1	62	0.9
	8	0.3	0.8	1	0	rw	0	0	1	62	0.9
	8	0.5	0.1	1	0	rw	0	0	1	62	0.9
	8	0.5	0.2	1	0	rw	0	0	1	62	0.9
	8	0.5	0.4	1	0	rw	0	0	1	62	0.9

Table 5.7: PTAT experimental results

PTAT	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
0.1	0.3	41%	8647	5090	84	30%	25	15	37	27	6
0.2	0.3	42%	8838	5095	87	30%	19	30	53	26	7
0.4	0.3	60%	12583	5074	123	30%	22	79	67	27	6
0.6	0.3	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
0.8	0.3	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
0.1	0.5	51%	9621	4752	98	50%	20	23	48	41	16
0.2	0.5	54%	10253	4757	101	50%	18	27	46	41	16
0.4	0.5	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

Break Deviation (BD)

We copy two experiments with MTC = 8, PTAT = 0.1 and a different ELF of 0.3 and 0.5 from the previous experiment category. We keep ELF constant at either 0.3 or 0.5 and not allow break deviations. We observe that the model can find a better solution compared to allowing break deviations. This is not what we expected, as the solution space of BD = 1 should encompass the solution space of BD = 0. This can probably be explained by the large optimality gaps, which indicate that the results are not near optimal. In the experiments with BD = 0, the solution space is decreased, which in turn results in faster convergence. This means that given enough time, the experiments with BD = 1 should find the same, or a better solution. Note, however, that significantly more break times of classes are violated (BrTV) in both BD = 0 experiments. It seems as if the model 'trades' break deviations (BD) for BrTV.

Table 5.8: BD experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
BD	8	0.3	0.2	1	0	rw	0	0	1	62	0.9
	8	0.3	0.2	0	0	rw	0	0	1	62	0.9
	8	0.5	0.2	1	0	rw	0	0	1	62	0.9
	8	0.5	0.2	0	0	rw	0	0	1	62	0.9

Table 5.9: BD experimental results

BD	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
1	0.3	42%	8838	5095	87	30%	19	30	53	26	7
0	0.3	38%	8488	5276	83	30%	*18*	*66*	0	28	5
1	0.5	54%	10253	4757	101	50%	18	27	46	41	16
0	0.5	50%	9965	4981	98	50%	24	58	0	42	15

Use Therapist Once (UTO)

Experiment MTC = 8, UTO = 0 and ELF = 0.5 can again be copied from the PTAT category. By comparing the two experiments, we observe that using every therapist hurts the solution quality. The objective value and the corresponding performance indicators have drastically increased. Also, we observe that the LP has increased just slightly. We hypothesize that by forcing the model to use every therapist at least once, the solver generates an initial solution that satisfies the UTO restriction, but is worse than the initial solution found without the restriction. Therefore, the convergence of the experiment with UTO = 1 takes longer. The additional constraint is introduced in Equations 52. and 53..

Table 5.10: UTO experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
UTO	8	0.5	0.2	1	0	rw	0	0	1	62	0.9
	8	0.5	0.2	1	1	rw	0	0	1	62	0.9

Table 5.11: UTO experimental results

UTO	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
0	0.5	54%	10253	4757	101	50%	18	27	46	41	16
1	0.5	66%	14234	4848	140	50%	26	85	86	51	6

Constraints 49 and 50: Use all therapists, with at least one slot of availability, once. First, we introduce an additional binary variable: Therapist Once Available (t) (toa_t). Also, we introduce a sufficiently large parameter: M.

$$\sum_{d,h} TA_{t,d,h} \leq toa_t \cdot M \tag{52.}$$

$$\sum_{s,c,d,h} pt_{t,s,c,d,h} \geq toa_t \tag{53.}$$

Therapist Availability (TA)

Experiments in this category use the toy problem, as introduced in Section 5.2. The TA = tp experiment is the baseline for the comparison of results. We observe that increasing the available time slots of one physio from either 64 to 80 (TA = 1), or from 16 to 32 (TA = 3), slightly increases the objective value. This is not as expected, because we allow the model more freedom in terms of available slots to plan appointments. We expect that this phenomenon can again be explained by the large optimality gap and increased solution space, which results in slower convergence and therefore a larger objective value. Note however that the differences are minor and can be caused by chance as well. By increasing the available time slots of three therapists (one of each specialty) from either 64 to 80 (TA = 2), or from 16 to 32 (TA = 4), drastically reduces the objective value. The reduction in the objective value is primarily caused by a decrease in LT (and BrTV). We expect ELF-moment to be planned more easily because the availability of three therapists from three specialties increases the possible moments that ELF-moments can be planned. This in turn enables the model to decrease the number of required therapists per class. The effect of increasing the capacity of a therapist with a relatively low availability is of greater impact than increasing the capacity of a therapist with a high availability. Note however that the difference is very small and can be caused by chance. Also, the results could have been different when we added slots of capacity on another day, or at another moment in the day. Moreover, the results could have been vastly different for any other combination of TA settings. Lastly, we observe that the impact of increasing the capacity for three therapists has a greater impact on the solution quality than increasing the capacity of just one therapist.

Table 5.12: TA experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
TA	6	0.5	0.2	1	0	tp	0	0	1	30	0.9
	6	0.5	0.2	1	0	1	0	0	1	30	0.9
	6	0.5	0.2	1	0	2	0	0	1	30	0.9
	6	0.5	0.2	1	0	3	0	0	1	30	0.9
	6	0.5	0.2	1	0	4	0	0	1	30	0.9

Table 5.13: TA experimental results

TA	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
tp	0.5	66%	10134	3457	99	50%	11	45	26	40	17
1	0.5	66%	10219	3481	101	50%	14	43	31	41	16
2	0.5	55%	7666	3436	76	50%	7	25	24	38	19
3	0.5	66%	10426	3550	103	50%	17	41	28	36	21
4	0.5	54%	7529	3434	75	50%	6	14	32	38	19

Link Therapist Class (LTC)

In this category, we also use the toy problem. For comparison, we copy the baseline toy problem experiment (LTC = 0). In LTC = 1, we keep ELF constant and assign one therapist of high availability (LTC = 1) to one class in unit A. In LTC = 2, we also keep ELF constant but assign a therapist with low availability (LTC = 2). In the last experiment, LTC = 3, link a therapist with low availability to two classes in unit A. We see very little impact on the objective value when linking one, or two, therapists in advance to a class. It seems as if more links should be assigned in advance to have a significant effect on the objective value. This seems logical, as the total number of linked therapists observed in this experiment category (and earlier experiments) varies around 100. Linking less than 1% of therapists in advance is expected to have little impact. Experiments LTC = 1 and LTC = 3 resulted in the same solution, as the mandatory links between classes and therapists from LTC = 3 were also present in the solution of LTC = 1.

Table 5.14: LTC experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
LTC	6	0.5	0.2	1	0	tp	0	0	1	30	0.9
	6	0.5	0.2	1	0	tp	1	0	1	30	0.9
	6	0.5	0.2	1	0	tp	2	0	1	30	0.9
	6	0.5	0.2	1	0	tp	3	0	1	30	0.9

Table 5.15: LTC experimental results

LTC	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
0	0.5	66%	10134	3457	99	50%	11	45	26	40	17
1	0.5	66%	10148	3457	99	50%	12	43	26	41	16
2	0.5	66%	10411	3488	102	50%	15	51	32	38	19
3	0.5	66%	10148	3457	99	50%	12	43	26	41	16

Gym, Animal care, Hydrotherapy (GAH)

Again we copy a relevant experiment (GAH = 0) from the PTAT category to allow easy comparison. By comparing experiments GAH = 0 and GAH = 1, we observe that randomly choosing moments for GAH yields a comparable, but slightly better, result to the current distribution of GAH over the days and classes. Evenly distributing GAH moments of classes over the week (GAH = 2) improves the solution quality in terms of a decrease in linked therapists. Although the optimality gap is still 42% and 39%, we cautiously conclude that the quality of the blueprint plan can be improved by altering the distribution of GAH moments over the week.

Table 5.16: GAH experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
GAH	8	0.3	0.2	1	0	rw	0	0	1	62	0.9
	8	0.3	0.2	1	0	rw	0	1	1	62	0.9
	8	0.3	0.2	1	0	rw	0	2	1	62	0.9

Table 5.17: GAH experimental results

GAH	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
0	0.3	42%	8838	5095	87	30%	19	30	53	26	7
1	0.3	42%	8736	5039	86	30%	20	31	38	29	4
2	0.3	39%	8230	4997	82	30%	29	18	47	27	6

Block Times (BT)

In this experiment category, we constrain the model by not allowing any therapy to be planned during dedicated block times. Note, however, that we still allow therapy to be planned during breaks of classes, as indicated by BrTV. Again we copy the two experiments from PTAT for reference (BT = 1). By not allowing any predefined block times to be violated at all, the objective value increases for both values of ELF (ELF = 0.3 and ELF = 0.5). Note that this increase is also visible in the value of the lower bound (LP), which indicates that the BT = 0 problems seem to be notably more difficult. We see that the increase in objective value and the lower bound is greater for a higher level of ELF. The model compensates for the decrease in available slots for therapy by increasing LT and BrTV. We also observe that the increase in objective value (and the lower bound) between ELF = 0.3 and ELF = 0.5 is greater for BT = 0, compared to BT = 1. We cautiously conclude (due to the high optimality gap) that planning a higher % of ELF-moments becomes increasingly more difficult if predefined block times can not be violated.

Table 5.18: BT experimental parameter settings

Subject	MTC	ELF	PTAT	BD	UTO	TA	LTC	GAH	BT	n(T)	Util
BT	8	0.3	0.2	1	0	rw	0	0	1	62	0.9
	8	0.3	0.2	1	0	rw	0	0	0	62	0.9
	8	0.5	0.2	1	0	rw	0	0	1	62	0.9
	8	0.5	0.2	1	0	rw	0	0	0	62	0.9

Table 5.19: BT experimental results

BT	ELF	Gap	MILP	LP	LT	PELF	BTV	BrTV	BD	ELF_Out	ELF_In
1	0.3	42%	8838	5095	87	30%	19	30	53	26	7
0	0.3	43%	10670	6102	106	30%	0	59	50	26	7
1	0.5	54%	10253	4757	101	50%	18	27	46	41	16
0	0.5	58%	13931	5831	138	50%	0	86	77	48	9

5.4 Convergence

As mentioned in the introduction of this chapter, every experiment is run for a duration of 28.000 seconds (around 8 hours). Figure 5.4 shows an example of the convergence of the objective value and the LP lower bound over time for experiment PTAT = 0.2 and ELF = 0.3, from the PTAT category. To be complete, we copied the parameter settings and experimental results of this experiment in Tables 5.20 and 5.21 respectively. The convergence graph of most experiments resembles a similar pattern as shown in Figure 5.4: the LP lower-bound doesn't increase much after an initial solution and the MILP objective value decreases gradually during the first 15.000 seconds (around 4 hours) and minimally afterwards. The optimality gap for the experiment in Figure 5.4 is around 42%, which is comparable to the optimality gaps found in other experiments. This relatively high optimality gap can be explained by the nature of the problem: almost exclusively integer variables and a huge solution space. As mentioned in the introduction of this chapter, the large optimality gap imposes us to be cautious with drawing conclusions from the earlier observed results. In the discussion, we will further explore the limitations of the modeling approach, the experimental approach and the experimental results.

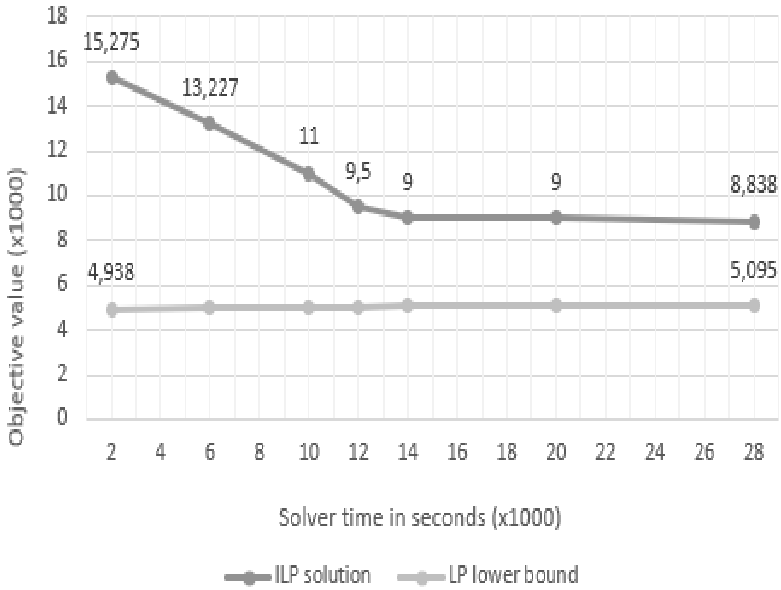

Figure 5.4: Example of convergence graph (experiment 18)

Table 5.20: PTAT experimental parameter settings

Subject	**MTC**	**ELF**	**PTAT**	**BD**	**UTO**	**TA**	**LTC**	**GAH**	**BT**	**n(T)**	**Util**
	8	0.3	0.2	1	0	rw	0	0	1	62	0.9

Table 5.21: PTAT experimental results

PTAT	**ELF**	**Gap**	**MILP**	**LP**	**LT**	**PELF**	**BTV**	**BrTV**	**BD**	**ELF_Out**	**ELF_In**
0.2	0.3	42%	8838	5095	87	30%	19	30	53	26	7

6 Discussion

In this section, we will go into more detail on the limitations of the modeling approach, the experimental approach and the experimental results. We are not able to compare individual results with previous research, as our case in combination with the parameter settings is too specific. Therefore we discuss general results and compare these with earlier research.

6.1 Limitations

Modeling approach

By comparing the model with previous research of for example Leeftink et al. (2019), Bikker et al. (2015) or van Oostrum et al. (2006), we see that our model is very detailed (many variables, many parameters and many constraints) to reflect the pediatric rehabilitation cases that we face. We think that every element of the model provides a necessary contribution to reflect the reality of the case. The model could have been presented more efficiently. For example, we could have created a set for the possible activities that every actor can undertake, such that constraints 9. to 13. can be modeled in one constraint. Introducing such a set also enables the user of the model to efficiently adjust the model to other settings, where for example ELF-moments are not necessary. We chose however not to do so, to improve readability. The model can construct a plan on a tactical level of control for regular therapy and ELF demand, given that products are already planned. To repeat briefly, a product is a fixed treatment procedure often consisting of several consecutive appointments between multiple therapists and multiple patients. As products consume the majority of total therapist capacity, a model that can plan products might be more valuable. During the course of this research, however, the organization was not ready to support the construction of such a model (i.e. there is no spare capacity in terms of therapist availability for therapists to be involved in such a project). In Section 6.2 we further discuss the requirements for constructing such a model.

Moreover, the model is based on several assumptions, which can have a negative impact on the solution.

1. We aim primarily on reducing the linked number of therapists, as agreed upon with the advisory group. This might however be a mistake. The main reason to focus on this objective is that classes experience too many stimuli when many therapists are linked. If we can solve the stimuli problem of the classes on a conceptual level instead, this will allow us to focus on other objectives like primarily reducing block time violations.

2. Products and block times are not planned by the current model. We implemented the functionality to plan block times, but have not yet been able to utilize this functionality in experiments due to time constraints. If block times can be scheduled at well-planned moments (e.g. during ELF-moments), this will positively influence the solution. Products use a large part of therapists' capacity. Allowing the model to plan products will therefore hugely influence the solution quality.

3. The distribution of patients over classes is predetermined. This has a very constraining effect on the solution. Evenly distributing patient demand over classes might prove to be very beneficial.

4. Physicians, and their corresponding problems, are untouched. Because the focus of the research was scoped to regular therapy, this excluded the agendas of physicians.
5. Identified problems of patients are not obtained from interviews with patients but via interviews with teachers and therapists. It might be valuable to talk to them (and/or to their caretakers) directly.
6. The model is very sensitive to new input data, as all slack variables are removed to reduce computation time.

Feasibility, verification and validation

Because we drastically reduced solving time, the model is very sensitive to the input data and can easily become infeasible when new data is inserted or slightly changed. We recommend temporarily re-introducing slack variables when new data is presented and taking a step-by-step approach to remove the slack variables to determine where/why the model becomes infeasible if it becomes infeasible. Another approach to counter the infeasibility is to first decrease demand and slowly increase demand until the model becomes infeasible.

We found no limitations in our verification process. Due to our continuous testing and improving cycle on low dimensional data we can completely verify the functioning of our model.

It is possible that the operational plan, corresponding to the generated tactical plans, doesn't exist in reality. We introduced several measures to ensure a feasible translation from a tactical plan to an operational plan, but we can never be 100% sure (only if we increase PTAT to 100%, but this issues infeasibility). Another option is to introduce the PTAT parameter with an index of p (i.e. using individual PTAT values on a patient level). In Section 6.2 we propose measures to increase the robustness of the tactical plan.

Experimental approach

The size of the problem (and the complexity of the model) limited us in the number of experiments that could be performed within the duration of the research. The introduction of the managerial questions enabled us to focus our experiments on answering practical questions that could improve the operational management of the blueprint planning in the pediatric rehabilitation department. By keeping some parameters constant and changing others, we were able to generate practical insights.
Experimentation was a cumbersome, not automated process. This was caused mainly by limited knowledge of AIMMS. We requested additional time from experts, both at the UT and Rhythm, but no additional budget (and time) was available. Therefore, after every experiment, we needed to manually copy the results, per decision variable, to a dedicated Excel sheet. Moreover, we implemented a VBA script to translate the output of the model to a more readable visual format, while AIMMS is probably able to generate a Gantt chart-like output that visualizes the output of the model automatically.

Experimental results

The observed results of the individual experiments are already discussed in Chapter 5. In this subsection, we primarily focus on the limitations of the experiment results due to the high optimality gaps found in the individual experiments. Ideally one would like to reduce the optimality gap to at least below 5%, as this will allow us to formulate conclusions with a high level of certainty. In other words, with a small optimality gap, only small changes to the solution are still possible. Therefore, the results are most likely comparable to the results of the optimal solution, given the parameter settings, and conclusions can be formulated boldly. In our case (high optimality gap), we need to be cautious in our interpretation of the experimental results, because the found solution can differ significantly from the optimal solution. Although the conclusions that we draw from our experimental results can still provide guidelines on how to improve the blueprint plan, they are not necessarily optimal guidelines. Therefore, we formulate our conclusions based on the experimental results cautiously in Chapter 8.

Moreover, members of the advisory group expected the required number of MTC to be lower and the number of % ELF-demand that we were able to plan to be higher. This indicates that therapists and planners are not fully aware of the scope of the challenge that they face every year. Here, we refer to challenge as the process of finding a blueprint plan that satisfies all actors and constraints.

6.2 Future research

In this section, we structure our suggestions for future research per subject. The different subjects and a brief description of the content that can be expected are summarized in the following bullet list:

- **Optimality gap.**
  We provide ideas for reducing the optimality gap by e.g. reducing solver time.
- **Model additions.**
  Introduces ideas to change existing constraints to extend the presented model.
- **Complementary models.**
  Provides suggestions for the construction of complementary models that work in cohesion with the proposed model.
- **Conceptual ideas.**
  In this subsection, we propose conceptual thoughts which can be investigated in future research.
- **Experiments**.
  Provides additional experiments that can be conducted to gain further insights.

Optimality gap

To reduce the optimality gap and allow the stronger formulation of conclusions we provide the following ideas:

- Use heuristics that are tested on similar combinatorial optimization problems. Examples are heuristics that address the nurse scheduling problem or machine scheduling problems (Gademann and Schutten, 2002, Jafari and Salmasi, 2015). Just as proposed in Jafari and Salmasi (2015), and concluded from Chapter 3, it might be wise to split the problem into phases. Wong et al. (2014) for example constructs an initial feasible solution by solving the (M)ILP for hard constraints and using a local search algorithm in the second phase. One could also try new methods. For example, to assign capacity of therapists to total demand per class, per specialty, ignoring the time and day dimensions. This approach is comparable to Rough Cut Capacity Planning (RCCP), where the capacity of machines is assigned to complete jobs (demand). Given the resulting distribution of therapists over classes, we can initiate a second phase that generates a blueprint plan. Note that both phases use exact methods, but together present a heuristic approach. Another option is to solve the blueprint plan for every unit (in serie).

- Let the solver run the exact approach, as proposed in this research, for a longer time. It might be that a drastic improvement in the objective will occur by doubling the run time. As the problem is categorized as offline, the long run duration will arguably not be a problem during practical implementation.

Model additions

Currently, the GAH moments, block times and absent hours of therapists are predefined and impose major restrictions. In future research, we advise incorporating the planning of GAH moments, block times, and absent hours of therapists to increase the flexibility of the model to find potent solutions. Instead of viewing the non-working days of therapists as a given, we should start to see them as a decision variable. The functionality of planning block times is already present. The planning of products is discussed in complementary models, as this is deemed a huge addition.

The MTC and PTAT parameters are currently modeled as a single integer and continuous value respectively. In future research, one can experiment by adding indices to the parameters. For example, use an individual PTAT per patient. Or, use an MTC per class. Both additions make the model more flexible, increasing the chance of increasing the solution quality.

In the current model, the planning of unit breaks is very constrained. For example, it is predetermined which classes can go outside together and which schoolyard they will use. In future research, it might be valuable to obtain the planning constraints behind these decisions such that the model is able to decide which class is best suited to play outside with another class, at a given moment, in a given schoolyard.

Currently, the model is a.o stimulated to reduce the total number of block time violations. To do so, the model might aggregate block time violations on a certain class. This would be very frustrating for the teacher(s) and therapists linked to that particular class. In future research it is possible to constrain the number of block time violations allowed per class, incentifying the model to evenly distribute the block time violations over classes.

We can also constrain the model by only allowing break deviations for therapists when at least two (or more) therapists enjoy the same break deviation. This ensures that a therapist will never have to take a break alone.

Lastly, we propose an addition in the form of counting the spread of physical activities (including GAH and physiotherapy) over the week. The wish exists to spread the physical load for patients as much as possible over the days of the week. Besides the constraint that ensures physiotherapy may not be provided on days that GAH is provided, we can add an incentive to evenly distribute physiotherapy of a class over the week. This in turn allows an easier translation of the tactical plan to an operational plan that satisfies physical load distribution on a patient level.

Complementary models

Complementary models can be one of the following:

- As mentioned earlier in Section 6.1, the development of a complementary model that is able to plan products would be very valuable because the bulk of total therapist capacity is used for products. Developing such a model would require the organization to dedicate several hours of capacity of (at least) one experienced therapist per week to the project. The therapist would support the developer of the model by a.o. explaining planning restrictions and supplying input parameters. Finding a method to combine a model that is able to construct a plan for products with a model such as presented in this research would be ideal for the pediatric rehabilitation department. One could also try to add the functionality of adding products to the model presented in this research and implement a heuristic approach to reduce the optimality gap.

- Construct a forecasting model that is able to predict the inflow and outflow of patients in combination with the intensity of treatment per class. The outcome of the forecasting model, or thorough data analysis of historic data, can be used to find suitable moments during a school year to resolve the presented model. The outcome of the forecast can also be used as an input parameter in a stochastic MILP. However, convergence will be even slower and we doubt whether introducing stochasticity to this case will yield a better blueprint plan.
- Currently, the distribution of children over classes is a given setting. This greatly constrains the model, and therefore greatly influences the resulting plans. Allowing the model to distribute children purposefully might yield a huge improvement in the solution quality. An example is to distribute demand evenly over classes (in the same unit), or aggregate children with similar available time periods. Before implementing this functionality, one might experiment with different distributions of children over classes to analyze the impact of changing this parameter.
- It might be valuable to construct an incremental improvement algorithm that can change an existing plan during a school year. When input data changes due to for example intensification of therapy, therapists going on maternity leave, or someone becoming ill for a long duration, we want to change the plan accordingly. However, we do not want a completely new plan, as this will upset (primarily) the children. Therefore, we need to design a model that makes as few changes as possible to an existing plan. The objective needs to be changed to accommodate a penalty for every change in the plan that is used as input. In practice, the input plan would be the plan drafted at the start of a school year.
- Construct a model that is able to translate a tactical plan into an operational plan. By making very few adjustments to the tactical model presented in this research, one is able to construct an operational plan. We only need to translate the class demand to individual patient demand. Instead of planning therapy sessions for classes, we plan therapy per individual patient. The objective, counting the number of linked therapists per class, can remain the same. The model that constructs an operational plan can use the input of the tactical plan as boundaries (e.g. the distribution of therapists over class). The operational plan can assist, or guide, the group of therapists in finding a satisfying operational plan. Note, we still require the tactical plan, as this provides us with flexibility when operation fluctuations occur during the course of the school year. Remember, the tactical plan enables planners to solve operational fluctuations more easily.

Additional large extensions to the model might be to automate the collection of input data or design a dashboard to measure the performance of the realized tactical/operation plan. The automation of input data can be achieved by designing software that is able to extract data from the electronic patient dossier. To automate this process, a change in culture in terms of accurate and up-to-date documentation of treatment plans by the physicians is necessary, as the entire plan will be based on the data provided by the physicians. The dashboard can be used to track the performance of the realized operational plan. For example, the progress of diagnosis-treatment combinations (dbc's), per patient can be displayed. Teams of therapists can use this dashboard to change their operational treatment plan and increase revenue on patient level.

Conceptual ideas

Currently, we introduce a tactical model that assigns therapists to classes. The result is a more flexible, more robust plan compared to an operational plan where we link therapists to individual patients. In essence, assigning therapists to classes (as we do in this research) can be viewed as a risk-pooling effect, as the absence of a child can be countered by treating another available child. Also, a group of therapists linked to a class enjoys a certain degree of autonomy. We introduce a conceptual idea that builds on the principle of risk-pooling. Instead of linking therapists to classes, we suggest looking into the possibility of creating groups of therapists responsible to treat an entire Unit. In this manner, we increase the risk-pooling effect and provide therapists with even more flexibility and ownership over their agendas. To accommodate this change, we can introduce a variable that stores the number of linked therapists to a unit.

Experiments

Currently, block times are an input parameter. In 6.2 we coined the possibility to extend the model to view block times as a variable. Before implementing such changes one might conduct similar experiments as introduced in the GAH experiment category. By conducting similar experiments, we may identify quick wins in block time distributions of moments in the week. For example, conduct an experiment in which block times of all classes are scheduled at the same time. This might cause ELF-moments to be planned more easily. If every class has a block time at the same time, say 9:30, then this creates a very easy moment for all therapists to have an ELF-moment. Therapists will then even be able to choose with whom to conduct an ELF-moment. If a therapist is not able to attend an ELF-moment during such centralized moment, administrative work or IDR can be executed.

Currently, the LTC experiments are not conducted in real-world settings. For future research, it might be valuable to conduct LTC experiments with the real-world preferences of therapists. This will provide more insights into the effects of the LTC parameter.

Continue parameter tuning in the objective function. Currently, we inquire a very low penalty for violating block times. One could argue that preventing several block time violations is worth one extra linked therapist (i.e. by linking an extra therapist, we are able to prevent several block time violations).

7 Implementation

This chapter focuses on practical recommendations to implement the model in the SMK. Moreover, we discuss the possibilities to adapt the model for future research and introduce potential uses of the model in other organizations and other contexts. Section 7.1 illustrates our strategic vision for the pediatric rehabilitation planning department on a conceptual level. We primarily go into detail about the idea behind a tactical plan.

7.1 Conceptual implementation

We advise the organisation to integrate a tactical level of control in the planning procedures. Before sharing the benefits of introducing a tactical plan, we share our vision on the matter on a conceptual level. Lastly, we share the requirement for implementation.

We envision self-managing teams of therapists per class. These teams consist of three to MTC number of therapists. One therapist can be assigned to multiple teams, as one therapist can provide therapy for multiple classes. Every team is responsible to satisfy the demand for a given class and is self-sufficient in translating the provided tactical plan (whether it be constructed by a model or manually) to an operational plan. This includes assigning children per therapist and deciding for every ELF-moment which children will be discussed. The team is free in changing their operational plan as they see fit every week, as long as the teacher agrees with the changes and the tactical plan is not violated. Every team assigns a lead therapist who is responsible for external communication with e.g. the teacher and to settle any internal debates.

For therapists, the tactical plan can help to increase the feeling of ownership for therapists, reduce the required communication between therapists and planners and enables therapists to even their workload over weeks. For planners, this will reduce the number of orders that are received per week, it will reduce the number of conflicts and will reduce the number of appointments required to reschedule. For children, the tactical plan will improve the attunement on a daily level, as therapists can deviate from their initial planning whenever a child happens to require rest instead of therapy at that specific moment.

To implement a tactical level of control, we need to settle on the following: In short, therapists will gain freedom and power over their own agenda, but with power comes responsibility. In this case, responsibility comes in the way of keeping an internal administration (for example keeping track of the number of times a child receives therapy versus the demanded amount). Moreover, therapists are required to feel responsible for the treatment of the entire class, not only for their own patients in the class.

7.2 Practical implementation plan

There will be three main users of the model: an integral capacity consultant (ICC), a tactical planner and the therapists. The users of the model will be the integral capacity manager (ICC). This is essential because the model is still a prototype, very sensitive to new input data and the user interface is still default AIMMS. We envision the following steps to be taken every school year:

1. The tactical planner collects input data in the format discussed with the ICC.

We envision the tactical planner to be responsible to collect input data in the organization. This can best be done in the last month before the start of the summer holiday, as we want the latest data available. The planner is responsible to collect the data in the format agreed upon with the ICC.

2. The ICC sets parameter settings of the objective (and formulates a shortlist of experiments if required).

The ICC is required to collect parameter settings for the goal function. It is important that every strategic objective and all actors are represented in the goal function. A shortlist of parameter combinations (around three combinations) is a possible result of this step. The combinations can be used as input for experiments, such that the solution best fitting the requirements can be chosen afterwards.

3. ICC processes input data and feeds input data to the model.

After collecting the input data, setting the parameters and discussing possible experiments, the input data is processed by the ICC and fed to the model. Within a week the ICC will have a shortlist of (around three) blueprint plans as potential solutions.

4. Therapists, the tactical planner and the ICC meet to discuss the output of the model and chose a tactical plan that will be implemented in the coming school year.

The planner and ICC will discuss the outcomes with the therapists to agree upon one plan that will be implemented. The tactical plan that is chosen will be entered into Hix, or any other scheduling software.

5. Therapists, independent from the planners, translate the tactical plan to an operational plan.

After the tactical plan is entered in Hix, the therapists can start to translate the tactical plan to an operational plan. The translation process of the tactical plan to an operational plan needs to be done before the start of the new school year. We estimate that one group of therapists (therapists linked to one class) will require at most an hour for the translation process, as every tactical slot is chosen with keeping the translation to an operational plan in mind. The therapists will only have to divide the children over the linked therapists and fill the tactical slots with operational appointments. If however, the tactical plan proves to be infeasible in the translation process, the therapists are expected to inform the ICC to find a solution.

6. Adjusting the tactical plan

During the school year, the input data will change over time due to operational fluctuations in demand and capacity. The tactical planner is responsible to keep track of the changes in input data and should notify the ICC and therapists whenever a to-be-defined threshold in the degree of change in input data is reached. The therapists and ICC should verify that the threshold is exceeded and that the wish for an altered tactical plan exists. The current input data can be used in an altered version of the model which has the objective to improve the initial plan by changing as little as possible, given the new situation. We estimate the threshold of change in input data to be reached around January (the half-year mark of the school year), as before the Christmas holiday a lot of operational changes still occur and no definitive changes in input data can be established.

7.3 Application of the model

This section is written for the ICC. The section explains the usage of the model for application in practice. We explain the format of the input data sheet and the way the parameters, decision variables and constraints are structured in AIMMS.

Input data

The input data is spread over two mediums: the accompanied Excel file and the AIMMs model itself. Large rows of input data are loaded via the Excel file. Small parameters in terms of dimension size can be adjusted in AIMMS. Table 7.1 summarizes the parameters that can be set in the Excel file. All input parameters of the Excel sheet are binary, except 't', which holds integer values of capacity. The sheets in the file are structured according to the indices that are present per parameter. For example, sheet 'p,c' holds binary information regarding the patients registered per class.

Table 7.1: Input sheets description

Sheetname **Input sheet**	**AIMMS format sheet**	**Description**
Indices	-	Indices used in sets
p,c	1_(p,c)	Patient (p) is registered in class (c)
p,d,h,	2_(p,d,h,)	Availability of patient (p) on days (d), at time period (h)
t,s	3_(t,s)	Skills (s) of therapist (t)
t	4_(t)	Total capacity of therapist (t)
c,s	5_(c,s)	Demand of class (c) for specialty (s)
t,c	6_(t,c)	Pre-linked therapist (t) to class (c)
t,d,h	7_(t,d,h)	Availability of therapist (t) on day (d), at time period (h)
t,d	8_(t,d)_Small 8_(t,d)_Large	Breakrequirement of therapist (t) on day (d) for both small and large breaks
c,d,h	9_(c,d,h)	Availability of class (c) on day (d), at time period (h)
c,d	10_(c,d)	GAH moments for class (c) on day (d)

AIMMS

The parameters set in AIMMS can be found in the declarations: 'Parameters to set' and Objective weights'. In 'Parameters to set', the user can for example change the continuous value of the PTAT parameter. In the declaration 'Objective weights' the user can adjust the continuous parameters used as weights in the goal function.

In AIMMS, all parameters, decision variables and constraints bear the same name as presented in Chapter 4 and are provided with comments that describe their definition.

The declaration sections speak for themselves. For example, the section 'ELF-constraints' hold the constraints relevant for planning ELF-moments and the section 'Excel read' in combination with the procedure 'Read Excel' are responsible for reading the input data from the Excel file. The declaration 'Subsets' contains two sets. One set holds a selection of constraints, the other holds a selection of decision variables that can be used to solve the model using a subset of constraints or variables.

7.4 Data collection tools

During this research, several VBA tools are designed to more easily collect and structure data. The following tools and applications are designed:

1. Aggregate demand: this tool aggregates patient demand per class for both therapy, IDR and ELF. Demand is documented per patient and needs to be translated to demand per class, which in turn can be used by the model to construct a tactical plan. New patients, with corresponding patient demand, can be pasted to the relevant sheet and the code can be run to generate class demand.
2. Translate from Word: translate Word files that contain the availability per therapist to data formats. If for any reason the SMK decides to keep documenting availability in tens of Word files, these VBA scripts can translate the relevant data to a data format in Excel.
3. Availability heatmap: this tool can be used to generate heatmaps of availability for therapists, per specialty, and patients. The heatmaps can be used for example as an insight to spread the availability of therapists more evenly over the week. Again, new input can be pasted and output can be generated accordingly.

8 Conclusions and Recommendations

In this chapter, we draw conclusions from the experimental results in Section 8.1 and we enumerate our recommendations for improvement of the pediatric rehabilitation department planning procedures of the St. Maartenskliniek in Section 8.2. We end the chapter by reflecting on our contribution to research and our contribution to practice in Sections 8.3 and 8.4 respectively.

8.1 Conclusions

We summarize the conclusions we can draw for the experimental results in a list and state the subject of the insight in bold. Note that due to the large optimality gaps observed in the results of the experiments some conclusions are cautiously formulated.

- **General**. It is not possible to satisfy all ELF-demand in combination with satisfying all therapy demand, given the current availability and MTC constraint. From the comparison of the plan generated by the model and the plan constructed by labor (performed in Chapter 5 and discussed in 6, we can not draw strong conclusions, as the plans are too distinct. We can only comment that the model is very good at finding ELF-moments with three participating therapists, but lacks the functionality to plan residual ELF-moments with two participating therapists. The plan constructed by humans performs worse in terms of linked therapists and schedule approximately 90% of all ELF-demand with two participating therapists. However, the manually drafted plan is a complete, functioning plan whereas the plans generated by the model still require some attention before they can be implemented.
- **Maximum therapist class.** The MTC parameter can drastically cut down on the computational time required to converge, as the solution space is greatly reduced. At least one class is required to have at least eight therapists linked to satisfy 50% of ELF-demand. Keeping the large optimality gap in mind, it seems as if 30% of ELF-demand can be planned without notably increasing the number of linked therapists.
- **PTAT**. The PTAT parameter is a very constraining parameter as it restricts the model on patient-level availability. Whenever PTAT increases, the number of available slots per class drastically decreases. This in turn makes the model harder to solve, as the same demand needs to be planned in a limiting number of slots, increasing the required number of linked therapists. From the parameter analysis in Section 5.2 and the experiments in Section 5.3, we conclude that a PTAT between 0.2 and 0.3 provides a balance between robustness and feasibility.
- **Break deviations of therapists.** It seems as if allowing break deviations of therapists doesn't greatly impact the number of linked therapists but can decrease the number of violated block times. The model seems to 'trade' an increase in break deviations for a decrease in block time violations.
- **Block time violation.** Not allowing any block times to be violated, seems to notably increases the difficulty of the problem. The model compensates the decrease in flexibility mostly by increasing the number of linked therapists but also increases the number of break deviations (this coincides with the previous bullet point).
- **Gym, Animal care and Hydrotherapy (GAH)**. The moments for GAH seem

to slightly reduce the number of required linked therapists (around -5%).

- **Using every therapist.** It is not necessary to use every therapist in the system to satisfy therapy demand. Including every therapist in the plan can increase the objective value.
- **Therapist availability.** We can not formulate a strong conclusion on the effect of increasing the capacity of one therapist. However, when we increase the capacity of three therapists, divided over three specialties, it seems to drastically improve the quality of the solution in terms of linked therapists.
- **Linking therapists in advance**. Linking a small percentage of therapists in advance has limited influence on the objective value. No conclusions can be drawn on the impact of assigning a higher number of classes in advance, as these experiments were not conducted.

8.2 Recommendations

In this section, we reflect on the research and provide the managers of the organization with practical recommendations to improve the planning performance in the pediatric rehabilitation department. To guide our recommendations we use the identified problems in Chapter 2.

- **Objectives in the year plan.** We recommend the organization to make use of the identified strategic pillars, KPIs and problems per actor in decision-making on every level of control. Before making a decision, the question: 'What impact will this decision have on all five strategic objectives?' will greatly improve the balance between the performance of the system and the well-being and happiness of patients and employees. The use of this tool can be applied in constructing the blueprint plan by clearly identifying needs, or goals, per actor. For example, one could argue to decrease the number of required block times, as this increases the model flexibility and in turn increases the solution quality (therapist point of view). But one could also argue to decrease the number of ELF-moments, as this also increases model flexibility and in turn increases the solution quality (teachers' point of view). The goal of the rehabilitation turtle is to accommodate the insight that pediatric rehabilitation planning requires a five-perspective view on every assumption and decision.
- **Tactical versus operational plan.** We advise the organization to integrate a tactical level of control in the planning procedures. We structure this recommendation by sharing our vision on a conceptual level and provide insights into the added value per actor.

  We envision self-managing teams of therapists per class. These teams consist of three to MTC number of therapists. One therapist can be assigned to multiple teams, as one therapist can provide therapy for multiple classes. Every team is responsible to satisfy the demand for a given class and is self-sufficient in translating the provided tactical plan (whether it be constructed by a model or manually) to an operational plan. This includes assigning children per therapist and deciding for every ELF-moment which children will be discussed. The team is free in changing their operational plan as they see fit every week, as long as the teacher agrees with the changes and the tactical plan is not violated. Every team assigns a lead therapist who is responsible for external communication with e.g. the teacher and to settle any internal debates.

  For therapists, the tactical plan can help to increase the feeling of ownership, reduce the required communication between therapists and planners and enables therapists to even their workload over weeks. For planners, this will reduce the number of orders that are received per week, it will reduce the number of conflicts and will reduce the number of appointments required to reschedule. For children, the tactical plan will improve the attunement on a daily level, as therapists can deviate from their initial planning whenever a child happens to require rest instead of therapy at that specific moment.

- **Computational support.** We recommend the hospital to make use of an automated planning tool (possibly the proposed model from this research), as this will enable management to better adhere to the strategic weights divided over the five pillars. Although the model seems and feels promising, we recommend implementing the model with care. Use the model as a support tool when drawing up the annual plan, but don't rely on it blindly to generate a fully functioning tactical plan for the upcoming year. It is still a prototype.
- **KPIs and strategic pillars.** We recommend constructing a dashboard that shows the realized operational performance of the pediatric rehabilitation plan. The performance of realization can be compared to the intended performance and performance of the tactical plan. By analyzing the performance of the realized plan, we can start a continuous improvement cycle to further improve the planning procedures. The identified KPIs and the strategic objectives from Chapter 2 can be used as a basis for future development.
- **Quick wins from the experimental results.**
  - **ELF-moments.** Re-evaluate the worth of ELF-moments. The current ELF-demand in combination with the demand of regular therapy, given the availability of therapists is infeasible. The main takeaway is that currently, the total demand for ELF-moments is too large. From experimental results, we concluded that ELF-moments are very constraining appointments due to their multi-disciplinary setting. It is worth re-evaluating which child receives an ELF-moment and who doesn't. Another option is to group the discussion of multiple patients during one ELF-moment, satisfying ELF-demand of e.g. three patients in one ELF-moments.
  - **GAH.** Try to influence the distribution of GAH-moments over the week. Evenly distributing GAH-moments of classes over the week seems to increase the quality of the blueprint plan in terms of required linked therapists.
- **Data collection for the blueprint plan.** The data collection phase of the blueprint construction process still requires a lot of time from the tactical planners. We advise investing in automating this process by implementing data extraction software to read the available data from the centralized electronic patient record system (Hix), instead of manually collecting and retyping the data. This will be a relatively low investment for a high reward, as a lot of capacity of planners will be saved every year and the data is easily available in Hix for data engineers. Whenever we chose this course of action, however, we need to keep in mind that the data in Hix needs to be accurate and up to date. Currently, this is not always the case. Especially physicians will need to develop a culture of systematically updating the patient files in Hix. Also, planners are required to coordinate the use of appointment codes. Appointment codes are characteristics of appointments by which a data analyst can recognize a certain appointment.
- **Validation cycles.** We strongly recommend the organization to continue performing

validation cycles of the model. The model is a proof of concept and validated on several aspects of reality, but further validation is required to safely use the model in practice.

8.3 Contribution to research

Most literature concerning optimization in healthcare is focused on subjects with high costs, such as the operating theatre, but little research has been conducted on multi-disciplinary blueprint settings. Moreover, a lot of research in healthcare is focused on the operational level of control where individual appointments between a caregiver and a patient are scheduled. The tactical level of control, in combination with the robustness constraints, has not been introduced in the body of literature concerning healthcare optimization settings as of yet. The model uses the principles of machine scheduling and combines this with a time period dimension. The result is a tactical weekly plan that provides flexibility on an operational level. This research applies the concepts of levels of control in healthcare, first introduced by Hans et al. (2012), and applies it in a practical setting. The synergy between the strategic, tactical and operational levels of control introduced in this research can be used as a guideline for other researchers and consultants to apply to different (healthcare) settings.

The model can be scaled to other organizations with a similar problem case. For example, to other pediatric rehabilitation centers (in the Netherlands). Via the lead therapist, we obtained information about the methods of planning used in other pediatric rehabilitation centers in the Netherlands. The settings at the other organizations are almost identical and differ only in their input parameters and weight distribution of the objective. Small adjustments in for example break times are easily implemented.

The proposed model is also broadly applicable to other settings. For example to assist universities to construct the blueprint for a module (or a semester) in assigning lecturers to rooms. We also expect the model to function well in schools where many children compete professionally in sports. The school, and the children, have to integrate moments for sport as efficiently as possible with their roster for school.

It is also possible to isolate the constraints responsible for scheduling the ELF-moments and implement the functionality to other blueprint scheduling problems where multiple actors are required to meet with one another. For example to support companies to organize multi-disciplinary meetings between certain professionals. The model could also help to schedule speed dates in an application process where multiple candidates need to visit multiple groups of interviewers in a serie.

8.4 Contribution to practice

Before the start of this research, there were no clear strategic objectives in the pediatric rehabilitation planning department of the St. Maartenskliniek and there was no tactical level of control. Yearly, an operational plan was constructed with much effort. A plan that dissatisfied many involved stakeholders. In this research we propose a shared strategic vision for the cooperation between stakeholders in the pediatric rehabilitation department, the planning department and the school. We introduce a currently non-existent tactical level of control in the shape of a model that generates a tactical blueprint plan. The tactical model functions as the translation tool between strategic objectives and operational performance. Robustness in the tactical plan ensures easy translation from a tactical plan to an operational plan. The model, in contrast to human ability, can construct a plan in one night and can thus be utilized at the last moment in the year to construct a plan if deemed necessary or desirable. This allows the organization to use the most recent input data. Due to the tactical level of the plan, we expect planners to be burdened with less rescheduling of appointments, fewer conflicts and less time lost in communications with therapists. Therapists will enjoy more ownership over their agenda and a decrease in planning mistakes caused by planners. The teacher will enjoy fewer linked therapists. The children will feel little change, maybe a slight decrease in irregularity of treatment.

The approach used in this research can function as a road map to synergize strategic, tactical and operational levels of control in other projects (e.g. in other departments of the SMK) where P&S processes need to be improved. The model can be further developed into a mature service that can be scaled to other pediatric rehabilitation departments (in the Netherlands). Because the tactical plan needs to be generated at least once a year, Rhythm can provide the service as part of a yearly service contract that is easily scalable to a large number of customers. Rhythm can also apply the approach presented in this research to any new project concerning P&S processes.

Thank you for reading this thesis.

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