INTRODUCING BLOCK SCHEDULING IN A HOME CARE ENVIRONMENT AT TWB

C.R.P. WEIBULL
S2478226
Industrial Engineering and Management
University of Twente

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Rasmus Weibull

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AUTHOR(S)
Rasmus Weibull, s2478226

SUPERVISORS
Daniela Guericke (first supervisor)
Gréanne Leeftink (second supervisor)

EMAIL
c.r.p.weibull@student.utwente.nl

POSTAL ADDRESS
P.O. Box 217
7500 AE Enschede

WEBSITE
www.utwente.nl

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Management summary

This research has been conducted together with Thuiszorg West Brabant (TWB) in Roosendaal in the western Netherlands. TWB is a large home care organization serving an area in the region west Brabant. They offer various types of care to their clients, from regular care and help with for instance cleaning or showering, to more complicated care such as wound treatment.

PROBLEM DESCRIPTION

Currently, TWB makes use of varying shift lengths, which means that a nurse does not know exactly how long their shift will be until the day before the shift is to take place. This is not a good system from nurses' perspective, because it leads to much uncertainty with regards to how their work-day will look like. In order to improve this situation, TWB wants to investigate the possibility of introducing a block-schedule instead. In this report, a block schedule will refer to a shift of a specified length, where the nurses would be paid for the full length of the shift even if there are not enough appointments to fill it. To be able to introduce this type of changed scheduling, however, the original schedule might need to be adjusted, to be better suited for a block-schedule by minimizing the amount of over- and under capacity that it contains. This has resulted in the following main research question to be defined.

How can the capacity planning and scheduling at TWB be improved to allow the use of block scheduling?

METHOD

The scheduling situation at TWB is complex, because it consists of serval different levels of nurse qualifications, different teams, corresponding to geographic locations, as well as limitations on which days and times of a day an appointment is scheduled. All of these aspects are significant in the schedule, but only few of them are hard constraints. This means that there is much room to change the schedule to better fit with a block schedule. In this research, we develop a simulated annealing algorithm to investigate what performance a schedule can have if it is changed into a block schedule.

To create this block schedule, a simulated annealing heuristic algorithm was developed. This algorithm is able to take a current, existing schedule, and turn it into a block schedule, given certain costs for day mismatches, location mismatches, and qualification mismatches. The simulated annealing algorithm uses the move or swap operator to change the combination of day, team, and level parameters, at which an appointment is scheduled. This results in a new demand at this combination of parameters, which is evaluated. To do this evaluation, an LP model was designed, that is able to determine the optimal shift schedule given a certain demand for each part of the day.

RESULTS

The algorithm was hence able to compare an initial solution, which assumed that no appointments were moved from their original days, teams, or levels to the new schedule, where these movements were allowed. As can be seen in Figure 1, the allowed changes to the schedule did decrease the amount of over- and under capacity of the schedule, at least for some experimental settings. In experiment 2 and 3, more weight was given to the KPIs of over- and under capacity, which explains why these KPIs were more improved in these experiments. In experiment 1, barely any improvements were made, which suggests that for some weights, the initial solution is near-optimal. Hence, the algorithm is only able to improve the schedule if flexibility is allowed in terms of movements of appointments.

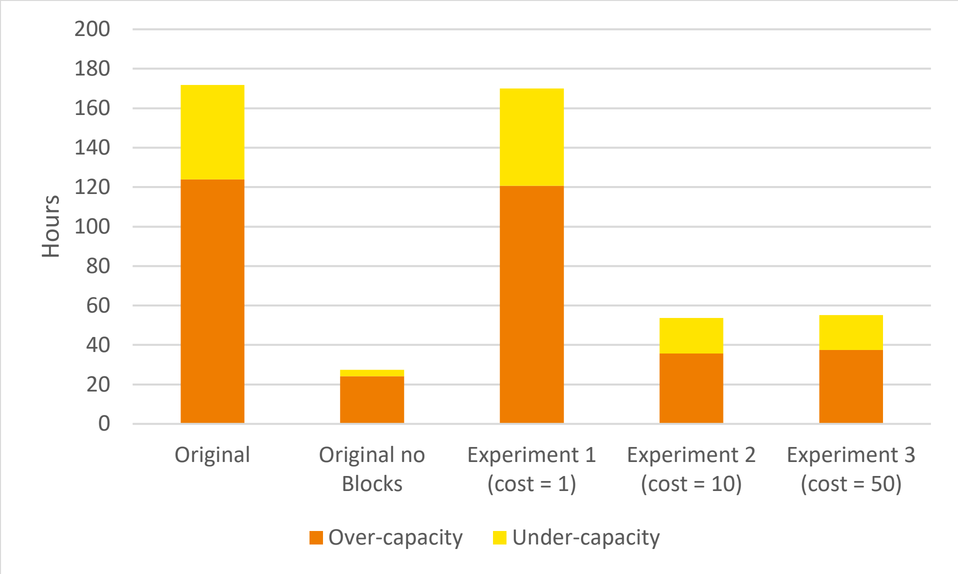

Figure 1. Over- and under capacity of the three experiments (average of 3 replications) compared with the original solution and the situation if block scheduling is not used.

From this graph, it can be seen that the simulated annealing algorithm was able to significantly improve the initial solution for some weights. For experiment 3, the algorithm led to a 60% improvement of the objective value. However, this resulted in a significantly changed schedule, as can be seen in Table 1. If a higher mismatch cost is chosen, a much smaller improvement was made to the schedule, but this also led to a smaller improvement of the objective function. Hence, the possibility to significantly improve the schedule is heavily dependent on the different cost parameters chosen.

Table 1. Results from the three experiments, translated back into hours and moves, and compared with the original solution.

	Run	Over-capacity (Hours)	Under-capacity (Hours)	Day Moves	Team Moves	Level Moves
Original	1	123.9	47.9	0	0	0
Original if no block scheduling is used	1	24.2	3.2	0	0	0
Experiment 1	1	123.9	47.9	0	0	0
	2	123.9	47.9	0	0	0
	3	114.3	52.2	15	8	0
Experiment 2	1	25.3	20.2	1435	1075	2635
	2	38.2	17.2	1447	1097	2558
	3	43.6	16.5	1421	1129	2481
Experiment 3	1	32.7	17.6	1444	1148	2646
	2	46.5	16.4	1440	1090	2604
	3	33.1	19.1	1451	1120	2649

CONCLUSION

In this research, a simulated annealing-based algorithm was developed to investigate the possibility of changing a schedule into a block-schedule, by allowing some movements of appointments between days, teams, and qualification level by which the appointments are served. This algorithm takes as input different cost parameters for over- and under capacity, as well as for the movements of appointments between days, teams, and levels. Given a certain schedule, it can then be used to determine how this schedule can be changed in order minimize over- and under capacity, and the closeness of the schedule to the initial schedule. As can be seen from the result section, this the algorithm shows that the over- and under capacity of the schedule can be significantly improved by allowing this type of changes. However, to achieve a large improvement, the schedule has to allow for quite large changes to the schedule. This research suggests that the introduction of this form of block scheduling is feasible, and that future research can investigate how it can practically be achieved.

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1. INTRODUCTION

This chapter introduces the research project and the problem at Thuiszorg West Brabant (TWB) that the research is intended to solve. Firstly, there is a general introduction to TWB and the project in section 1.1. Then, the problem identification and problem description will be addressed in section 1.2. From this, a research question will be defined in section 1.3, and the problem-solving approach to solve this research question will be addressed in section 1.4. In section 1.5, the research design will be addressed, and in section 1.6, the knowledge problems that have been derived from the research question will be discussed. In section 1.7, a discussion on the validity and reliability will be had, and finally section 1.8 will discuss the conclusions.

1.1 HOME CARE AT TWB

Thuiszorg West Brabant is a large home healthcare organization based in the city Roosendaal in the west of the Netherlands. TWB provides home care in the entire region of West Brabant; in the city of Roosendaal, as well as the cities Etten-Leur and Bergen op Zoom, and several smaller towns and areas in the region (TWB, n.d.). With around 2000 employees, TWB serves thousands of clients each day with different types of care, depending on the patients' need. The most common patients that TWB serve are elderly, or people in need of after-care after for instance a surgery. The care given by the employees of TWB allows these patients to stay and receive care at their home, instead of moving to for instance an elderly home or stay at the hospital. The employees of TWB perform a wide range of tasks for their patients, ranging from regular care and help, such as showering or cleaning, to more complicated tasks such as giving medicines or wound treatments. Several of the more complicated care require specific competences from the staff.

To differentiate between which employees are allowed to perform different types of care, TWB is organized in several qualifications, or levels. We will distinguish between six different levels at TWB. The lowest of these levels is the cleaning service, which is referred to as ADL. They primarily work with helping patients with tasks that do not require special competences, such as clothing, washing, and showering. Then, there is level 2, level 3, level 3IG, level 4, and the highest qualification level is level 5. The higher levels, level 3, or level 4, also include tasks that require higher competences. Someone with a certain level can also perform the tasks on the lower levels, which means that for instance a nurse working at level 4 is able to perform all the work on levels 3 and level 2 as well. The highest competence level is level 5, and nurses of this level are able to perform all work done at TWB.

Furthermore, TWB is organized in several different clusters, that have responsibility for a certain geographical area. Each cluster consists of around 40-70 employees, and is often further sub-divided into smaller teams, that again have the responsibility for a specific area within the cluster. Each cluster includes a full-time planner, and in many cases some part-time planners that also work as nurses. Thus, the scheduling for the different clusters is organized largely independently, with little communication between the clusters. Furthermore, due to differences in working culture and procedures, the staff often prefer to work within their own cluster. The schedulers generally schedule all working times and appointments for the levels 2 to 4. This is done with the support of a computer system by NEDAP, which allows them to drag-and-drop appointments in pre-existing routes, as well as define new routes if necessary. The NEDAP system does not give suggestions for when the appointments can be scheduled.

There are usually around 5-10 level 5 nurses in each cluster. These nurses have the highest level of competence, and have the competence needed to perform any task at TWB. They are relatively independently organized from the rest of the cluster, with one senior nurse who oversees the group. The level 5 nurses have a wide range of tasks. For instance, in addition to working with some of the care that requires very high competence, they also work with potential new patients for the initial two weeks, to be able assess whether the patient needs home care, and if so, what type of care is suitable.

1.2 PROBLEM DESCRIPTION

Currently, the length of a working day for nurses working at TWB depends on the number of appointments that are scheduled that day. For example, this means that even if a nurse wishes to work 8 hours on a day, they cannot do that if the appointments scheduled that day are only for 6 hours and 30 minutes. Then, the nurse can only work these 6 hours and 30 minutes that day, and only gets paid for 6 hours and 30 minutes. This means that the nurses have very little freedom to determine their working hours. If a nurse wants to work full-time, this often means that they need to work six days in a week, because the shifts they have during the weekdays are not filling the 36 hours required for a full-time working week. Furthermore, appointments are often rescheduled on short notice, which means that the length of a working shift can be adjusted as soon as one day before the shift takes place. This type of rescheduling of an appointment is known as a mutation. Most appointments at TWB are scheduled on a repeating weekly schedule, and for new appointments, there is usually sufficient time for the planners to anticipate them due to the two weeks of screening done by the level 5 nurses. Thus, the main source of variability in the schedule is from the different mutations that are caused by a client needing to move their appointment. Some of these are possible to anticipate, such as a planned hospital visit. Others are on shorter notice, sometimes as little as a day before the appointment. The mutations are often initiated by the client calling TWB to make the change. While many mutations, for instance an emergency hospital visit, are unavoidable, some are not necessary, for instance if they are caused by hairdresser appointments. If one or more mutations affect a shift, the length of it might be shortened or lengthened.

Many of the nurses are unhappy with this system, because they cannot choose how long they work in a day, and especially because they often do not know how long their working day will be, because of the mutations. To become a more attractive employer, TWB wants to change this system, by starting to use block-scheduling, which would mean that shifts of specified lengths; 4, 6, or 8 hours, are used. In this report, a block schedule will refer to a shift of a specified length, where the nurses would be paid for the full length of the shift even if there are not enough appointments to fill it. The number and types of shifts used on a certain day would be determined beforehand, so that the employees know exactly when and for how long they will work, regardless of the number of appointments that are scheduled in such shifts. This would also give the employees more freedom in choosing the length of shifts they work.

This change is intended to improve the working conditions at TWB, and hence make the company a more attractive employer. This is important both to ensure that TWB can keep their current staff and attract new employees. There is a world-wide nurse shortage (World Health Organization, 2020), and this shortage is also noticeable in the Netherlands, where the demand for home care is growing, much due to an aging population, while the number of nurses is decreasing (Waal et al., 2019). TWB also faces these challenges, which is one of the motivators to make the change to block scheduling Thus, becoming an attractive employer for current and future staff is important for TWB. Nevertheless, the change to block scheduling is not a simple change to make. The main challenge with this change is that TWB needs to predict how many employees, or shifts, should be scheduled each day with a higher accuracy, because the lengths of the shifts can no longer be adjusted if they are not filled or too many appointments are scheduled. Since TWB can no longer adjust the lengths of the shifts if they have too much or too little capacity, the cost of variability in the demand and redundant capacity will increase, which increases the importance of having a good approach to predicting the number of employees or shifts needed on a given day.

Thus, a consistent method to determine the number of shifts to schedule each day is an important step in being able to introduce block-scheduling at TWB. However, the nature of the appointments at TWB allow for some flexibility in when some of the appointments are scheduled. While some appointments, for instance for treating a wound or giving medicine, need to be scheduled at regular intervals, many others do not have such restrictions. Thus, there is a possibility to move appointments around to better fit into a block-scheduling system. Thus, the number of staff does not only need to be scheduled around the appointments already determined, but some appointments can be moved around to make sure that a schedule works even better.

1.3 DERIVATION OF THE RESEARCH QUESTION

In Figure 1.1, the problem cluster and potential core problems that were identified for this research can be seen. The potential core problem that care at TWB is organized in small units, or that there are many mutations at TWB were not chosen, because of the lack of possibility to influence them and their lack of possibility to solve them, especially by using operations research or other common IEM problem solving methods.

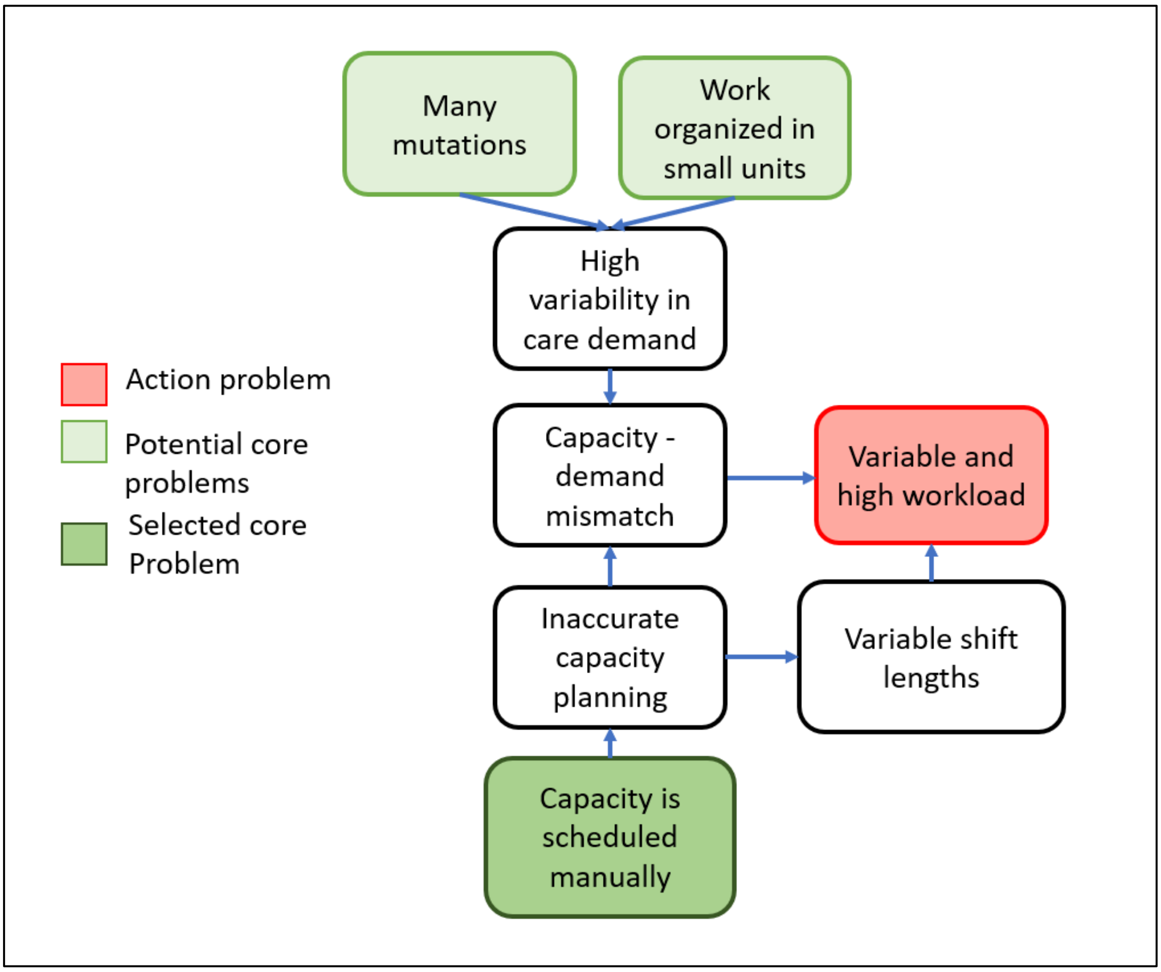

Figure 1.1. Problem Cluster

Instead, the last of these problems, that capacity planning and scheduling is done largely manually, will be the problem focused on in this research. This is common approach to scheduling in health care operations (Burke et al., 2004). This problem is highly relevant for TWB, because as previously discussed, they want to introduce block-scheduling. As is shown in the problem cluster, the inaccurate capacity planning is a large challenge to be able to do that. Hence, the core problem that capacity planning and scheduling is done manually is very important to address before TWB can properly introduce block-scheduling. In addition to its relevance for the introduction of block-scheduling, however, the core problem of capacity planning and scheduling done manually is a relevant problem on its own merits. It is expected to have a large impact on the action problem, both indirectly because it allows block-scheduling, and directly, because a better scheduling system will reduce the variability in workload and help create a more manageable workload, by ensuring that the available capacity is used well.

This problem is also possible to address in terms of a *norm* and a *reality,* which is an important feature of a good core problem (Heerkens, 2017). The *reality* is a capacity planning and scheduling that is relatively inaccurate, which means that introducing block-scheduling in the current situation will have large consequences in terms of capacity and costs for scheduling nurses when they are not needed, as will be shown in section 2.2. The company wants to achieve the *norm* where the accuracy of the capacity planning has been improved to an extent sufficient to allow the introduction of block-scheduling to be feasible.

1.3.1 Main Research Question

To address this core problem, the following research question has been defined.

How can the capacity planning and scheduling at TWB be improved to allow the use of block scheduling?

There are two main parts to this question. Firstly, it addresses both capacity planning and scheduling. Even though the main focus for the research is to improve the capacity planning at TWB, changes to the scheduling will to some extent be necessary in improving the capacity planning. Secondly, while it is of course desirable to improve the capacity planning as much as possible, the tangible goal of the research is to improve it sufficiently to allow for block scheduling to be feasibly introduced at TWB. Thus, to answer this research question, a general scheduling tool will be developed, that will create a block schedule given these constraints.

1.4 PROBLEM SOLVING APPROACH

To answer the research question, we will use the *Managerial Problem-Solving Methods*, or MPSM, as a framework. The MPSM is a problem-solving approach commonly used in Industrial Engineering and Management research. It is designed to solve action problems, i.e., problems that can be described as the discrepancy between a *norm*, or desired state of affairs, and *reality*, or current state of affairs (Heerkens, 2017). Because the type of problem solved in this research is an action problem, the MPSM is a suitable problem-solving framework to use. The MPSM consist of seven phases, each with a different focus of the research process.

1. Problem identification
2. Solution planning
3. Problem analysis
4. Solution generation
5. Solution choice

6. Solution implementation
7. Solution evaluation

The first two of these phases, the problem identification phase and the solution planning phase, will be addressed in this project plan. The problem identification phase is concerned with defining an appropriate action problem, which has been done in the first parts of this project plan, where the action problem was identified, and the problem cluster was used to derive a core problem. The second phase, the solution planning phase, will be executed in the following sections of this project plan. The purpose of this phase is to plan on how to solve the problem that has been derived in phase 1. This is done in section 2 and 3 of this project proposal, by first defining eight knowledge questions, and providing an overview for how each of these knowledge questions will be answered.

The following five phases of the MPSM are each addressed through different knowledge questions and will hence be discussed in relation to these knowledge questions. In Appendix B, an overview of the research design can be seen. In the following section, each of these knowledge questions will be discussed in more depth, and the research plan and research design choices to answer this knowledge question will be expanded upon.

1.5 KNOWLEDGE PROBLEMS

To be able to answer the research question, it has been broken down into six separate sub-research questions. In Figure 2, an overview of the different research questions, the phase of the MPSM they belong to, as well as the type of research and the data gathering methods that will be used can be seen. In the following section, the general structure of the research design will be discussed, taking into account how the knowledge question fit into the general MPSM structure, as well as any relevant considerations in terms of validity and reliability.

1. *How is capacity management currently organized at TWB?*

This is the first question concerned with phase 3 of the MPSM, the problem analysis phase. To answer this question, interviews and conversations will be conducted with different employees at TWB, to get a deeper understanding of how the current scheduling system and capacity management is organized. From these data, a description of the current method of capacity planning and scheduling will be created.

2. *Which KPIs are relevant in determining the quality of a schedule for TWB?*

This question is the first out of several sub research questions about phase 3 and 4 of the MPSM, the solution generation phase. Based on interviews and conversations with staff from TWB, as well as some relevant literature, the most significant evaluation criteria for a scheduling and capacity planning system will be determined. Through this research, a better understanding of central requirements, preferences, and challenges is intended to be achieved. This can concern for instance the general preferences towards longer or shorter shifts, as well as the ability of TWB to cope with under capacity and the differences in consequences of overcapacity for different competence levels of the nurses.

3. *What is the potential impact on capacity of the change to block-scheduling?*

This question is related to phase 3 of the MPSM. The purpose of this question is to get a numerical, in-depth understanding of the current scheduling system and capacity planning at TWB. By assessing the impact of changing to block-scheduling without adjusting the scheduling and capacity planning, we will get a better understanding of the discrepancies between the current system and the desired one. To achieve this, a basic data analysis of the data available from the current scheduling system of TWB will be used. This data system contains information about for instance appointment times, route length, and competence level required.

4. *What are existing methods and heuristics in optimizing capacity planning in healthcare?*

This question is related to phase 3 of the MPSM, the problem analysis phase, as well as to some extent related to phase 4, the solution generation phase. The aim of this question is to gain insight into what heuristics have been used in similar research projects, and hence get a better understanding of the problem. This will also give inspiration for the creation of the specific heuristic for this project. To do this, a systematic literature review will be used to create a list of heuristics that are commonly used in similar projects.

5. *How can these KPIs be evaluated to investigate the feasibility of Block Scheduling?*

This question is also related to phase 3 and 4 of the MPSM. The general research question is defined in terms of whether the capacity planning can be improved sufficiently to allow the introduction of block-scheduling, rather than in terms of general improvements. Thus, the criteria for this change to be considered feasible needs to be determined, which is the aim of this research question. The aim of this question is to determine what values of the KPIs can be considered as acceptable to allow the change to block-scheduling, thus defining the minimum target values for the improvements. This question will be answered through the use of interviews and conversations with staff at TWB, primarily targeting the management.

6. *What heuristic can be designed for the capacity planning at TWB?*

This is the most central question for the research, and it combines phase 4, the solution generation phase, and phase 5, the solution selection phase, of the MPSM. Based on the list resulting from research question 5, as well as the criteria determined in previous questions, a heuristic will be designed for the capacity planning and scheduling system at TWB.

7. *How are the KPIs improved or influenced by the new schedules created by the heuristic?*

This question also relates to phase 5 of the MPSM. In this question, the different solutions that are created by the heuristic will be evaluated based on the KPIs defined in question 3, and the feasibility criteria defined in question 4. By comparing this to the values of the current situation found in question 2, the amount of improvement that is created by the heuristic will be found.

8. *How should a successful implementation and evaluation of the solution be ensured?*

This question relates to both phase 6, the solution implementation phase, and phase 7, the solution evaluation phase, of the MPSM. In this question, we will, in collaboration with TWB, define how block scheduling can be best implemented at TWB, and how the evaluation of the solution and its implementation can be monitored and evaluated after the research project.

1.6 VALIDITY AND RELIABILITY

The data analysis part of this research will be based on the database from the current scheduling system of TWB. This means that all data analysis will be based on a large set of real-life data. The size of the data set makes the data analysis more reliable, because it ensures a large sample. Furthermore, the data is taken from the real, and current, scheduling system. Hence, to ensure the validity of the results, data from a real scheduling system will be used. To ensure the reliability of the result, a large amount of data will be used.

Secondly, several interviews and less formal conversations will be held with employees at TWB throughout the project, to ensure that that the input data, for instance the requirements of the employees, and outcomes are realistic and relevant for TWB. Hence, to ensure the validity of the results for the research questions that depend on interviews, interviews will be conducted with people from TWB, that hence have first-hand experience with the problems discussed. To ensure the reliability, all questions will be answered through conversation with more than one person.

1.7 CONCLUSION

This research is aimed at determining whether it is feasible for TWB to transition to the use of block-scheduling. In doing so, it also needs to find ways to change the staff scheduling at TWB to reduce the impact of this change. To do this, a heuristic will be used to investigate to what extent the schedule has to be changed in order to allow for the introduction of block scheduling. To determine this, several research questions have been defined. By answering these research questions in turn in the following sections, the main research question will be answered.

2. CURRENT SITUATION

In this chapter, the current scheduling process and situation at TWB will be discussed. This chapter is related to the third phase of the MPSM, the problem analysis phase, where the problem is analysed and discussed in more depth. The topics in this chapter relate to research questions one and two. In section 2.1, a qualitative analysis of the current situation will be given, as an answer to research question 1. In section 2.2, a quantitative analysis of the current schedule and the potential impact on changing to block-scheduling will be analysed, relating to research question 2. Finally, the conclusions will be discussed in section 2.3.

2.1 CURRENT SCHEDULING AT TWB

There are several relevant aspects to the scheduling at TWB that need to be considered when designing a scheduling system. In this section, we will discuss the how the scheduling is generally done at TWB, by discussing several relevant aspects of the current scheduling system.

2.1.1 Manual Scheduling

The scheduling at TWB is currently very dependent on manual input. The scheduling is done independently for each cluster. Each cluster has one main planner, and sometimes additional part-time planners that also work as nurses, depending on the size of the cluster. The planner uses a computer system in which they can drag-and-drop the appointments that need to be scheduled to a suitable shift. The planners have a map showing them an approximate route as a help and can then decide in which shift to place an appointment. The number of shifts to be scheduled is generally decided one month in advance and is based on estimates and historical data. Since many of the appointments are recurring for a longer period than 1 month, the amount of care does not change very much within one month. The schedule that is created is approximate, which means that if a nurse for instance is scheduled for a 4-hour shift, this only means that they will be paid for at least 3 hours of work. This means that even if the shift is shorter than 3 hours, the nurse will still be paid for the full 3 hours, but if it is longer than 3 hours, they will only be paid for the time reported.

2.1.2 New Patients

Before a patient enters the regular TWB system, they are attended by a level 5 nurse, who make a care plan for this patient. This level 5 nurse assesses the patient's need for care; whether or not they need care, as well as what type of professional should give the care, and how much care is necessary for this particular patient. This assessment depends both on the needs of the patient, as well as how much of their care they are able to do themselves. This is done through consultation with the patient at the start of the two-week period. After the two weeks, there is a re-evaluation of the patients' needs before they enter the regular TWB system. Hence, TWB does not follow the recommendations from the GP directly but make their own evaluation of the patients need before admitting them to the system. In the case of after-care after a surgery, they sometimes contact the patient before the surgery, to assess together with the patient what they need support with, and what the patient can do themselves.

2.1.3 Recuring appointments

Most appointments at TWB are scheduled recurringly, which means that they are scheduled at the same day or days each week. While for most of these appointments the specific day of the week is not important, some appointments need to be had with a fixed interval, for instance every two days. These might relate to for instance medication that needs to be given. For some appointments, the time of the day is also important, while for most it is not. This means that there is always a preliminary schedule for a week, that contains all the recurring appointments. The new appointments of that week will then be added in addition to these. The amount of recurring care is higher for the type of care that requires lower qualifications. For the lower levels, the planners estimate that around 80% of appointments are recurring, whereas they estimate closer to 50% for the higher levels, such as level 4. Several of these recurring appointments can also undergo mutations, which means that the client needs to move their appointment to a different day or a different time.

2.1.4 Special scheduling considerations

Most employees at TWB are scheduled within their cluster, by the planner of the cluster. There are, however, a few exceptions to this, that needs to be noted when creating a scheduling system. The most notable of these exceptions are the level 5 nurses, and the emergency team.

Level 5 Nurses

The level 5 nurses are managed independently from the other nurses at TWB. In each cluster, they have a senior nurse who is managing all level 5 nurses, independently from the manager who manages the rest of the nurses. The level 5 nurses are highly educated, and the senior nurse also supports them with professional development. While the planner schedules the other levels of nurses, the level 5 nurses are relatively free to schedule their tasks by themselves and are not scheduled by the planners in each cluster. Hence, the level 5 nurses are not scheduled together with the rest of the nurses at TWB.

Emergency Team

There is also an emergency team at TWB, who handle unscheduled appointments. The emergency team usually has three nurses working at any time, one to take calls and two that help patients. The emergency team can both handle unplanned tasks and emergency tasks. Unplanned tasks are usually from TWB internally and can for instance be that the care needed in a regular appointment is not what has been planned and is expected to take longer. Then, the emergency team can take this appointment, so the regular nurse is not interrupted in their schedule. The emergency team also see patients referred by the GP, if their workload is too high. They also follow up on the personal alarm systems within TWB, among other things. All nurses in the emergency team are level 4 or level 5 and can hence handle almost any care within TWB. They can sometimes be called for things that does not require this level of education, such as helping a patient go to the bathroom, but they try to minimize giving this type of care via the emergency team.

2.1.5 Mutations

As was discussed in Chapter 1, mutations are changes to the schedule that occur when a client needs to move their appointment. The scheduling system needs to be able to handle these mutations. Mutations are relatively common at TWB: a single cluster might receive as many as 80 mutations in a day. As a day can contain around 800 appointments, depending on the cluster, these mutations are relevant both because they take time from the planners, and because they cause uncertainty in the planning process. Generally, the planners can change the routes until 12 pm the day before. If they need to make a mutation after this, the planner will contact the nurse who is doing the route, to inform them of the change.

2.2 KPI SELECTION

In extensive conversations with the nurses at TWB, a large number of considerations were voiced, which should or could all be taken into account in creating a scheduling system. In the following section, some of these voiced considerations will be discussed as possible KPIs. It will also be discussed which KPIs are chosen, and how they can be represented.

2.2.1 Over- and Under Capacity

In general, any system where the over- and under capacity can be minimized will be more optimal. Hence, these will be chosen as focus points for the optimization. In this first analysis, it will be assumed that no under-capacity will be tolerated, and hence only over capacity will be considered.

2.2.2 Further Relevant Considerations

Here, we will list some aspects of the scheduling problem at TWB that are relevant to consider in a scheduling problem. By topic, we will discuss to the different possible considerations, and then discuss which of these will be considered in the problem and give a justification for why some KPIs have not be included.

Capacity

The most central KPI for this type of scheduling problem is to measure over- and under capacity. In the previous situation, the length of a workday was mainly dependent on the number of appointments that day. If block-scheduling is used, however, any mismatch between the work schedule for the nurses and the work they need to do will be noticed in the form of over- or under capacity, depending on whether the nurses have too much or too little time scheduled, respectively. With the introduction to block scheduling, over- and under capacity play a much larger role, because the blocks in which people are scheduled will be pre-determined. This means that this KPI becomes even more relevant. Hence, some of the most central KPIs need to be both over- and under capacity.

Different nurses have different preferences. Some prefer to work full, 8-hour shifts, while others prefer to work shorter shifts. Furthermore, there is a large variety in how many people work full time at TWB. This discrepancy will, however, not be considered in this research.

Appointment Times

There are many different types of appointments at TWB. Some appointments need to be scheduled at fixed intervals, for instance every day, or every other day. Some appointments need to be scheduled at a specific time in a day, while others only have a preference to be scheduled at a certain part of the day. To handle this, each appointment will be considered as scheduled in a specific part of the day, for instance in the morning or in the afternoon. Hence, the model will not consider if an appointment needs to be scheduled at a specific time, but only consider the general time it will be scheduled in. The fact that some appointments need to be considered at certain intervals or on fixed days is considered as beyond the scope of this research. This is an acceptable simplification, because this is very uncommonly the case for all appointments in a certain shift, which means that as long as the parameter that allows the appointment to be moved between days does not move almost all appointments from a day, the total sum of care that day should still be feasible.

Teams and Clusters

The appointments need to be done at specific geographic locations, corresponding to the clients' homes. It is, however, possible to schedule a patient to a different team, or a different cluster entirely. This of course leads to an increased travel time, as well as an increased time because the nurses are less familiar with clients in different clusters and hence need time to get to know them and read what type of care needs to be given. To account for this possibility, and the corresponding costs, the assumption will be made that clients will only be treated by people within their own cluster or their neighbouring clusters. Because the differences in travel time will then be low, only the cost of being served by someone from a different cluster will be considered. Thus, for each team the neighbouring teams will be defined, for which it is feasible to transfer an appointment. Doing so will then incur an increased cost.

Qualifications

Lastly, there are nurses of six different levels at TWB, where a nurse with a higher level of qualification can perform the work that requires this level of qualification, as well as all below it. However, no one can perform the work at the higher levels. Nevertheless, because nurses with the higher qualifications are more expensive, and because nurses generally do not like to perform work that requires a lower level of qualification that they have, this has an additional cost.

2.2.3 Chosen KPIs

Thus, there are five KPIs chosen. The main KPIs to determine the performance of the schedule are over- and under capacity. In addition to these, the three KPIs of date mismatch, team mismatch, and qualification mismatch will be used.

2.3 CURRENT SYSTEM PERFORMANCE

The current system does not use block-scheduling, but only schedules an employee if there are actually appointments. This is of course very good for over- or under capacity, as capacity is adjusted to demand rather than pre-determined. In this section, this current system, and its differences to a system based on block-scheduling, will be analysed. In order to determine the potential impact of a change to block-scheduling, a basic data analysis has been conducted on the current schedules at TWB. This analysis has been conducted on the data about the past employee schedules found in the TWB database.

2.3.1 System Analysis

Firstly, a few metrics were chosen to give a numerical confirmation to the discussions had with the employees at TWB. To get a better idea of the current scheduling system at TWB, the shift data for 1 year, between 1st of May 2022 and 1st of May 2023, was analysed. This data consists of 116,379 shifts.

Total Number of Employees

In total, TWB currently has around 2180 employees, with this number slowly increasing over time. 5% of these employees work full-time, 72% work part time, and 23% work with a 0-hour contract, or a flexible contract where they are only paid per hour they work. The dataset analysed consists only of 1120 employees, which can to some extent be explained by that not all employees are scheduled using this system. For instance, level 5 nurses have largely independent schedules.

Levels of Qualification

In the Figure 3.1, the distribution for the different levels of care can be seen. From this graph, it is clear that the most appointments are at level 2, level 3, and level 3ig.

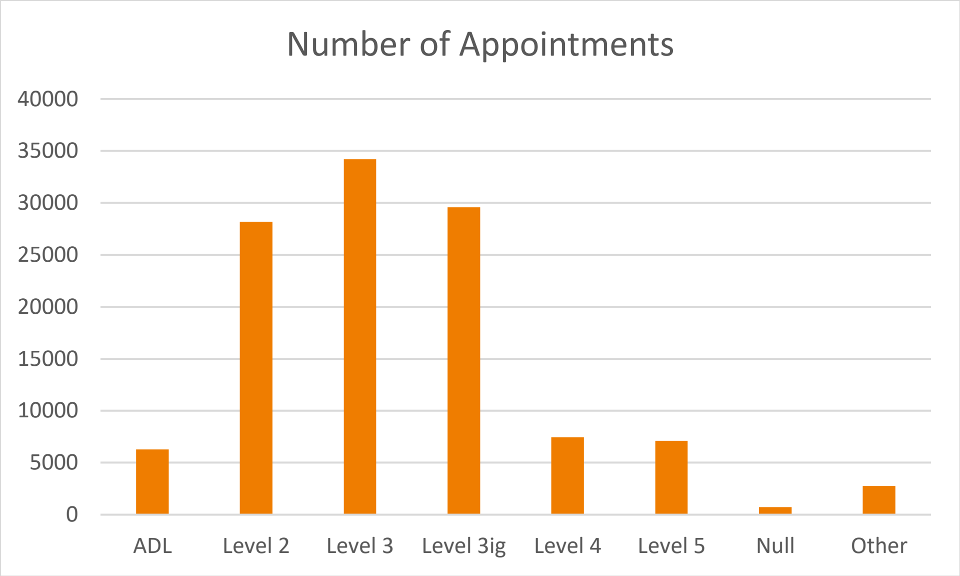

Figure 3.1. Number of appointments per level of qualifications of nurses.

Teams

TWB consists of 46 different teams, including both geographical teams and specialized teams, such as the emergency team and the hospice team. Because the team division is based on geography, the number of nurses in a team varies significantly, but most teams consist of between 5 and 10 shifts each day, with some having as many as 20.

2.3.2 Expected Impact of Block Scheduling

In this section, the current situation at TWB will be analysed, and then be compared to how they it would change if block-scheduling was implemented at TWB. For this part, the assumption that no adaptions would be made to the schedule is used. Firstly, the current common lengths of shifts will be discussed for the different levels at TWB. Secondly, a comparison suggesting how much over- and under capacity will be created if block scheduling is used and no changes to the appointment structure is made.

Length of Shifts

In Figure 3.2, the different lengths of the shifts can be seen. The most common lengths of shifts are 4 hours and 4 hours and 30 minutes. This shows that only a small number of shifts are the long enough to be 8 hours, or a full day's work. In the figure, the upper limits of the time buckets are visualized. The interval of 30 minutes is chosen because most shifts vary in length in units of 30 minutes. One minute is added to each time bucket, to ensure that no rounding errors occur, which would place a shift in the wrong bucket if the length of the shift was rounded up to a number slightly higher than e.g., 30 minutes. This also makes it clear that in for instance the bucket '06:31:00', all shifts that are 6.5 hours are included.

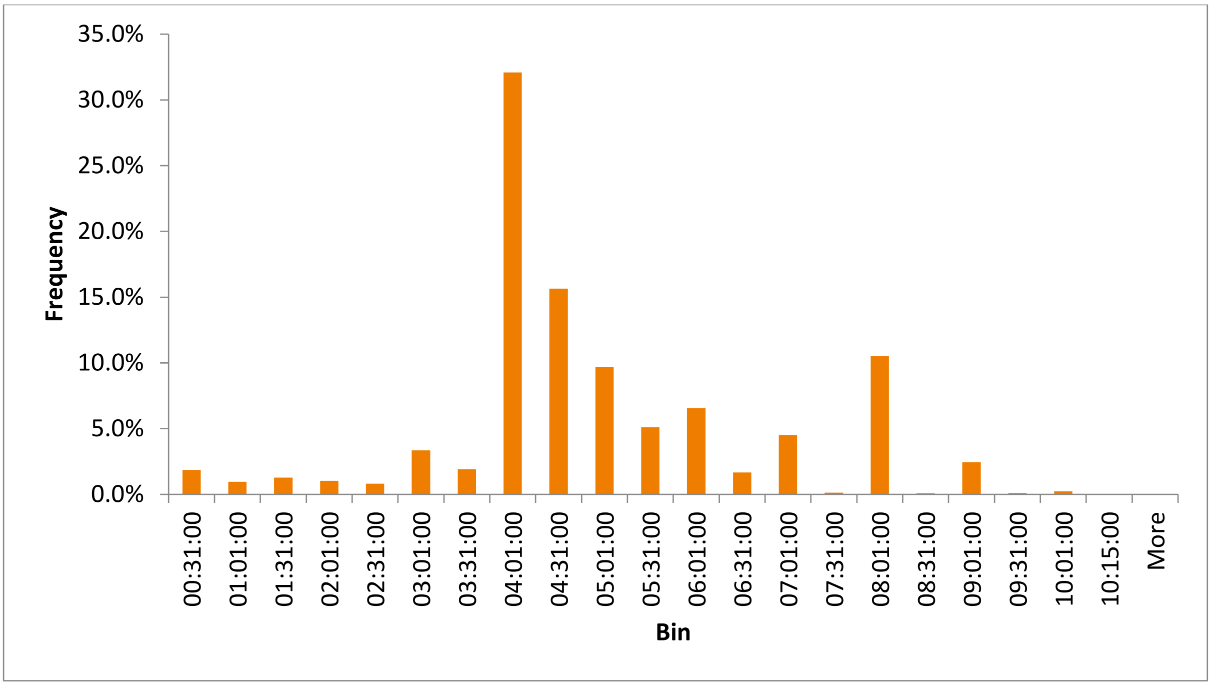

Figure 3.2. Histogram showing the number of shifts in each time bucket, showing the upper limit of the bucket.

Indeed, the majority of shifts (56%) are between 4 and 5 hours long, with 4 hours being the most common length (31%). 48% of all shifts follow the proposed block-lengths of 4, 6, or 8 hours, as can be seen in the table below.

Table 3.1. Percentage of shifts that are 4, 6, or 8 hours respectively.

Shift length	Percentage
4 hours	31.35%
6 hours	6.57%
8 hours	10.51%
Total	48.44%

There is, however, a large difference between the different levels when it comes to which lengths of shifts, they normally have. In the figures below, the differences between level 2, level 3ig, and level 4 can be seen clearly. In Figure 3.3, it can be seen that for level 2, the shorter shift lengths are most common. The most frequent length is 4 hours, and together 4- and 4.5-hours long shifts make up more than 65% of all level 2 shifts.

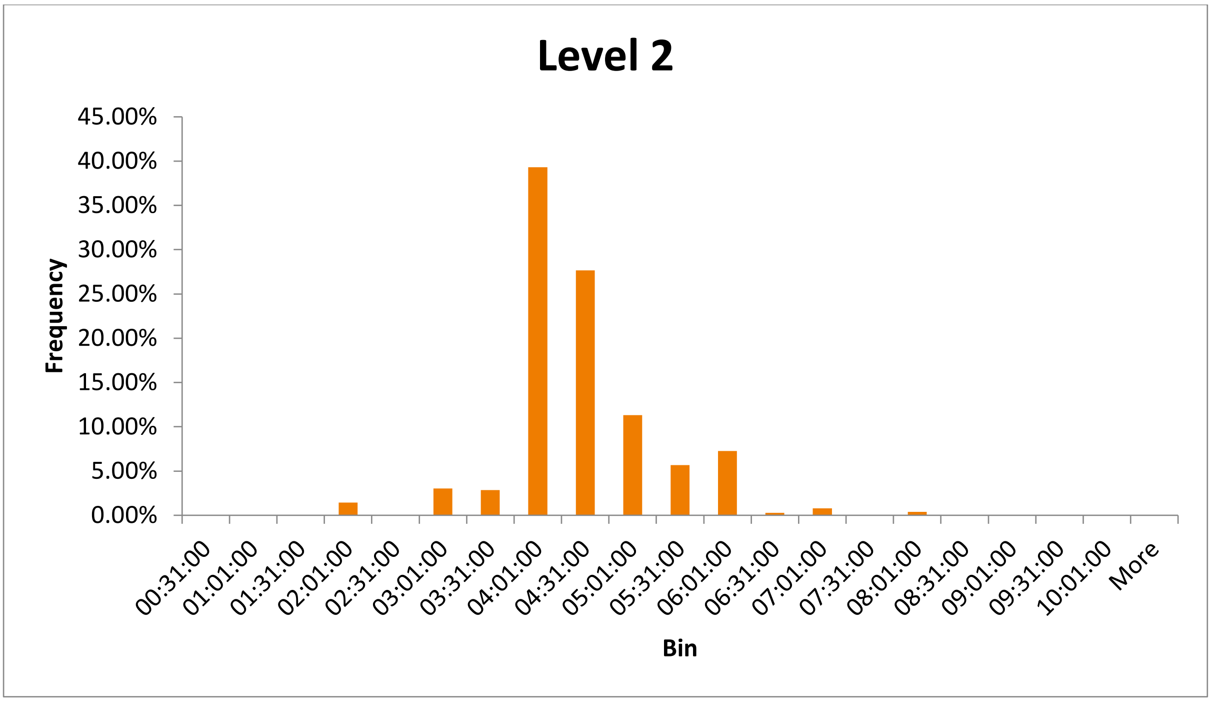

Figure 3.3, Histogram showing the number of shifts for level 2 in each time bucket, showing the upper limit of the bucket.

In Figure 3.4, the lengths of the level 3ig shifts can be seen. From this graph, it is clear that also at this level the most frequent length of a shift is 4 hours. However, at this level, the longer shifts of 8 hours are much more common than for level 2.

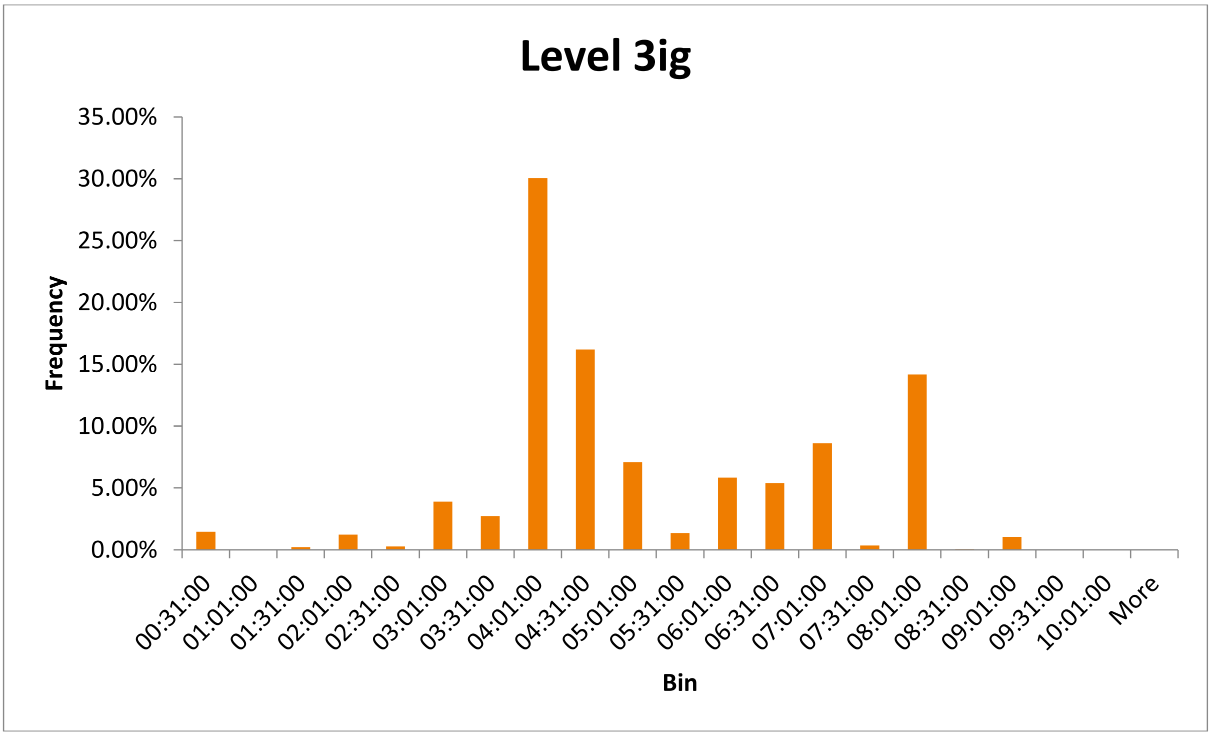

Figure 3.4, Histogram showing the number of appointments for level 3ig in each time bucket, showing the upper limit of the bucket.

In Figure 3.5, the shift lengths for the level 4 nurses are shown. In this graph, it can clearly be seen that for the level 4 nurses, the 8-hour shifts are much more frequent than for the other levels. At level 4, 8-hour shifts make up nearly 60% of all shifts.

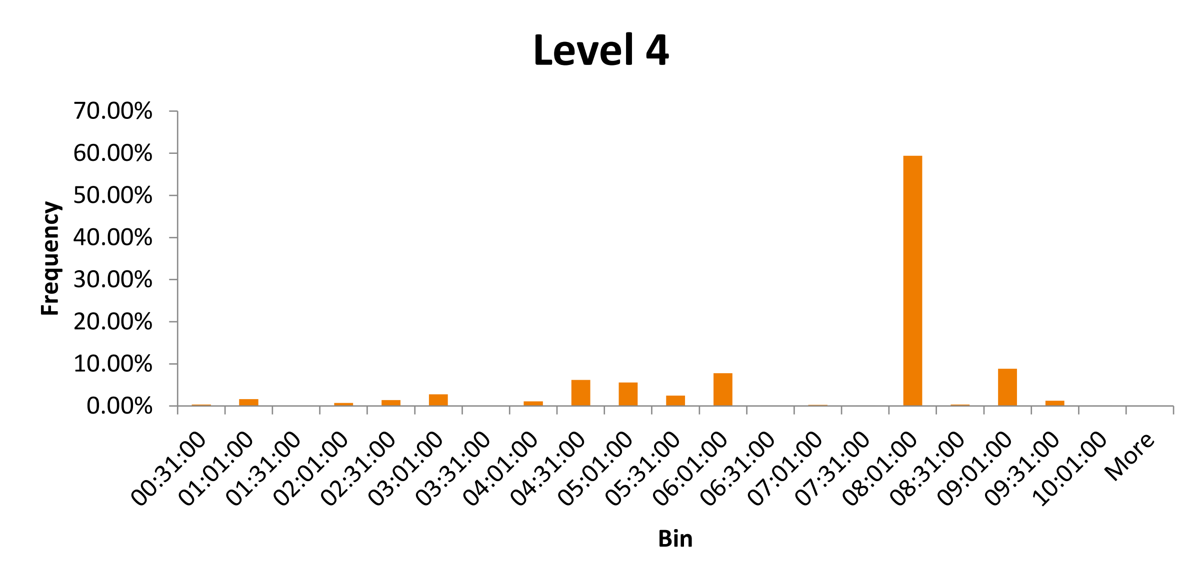

Figure 3.5, Histogram showing the number of appointments for level 4 in each time bucket, showing the upper limit of the bucket.

Although the most common lengths of shifts are the ones considered for block-scheduling, a large portion of shifts have a different length from these. Furthermore, it is clear that the common lengths of shifts vary greatly per level, and that there is a general trend that the higher levels make use of longer shifts. In Appendix C, the frequencies of shift lengths can be seen for the other levels as well, which to a large extent confirms this.

Adaptions

The least disruptive form of block-scheduling that could be introduced is if each current shift was simply rounded up to the nearest block schedule. This will, of course, not be a feasible solution, because it will lead to a large deviation between the care needed and what is actually offered. Also in this case, however, most shifts (43%) will be 4 - hour shifts, as can be seen in Figure 3.6.

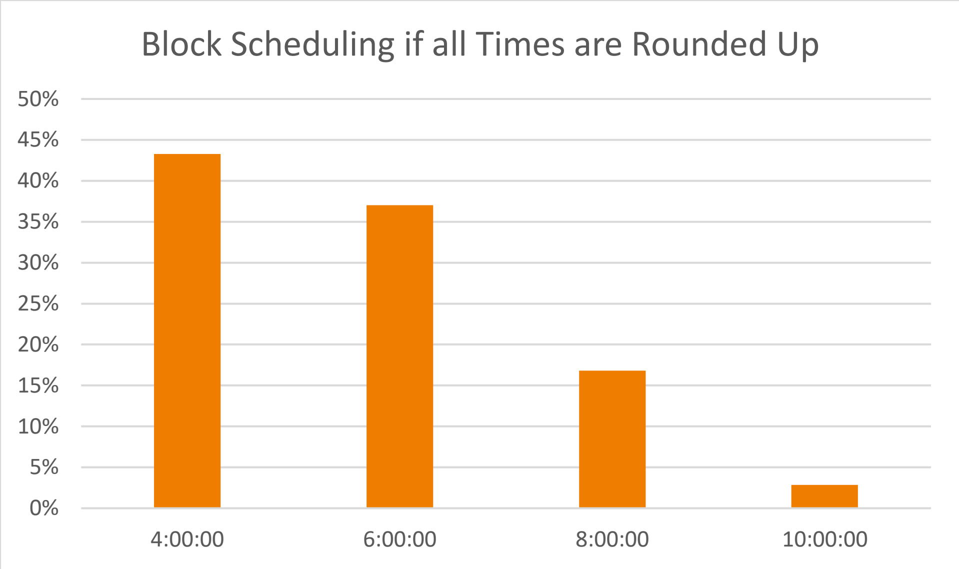

Figure 3.6. Frequency of shift lengths if all shifts were simply rounded to the up to the nearest possible shift length.

This would lead to an average increase in time needed to give care of about 200 hours per day, or almost 12%. Nevertheless, some of the shifts that are a part of the data are very short, which of course leads to a large increase in time. If all shifts shorter than 2 hours are excluded, the increase in hours is only 150 hours, or 9.3%. However, the total mismatch of hours will be around 170 hours per day, 160 of which are over capacity hours, and 10 of which are under capacity hours.

The purpose of this research is to evaluate whether block-scheduling is feasible, and to do this, some care will be shifted to different days, so as to spread the care evenly over the days. This means that rounding up will not be necessary, because some of the appointments can be shifted between different shifts on the same day. If the length of a shift is directly rounded, however, the total amount of care is less than the original number, which is of course infeasible. Instead, we investigated what would happen if shifts that are up to 30 minutes longer than a specific shift length were rounded down, while the rest were rounded up. In this investigation, only shifts longer than 2 hours were considered.

As can be seen from the Figure 3.7, this would further increase the number of shifts of length 4 hours to 55%. On average, this configuration only increases the average service time per day with 49 hours. This translates to around 82 hours of overcapacity, and 36 hours of under capacity, meaning a total of around 118 capacity mismatch hours per day.

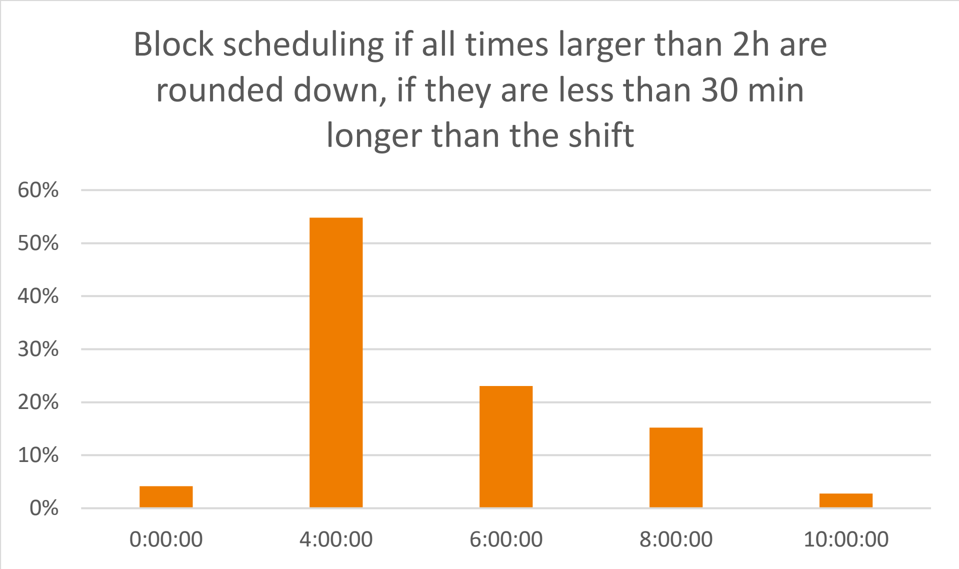

Figure 3.7. Frequency of shift lengths if shifts were rounded to the up to the nearest possible shift length, unless they were of a length of only 30 minutes from a shift length, in which case they would be rounded down.

2.4 CONCLUSION

The appointment scheduling at TWB is complex, with a wide variety of care being given. There are structures of different types of care, organized in levels, and different geographic locations, organized in teams and clusters. In addition to these structures, there are other, specialized teams such as the emergency team that is not clearly bound to these structures. What makes the scheduling problem at TWB complex is the fact that there are mainly soft restrictions between these different structures, which means that there is quite some freedom in which appointment is served by which type of employee. However, this is not a preferred option, both from a cost perspective and based on the preferences of the employees.

From the data analysis, it can be seen that introducing block-scheduling is possible, but costly, if no changes at all are done to the scheduling. This is however not likely, because with the current manually based scheduling, the planner that makes the schedule could quite easily shift some appointments from a shift that is slightly too full to one that is less full. Such decisions would have a large positive impact on the ability to use bock-scheduling. Whether this change is sufficient is, however, not possible to determine from this basic data analysis, and this will hence be investigated further in the rest of this thesis. Nevertheless, it can be concluded that there is a large potential for improvement to ensure the possibility of introducing block-scheduling.

3. RELEVANT LITERATURE

In this chapter, the problem will be analysed from a theoretical perspective, by placing it in a relevant theoretical framework, as well as discussing similar problem statements and related solution methods. This will be done with the aim of better understanding the problem and the existing knowledge around it. Hence, this chapter is also related to phase 3 of the MPSM, the problem analysis phase. In this chapter, the third research question, "*What are existing methods and heuristics in optimizing capacity planning in healthcare?",* will be answered. To answer this research question, a literature review has been conducted. In section 3.1, this research will be placed in an appropriate theoretical framework. In section 3.2 relevant literature will be discussed, and section 3.3 will contain a conclusion.

3.1 THEORETICAL FRAMEWORK

To frame this research with other research in a healthcare area, it was compared to a generic framework for health care planning and control as described by Hans et al. (2012). In Figure 2, an overview of this framework can be seen.

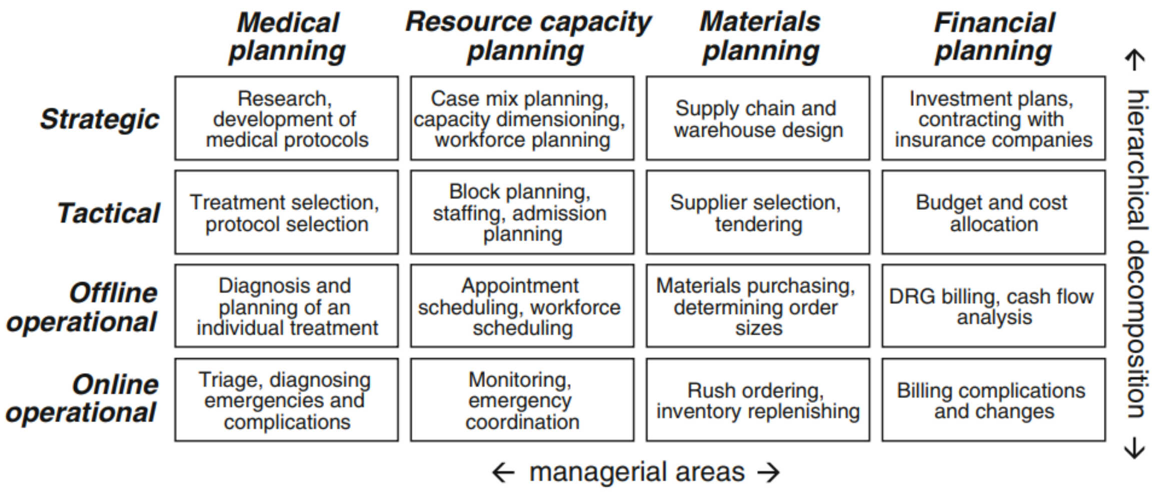

Figure 2. A Framework for Healthcare Planning and Control (Source: (Hans et al., 2012)*)*

In relation to this overview, this research should be considered as resource capacity planning, because it is concerned with the scheduling of shifts and staff, which can be considered as a renewable resource, and hence fit in this category. It cannot be said to be on a strategic level, because the planning horizon and capacity decisions it is concerned with is not on a sufficiently large scale to be considered strategic. It can certainly not be considered to be on an online operational level, because it is not concerned with real-time decision making. To some extent, the research can be said to be related to offline operational planning, because it is concerned with the scheduling of appointments and staff. However, it is not concerned with the scheduling of specific appointments, or the assignments and rosters of specific staff. Rather, the research is focused on the amount of care that is planned for each type of staff, and hence how different types of shifts can best be fitted to this. This means that this research should be considered to be on a tactical level. Generally, the research is concerned with a planning horizon of one month, which fits well with considering the research to be on a tactical level.

3.2 RELEVANT LITERATURE AND THEORY

There are two main problems to which this research can be said to be related. The first of these is the Home Healthcare Problem (HHCP), which is discussed by Guo & Bard (2023) and Alkaabneh & Diabat (2022), among others. The second type of problem that is closely related to this research is the Nurse Scheduling Problem (NSP), as is discussed by (Legrain et al. (2015); Muniyan et al. (2022); Petrovic et al. (2012)), among others. In the following sections, both of these problems will be discussed in more detail, and the relevant differences to this research will be discussed.

3.2.1 Home Healthcare Problem

The home healthcare problem (HHCP) is a well-known problem within operations research and has been described before in several different ways in literature, e.g., Cissé et al., 2017; Di Mascolo et al., 2017; Fikar & Hirsch, 2017. Because the problem addressed in this research is concerned with home care scheduling, it should be considered as an HHCP. The HHCP is usually concerned with a mix of routing and scheduling staff (Fikar & Hirsch, 2017), and can hence even be considered as an extension of a vehicle routing problem (VRP) (Cissé et al., 2017). This is very different from the problem discussed in this research because the routing is not considered. Nevertheless, there are many different variations of the HHCP often depending on the local regulations and conditions. This means that many of the solution methods and considerations can still be very relevant for this problem.

3.2.2 Nurse scheduling problem

The nurse scheduling problem, or nurse rostering problem, is also a well described problem in literature, for instance in Abdalkareem et al. (2020), who discussed several different healthcare-related optimization problems, including the NSP. The NSP is usually concerned with the scheduling of specific nurses to sometimes pre-determined shifts, and often take constraints such as resting days, breaks, and personal preferences into account (Legrain et al., 2015). Some for simplicity consider the nurse scheduling problem as a one-dimensional problem (Legrain et al., 2015), while it is in fact a combinatorial optimization problem (Bilgin et al., 2012; Muniyan et al., 2022), because the nurses can be scheduled to the appointments, or the number of appointments can be adjusted for the number of nurses.

This research is different from the nurse scheduling problem in that it does not attempt to match shifts with employees, but rather determine what is an optimal way to schedule shifts to cover the demand needed. Because nurse scheduling is usually relevant for hospitals, where the clients arrive to the nurses rather than the nurses travel to the clients, the situation is significantly different from that as is considered in this research. Nevertheless, it has some relevant similarities to this research because the NSP is also does not consider any routing, but rather a fixed amount of specific amount of work that has to be performed by some nurse.

3.2.3 Solution Methods

The HHCP and the NSP are both usually considered to be combinatorial problems. A combinatorial problem is a problem that tries to arrange a number of discrete variables in an optimal order. Combinatorial problems can be solved with exact methods, such as linear programming. However, as the number of variables increase, the number of possible combinations might increase exponentially, leading to unmanageable computation times (Blum, 2003). For this reason, approximate methods, or heuristics, are often used. There are many different common heuristics that can be used, with different applications and different use cases. For instance, a local search heuristic, locally transform a solution through pre-defined neighbourhood structures. These moves are then guided by some form of heuristic measure, which determines whether they will be accepted or not (Voß, 2000). Metaheuristics are heuristics that combine simple heuristics with a higher-level structure aimed at guiding the heuristic into finding the optimal solution (Blum, 2003). A meta-heuristic is thus intelligently combining different concepts and search strategies in order to efficiently find a near optimal solution (Voß, 2000).

There are many solution methods used for different HHCPs, both exact solutions, heuristics, and combinations of the two (Fikar & Hirsch, 2017). This wide variety of solution methods mirror the diversity in problem definitions that exists between different HHCPs. Some exact methods exist, but they tend to have a large running time, due to the complexity and size of the problem (Yuan et al., 2015). Heuristic solutions are therefore common. These are often split into two phases, with a solution generation phase and an improvement phase, often using some form of local search algorithm (Alkaabneh & Diabat, 2022; Fathollahi-Fard et al., 2020; Guericke & Suhl, 2017). Other, similar heuristic methods are also commonly used. For the NSP, there also exists both exact methods, such as linear programming, and a variety of heuristic methods (Naidu et al., n.d.).

3.2.4 Description of the Problem

Both the NSP and the HHCP are optimization problems, and often take relatively similar constraints and considerations into account. While the scheduling problem at TWB is of course a HHCP, the scope of this project can be seen to take some significant inspiration also from the NSP. However, because of the similarities between the solution methods, this difference is not so significant. Some HHCPs, such as Guericke & Suhl (2017) are more focused on the staff scheduling aspect of the HHCP.

This means that while we can take quite some support in literature in terms of different solution methods and alternatives, there is no existing formulation of the problem that can be directly applied to the situation as considered in this research. The main focus of the research is to determine the shifts that should be scheduled, in specified time-blocks, in order to best cover the demand. Taking all the relevant considerations into account results in a relatively complex multi-objective optimization problem, that is trying to minimize the changes made to a schedule while simultaneously trying to minimize the costs of having this specific schedule. To handle these different objectives, each objective of the problem will be translated into a weighted objective function, in order to ensure that they can be considered in the same objective function. In the following chapter, a more detailed mathematical problem formulation will be presented.

3.2.5 Preferred Solution Method

In the literature, a large number of different solution methods can be found to both the HHCP and the NSP. While some of these rely on exact methods, such as linear programming, most make use of heuristic methods. Many of these (Alkaabneh & Diabat, 2022; Fathollahi-Fard et al., 2020; Guericke & Suhl, 2017) make use of a two-step process, starting with a method to determine a solution, and then using an improvement heuristic, often a local search algorithm, to improve this solution. For this phase, there are several different heuristics that can be used. In this research, we will take a similar approach, starting with a pre-determined solution, based on the original schedule that is used by TWB, and where each appointment is served by the qualification and team that was originally intended, and at the day when the appointment was originally scheduled. From this starting solution, a neighbourhood-based improvement heuristic will be used to improve the solution. One heuristic that is frequently used in this context, is simulated annealing. Because this heuristic has been shown to perform well in this type of context (Ceschia et al., 2023; Hiermann et al., 2015), it will be used in this research.

3.3 CONCLUSION

In conclusion, there is, to the best of our knowledge, no problem defined in literature that is the same as the problem addressed in this research, which means that a new problem definition is required. This problem is related to home care, and is hence a HHCP, but can be considered to have many similarities also to the NSP. This means that both of these problems can be considered when defining the problem specifically, as well as when considering which solution methods to use. For both the HHCP and the NSP, a wide variety of solution methods exists, including both exact and heuristic solutions. For this specific problem, we will make use of the heuristic simulated annealing.

4. PROBLEM DESCRIPTION AND SOLUTION REQUIREMENTS

In this chapter, we will discuss the different requirements for a good solution, by investigating the different evaluation criteria that are relevant for the project. To do this, several interviews with staff at different positions at TWB have been held, and the problem will be defined mathematically. This chapter is related to phase 3 and 4 of the MPSM, and will answer the research questions 4, Which KPIs are relevant in determining the quality of a schedule for TWB? and 5, How can these KPIs be evaluated to investigate the feasibility of a solution?

4.1 PARAMETERS AND VARIABLES

In this section, the problem is described mathematically, and the decision variables are discussed and defined. The sets of the problem can be described as follows.

4.1.1 Sets

Notation	Definition
D	Set of days
T	Set of Teams. The area served by TWB is divided into smaller areas, each served by a team.
Q = {1, …, 6}	Sets of qualifications. The work at TWB is divided into six levels, each requiring a different qualification.
L = {4, 6, 8}	Set of possible lengths of shifts
J	Set of appointments to be scheduled.
$d_j \in D$	Daypart in which job $j \epsilon J$ is scheduled.
$t_j \in T$	Team in which job $j \epsilon J$ is scheduled.
$q_j \in Q$	Qualification for which job $j \epsilon J$ is scheduled.
λ_j	Length of job $j \epsilon J$.
$f_{j,d} \in \{0,1\}$	1 if job j needs to be scheduled on daytime D, 0 otherwise.

4.1.2 Decision Variables

The decision variables for the model are hence when each appointment is scheduled, as well as how many shifts to schedule in each day.

Notation	Domain	Definition
$\alpha_{j,d,t,q}$	$\in \{0,1\}$	1 if appointment $j \in J$ is scheduled on day $d \in D$, in team $t \in T$, with qualification $q \in Q$.
$S_{l,d,t,q}$	$\in \mathbb{N}$	Nr of shifts of length $l \in L$ scheduled on day $d \in D$, in team $t \in T$, with qualification $q \in Q$.

4.2 EVALUATION OF THE SCHEDULE

In this section, the different ways a schedule is evaluated will be discussed.

4.2.1 Over-Capacity

The most significant costs to calculate are the costs of over- and under capacity. The cost of over-capacity will be directly related to the cost of a shift, because over capacity means that there is an unnecessary shift that is scheduled. The over capacity for each shift length will be calculated as follows:

$$O(d,t,q) = Max\left(0, S_{l,d,t,q} * l - \sum_{j \in J} \lambda_j * \alpha_{j,d,t,q}\right) \quad \forall\, l \in L \qquad (1)$$

Where λ_j is the length of appointment j, $\alpha_{j,d,t,q}$ is 1 if appointment j is scheduled at combination of parameters, d, t, q, and 0 otherwise, and $S_{l,d,t,q}$ is the number of shifts of length l scheduled at combination of parameters, d, t, q.

4.2.2 Under-capacity

The second relevant cost is the cost of under capacity, which directly corresponds to the cost of over-time. The calculation is as follows:

$$U(d,t,q) = Max\left(0, \sum_{j \in J} \lambda_j * \alpha_{j,d,t,q} - \sum_{l \in L} S_{l,d,t,q} * l\right) \qquad (2)$$

Where λ_j is the length of appointment j, $\alpha_{j,d,t,q}$ is 1 if appointment j is scheduled at combination of parameters, d, t, q, and 0 otherwise, and $S_{l,d,t,q}$ is the number of shifts of length l scheduled at combination of parameters, d, t, q.

There under-capacity uses the maximum, because if there are more shifts scheduled than are necessary, there will be no under-capacity. If the total length of the appointments scheduled at combination of parameters, d, t, q is larger than 0, however, the under-capacity can be found by subtracting the sum of the lengths of all shifts scheduled at this combination of parameters, from the total length of the appointments scheduled.

4.2.3 Day mismatch

There are three ways in which appointments can be shifted. The first of these is that appointments can be moved to different days. As this is not very nice to do, the cost of this should be relatively high. The cost is proportional to the number of days an appointment has been shifted. Hence, the total number of days the appointments in a certain combination of parameters, have been shifted can be calculated as follows:

$$Md(d,t,q) = \sum_{j \in J} \left|\left(d - d_j\right) * \alpha_{j,d,t,q}\right| \qquad (3)$$

Where d is the current day, d_j is the day on which the appointment was originally scheduled, and $\alpha_{j,d,t,q}$ is 1 if appointment j is scheduled at combination of parameters, d, t, q, and 0 otherwise.

4.2.4 Team Mismatch

There are several ways to consider the possibility of moving an appointment to a different shift. The easiest of these is to, for each cluster, define a number of feasible clusters with which an exchange can be made. Then, a fixed cost can be added for a scheduling mismatch. Hence, the number of combination of parameters can be found as follows.

$$Mt(d,t,q) = \sum_{j \in J | t \neq t_j} \alpha_{j,d,t,q} \quad (4)$$

4.2.5 Qualification mismatch

The calculation for the qualification mismatch is very similar to that of the day mismatch. Nevertheless, because it is not possible to serve someone that requires a higher level of qualification, the calculation does not need to make use of the absolute value. The calculation is hence as follows:

$$Mq(d,t,q) = \sum_{j \in J} (q - q_j) * \alpha_{j,d,t,q} \quad (5)$$

4.2.6 Normalization

In order to better compare the different costs, they are normalized, by being divided by their theoretical maximum value. For over- and under capacity, this value is the total length of all appointments in the system, found according to the following formula.

$$K^o = K^u = \frac{1}{\sum_{j \in J} \lambda_j} \quad (6)$$

For movements in days, teams, and qualifications, the theoretical maximum depends on the total number of appointments, as well as the total number of days, teams, or levels in the problem. Hence, they can be found according to the following formulas.

$$K^D = \frac{1}{J * D}, \quad K^T = \frac{1}{J * T}, \quad K^Q = \frac{1}{J * Q} \quad (7)$$

4.2.7 Objective Function

The objective function can hence be written as a sum of these KPIs. In addition to the normalization, however, the normalized KPIs will be multiplied by certain cost variables, C^u, C^o, C^{Md}, C^{Mt}, and C^{Mq} respectively. These weights can be used to scale the different KPIs against each other.

$$\min_{S_{l,d,t,q}, \alpha_{j,d,t,q}} \sum_{d \in D} \sum_{t \in T} \sum_{q \in Q} (C^u * K^u * U(d,t,q) + C^o * K^o * O(d,t,q) + C^{Md} * K^D * Md(d,t,q) + C^{Mt} * K^T * Mt(d,t,q) + C^{Mq} * K^Q * Mq(d,t,q))$$

4.2.8 Constraints

The model is subject to the following constraints.

Qualification constraint

The constraint ensures that each appointment is only served by someone of a qualification that is sufficient to treat that patient.

$$q \geq q_j * \sum_{d \in D} \sum_{t \in T} \sum_{q \in Q} \alpha_{j,d,t,q} \quad \forall j \in J$$

Appointment Constrain

The constrain ensures that each appointment is scheduled exactly once.

$$\sum_{d \in D} \sum_{t \in T} \sum_{q \in Q} \alpha_{j,d,t,q} = 1 \qquad \forall j \in J$$

4.3 CONCLUSION

In this section, several of the possible KPIs for TWB have been discussed, and how they might be relevant to consider. The main KPIs selected are over capacity and under capacity, because together they ensure that the shift schedule that is determined is as well filled as possible, and hence that the accuracy with which the nurses will know their working times is as high as possible.

In addition to these two KPIs, three main KPIs that can be used as soft constraints in order to improve the schedule have also been selected. These are day of scheduling, which allows an appointment to be moved to a different day, team, which allows an appointment to be served by a team that is based in a different geographic location, and lastly qualification, which allows an appointment to be served by someone with a higher qualification than is necessary for that appointment. These KPIs have been selected, because they are all relevant measures of the consistency of a schedule. Hence, they can be used as a soft constraint in order to determine whether a schedule is a good, and a feasible, schedule.

The first two KPIs of over- and under capacity are directly opposed to the latter three KPIs of mismatching, because the more mismatching that is allowed, the better the schedule can be fitted to the possible shifts, and hence the lower over- and under capacity can be ensured. This means that the result of the schedule is heavily dependent on the parameters chosen for these different constraints.

These different KPIs can also be used to evaluate the feasibility of a schedule, by for instance putting a maximum allowable amount of any of them and see if the algorithm can find a solution.

5. HEURISTIC IMPLEMENTATION

In this chapter, the actual implementation of a heuristic solution of the problem will be discussed. The main structure of the solution will be based on the simulated annealing metaheuristic, as has been discussed in chapter 4. The specific implementation of this heuristic to the problem described in the previous chapter will be discussed. Hence, this chapter addressed phase 5 of the MPSM, and is aimed to answer research question 6, *What heuristic can be designed for the capacity planning at TWB?* In section 5.1, the general approach of simulated annealing will be discussed, and section 5.2 will handle the neighbourhood structure of this particular problem. In section 5.3, the LP for determining the specific number of shifts given a certain demand will be defined, and in section 5.4 the implementation of the algorithm will be discussed. In section 5.5, the parameters for the simulated annealing will be determined, and section 5.6 will contain a conclusion.

5.1 SIMULATED ANNEALING

Simulated annealing metaheuristic, that often uses local search algorithms to find local optimums, as well as a guiding procedure to accept sub-optimal solutions in order to escape these local optimums. The simulated annealing algorithm is based on an allegory to the process of *annealing*, which is a process to heat up solids to a high temperature, and carefully cool it down to a highly structured, low energy state. Similarly, the simulated annealing process starts at a high 'temperature', where almost all solutions are accepted, and though carefully chosen cooling parameters, decrease the 'temperature', or the likelihood of accepting a solution, to be able to find a near-optimal solution (Rutenbar, 1989). At the higher temperatures, many sub-optimal solutions will be accepted, which allows large changes to the structure of the problem. As the temperature cools, the probability that a worse solution will be accepted decreases, which means that the heuristic is more likely to only accept strictly better solutions, and hence enter a local optimum.

5.1.1 General Structure of Simulated Annealing

In Figure 6.1, the process of simulated annealing can be seen. Firstly, an initial solution is generated, from which a candidate solution is found, based on the neighbourhood structure of the problem. The two solutions are then compared, and if the new solution is better than the old solution, it will be accepted. If it is not, it will also be accepted with a certain probability p, which is dependent on the current temperature t. If the solution is accepted, it becomes the new optimal solution. One of the parameters of simulated annealing is the Markov chain length k, which determines the number of replications made for each temperature. Once this number of replications have been

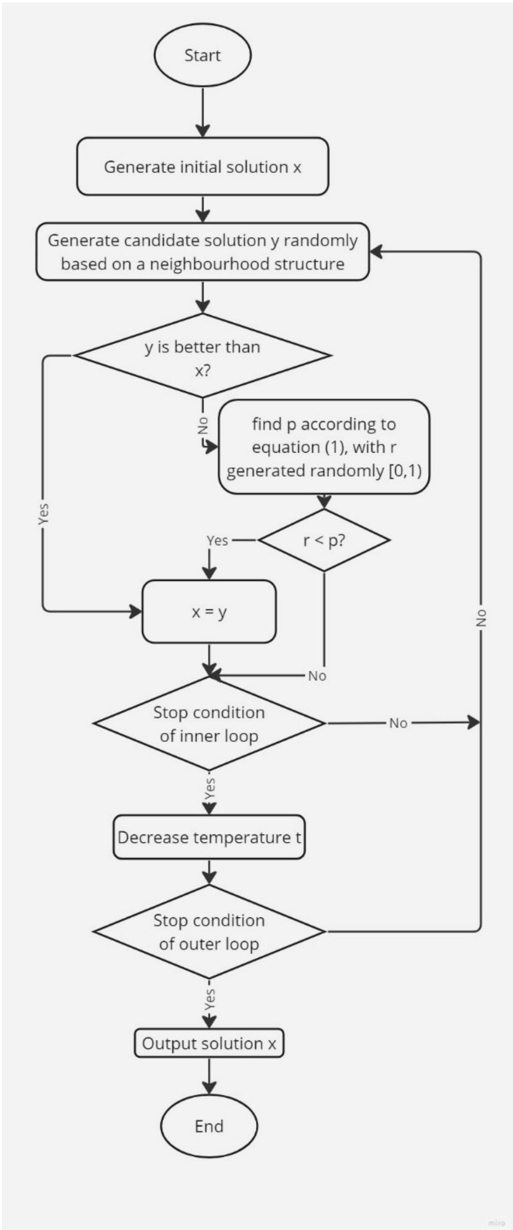

Figure 6.1. Process of Simulated Annealing. Inspired by Zhan et al. (2016)

made, the temperature will be decreased by being multiplied by a certain number α. This process will continue until a certain stopping temperature, t_stop has been reached. The current best solution at this point will be the final solution (Voß, 2000; Zhan et al., 2016).

5.1.2 Implementation of Simulated Annealing

In this research, a simulated annealing algorithm will be used to create a schedule that minimizes the mismatches in days, teams, and qualifications, while simultaneously minimizing the over- and under capacity that this schedule results in. Thus, the simulated annealing algorithm will move appointments to a different day, team, or qualification. This change will mean that the total demand changes, both at the combination of parameters which the appointment was moved from, and at the combination of parameters to which the appointment was moved. Since the total demand has changed, the best way to schedule shifts during these days might also have changed. Hence, an LP will be used to determine the new optimal way to schedule these shifts.

5.1.3 Determination of Original Schedule

Simulated annealing is an improvement heuristic, meaning that it needs to start from an existing solution, which can then be improved. Often, these original solutions are determined randomly. In our case, this original solution will not be determined randomly. Rather, it will be found by using the original solution that is pre-determined. This means that each appointment will be scheduled at the combination of parameters at which they were originally scheduled. The LP will then be used to determine how the shifts should optimally be scheduled if such a schedule were to be used.

5.2 NEIGHBOURHOOD

The neighbourhood structure will be designed to ensure the continued feasibility of the solution. In the simulated annealing heuristic, we will use two different operators, the swap, and the move operator. In addition to this, some constraints will be defined to ensure that the selected solution is feasible.

5.2.1 Combination of parameters

In the following sections, we will refer several times to a scheduling “combination of parameters”. This combination of parameters simply refers to a combination of a day, a team, and a qualification. Any appointment needs to be scheduled in a certain combination of parameters, and the actual heuristic will compare the scheduling of appointments at different combination of parameters, rather than at different days, teams, or qualifications individually.

5.2.2 Solution visualization

In Figure 6.2, an example of an original solution can be seen, where each appointment is scheduled in the original combination of parameters, they were scheduled for. Each row in the solution represents one combination of parameters, with the structure (day, team, level). Hence, in this example one single day is considered, for one single level (Level 3), and for four different teams. The colours represent the original combination of parameters, at which the appointments were scheduled, and the shade of the colours represent the part of the day at which the appointment needs to take place, with a darker colour representing a later time. Lastly, the columns represent the time in hours, which means that the width of an appointment box represents the duration of this appointment. The visualizations are not representative of the data that is used but should only serve to get an indication of how a solution can look.

5.2.3 Move

The Move operator consists of moving one appointment from a specific combination of parameters to a different combination of parameters. This operator has been visualized in Figure 6.3 below. The neighbourhood using the move operator is thus entirely connected, because any appointment can be moved to any combination of parameters.

There are two constraints for the move operator. Firstly, no appointment can be moved from an empty combination of parameters. Secondly, no appointment can be moved to a combination of parameters that has a lower qualification than is required for the appointment, because this would violate the constraint that each appointment needs to be served by a nurse from this level or from a higher level.

5.2.4 Swap

A swap operator will also be used. A swap operator swaps the location of two appointments, as can be seen in Figure 6.4. The neighbourhood of the swap operator is not entirely connected, because the number of appointments at each combination of parameters cannot be changed using only this operator.

The swap operator needs to be performed on two non-empty combination of parameters. Furthermore, the swap operator requires both combinations of parameters to have sufficiently high levels of qualifications for the appointments being swapped.

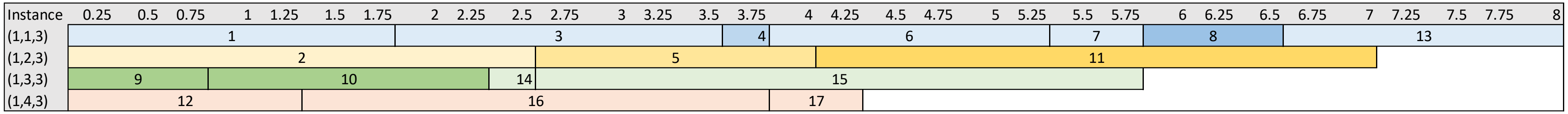

Figure 6.2. Visualization of a possible original solution

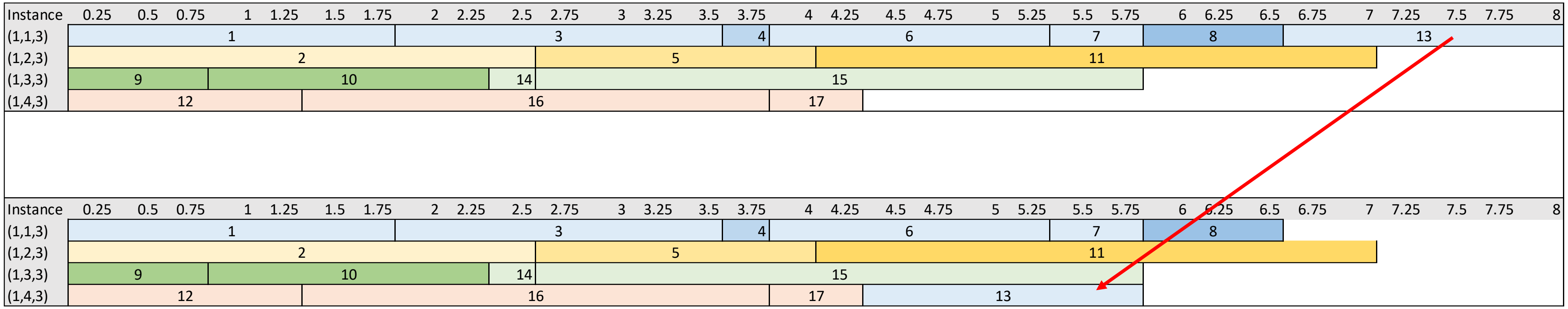

Figure 3. Move operator.

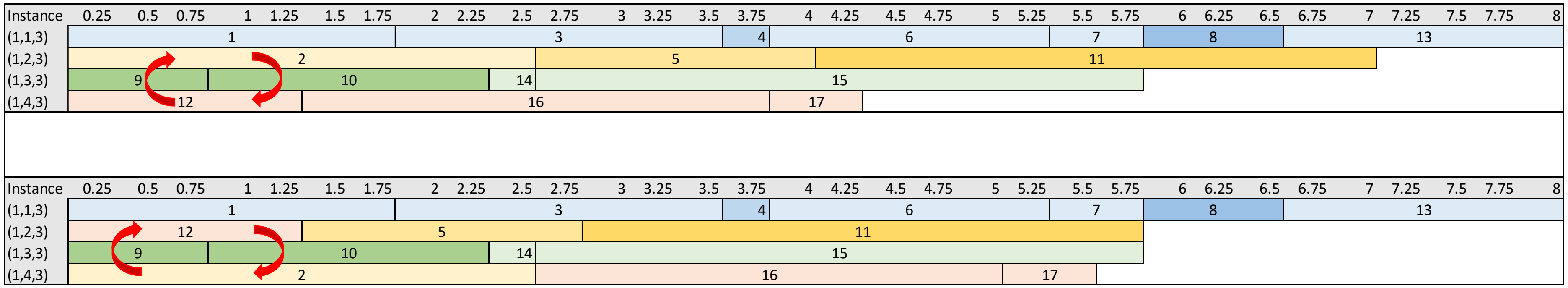

Figure 4. Swap operator

5.3 DETERMINATION OF SHIFTS

The abovementioned operators will determine which appointments, and hence how much care, should be scheduled on each combination of parameters. However, this does not determine how many shifts are scheduled at this combination of parameters to best accommodate the number of appointments scheduled. Nevertheless, this is a significant decision variable and needs to be determined by the model. In general, however, this problem is identical and independent for each combination of parameters, given a certain amount of care that has been scheduled at this combination of parameters, or a certain demand. Thus, this problem can be defined as an independent sub-problem, that takes a certain amount of demand and schedules the shifts in the optimal way given this demand. This problem can be formulated as follows.

Indices

i: parts of the day considered, $i \in \{Morning,\ Noon,\ Evening\}$.

s: Possible shift types, $s \in \{4,\ 6,\ 8\}$.

Parameters

d_i, Demand at time i, $d_i \in \mathbb{R}^+$. This is the sum of the lengths of all appointments scheduled at this time.

O_cost_i, the actual cost of over-capacity at time i, $O\_cost_i \in \mathbb{R}^+$

U_cost_i, the actual cost of under-capacity at time i, $U\_cost_i \in \mathbb{R}^+$

M, a large number.

C^o, the cost of one hour of over-capacity, where $C^o = 1$

C_i^u, The cost to have s hours of under-capacity in shift s at daytime i, where:

$$C_i^u = \left[\frac{11}{15}, \frac{31}{45}, \frac{30}{45}\right]$$

Decision variables

$x_{i,s}$, the number of shifts of length i scheduled at time s, $x_{i,s} \in \mathbb{N} \quad \forall i, \forall s$.

Due to the way in which the shifts are scheduled at TWB, a shift is not always completely enclosed within the part of the day in which it is scheduled. All 4-hour long shifts can be scheduled completely within the part of the day they are scheduled. Because the work usually starts at 7 in the morning, and the noon part of the day starts at 12, the 6-hour shifts that are schedule in the morning will only work in the morning for 5 hours, and for 1 hour in the noon part of the day, and the 8-hour shifts that are scheduled in the morning will only work for 5 hours in the morning and 3 hours in the noon part of the day. The evening shifts functions in a similar way. This constraint is computed in equations 2, 3, and 4.

Objective Function

$$\min_{x_{i,s}} \sum_{i \in I} \sum_{s \in S} C_i^u * O_{cost_i} + C^o * U_{cost_i} \qquad (1)$$

Constrains

1. Constraints finding the capacity for each day part, given the number of shifts scheduled:

$$capacity_{Morning} = 4 * x_{Morning,4} + 5 * x_{Morning,6} + 5 * x_{Morning,8} \qquad (2)$$

$$capacity_{Evening} = 4 * x_{Evening,4} + 5 * x_{Evening,6} + 5 * x_{Evening,8} \qquad (3)$$

$$capacity_{Noon} = C^o * \left(d_{Noon} - 4 * x_{Noon,4} + 6 * x_{Noon,6} + 1 * x_{Morning,6} + 1 * x_{Evening,6} + 3 * x_{Morning,8} + 3 * x_{Evening,8}\right) \qquad (4)$$

2. Constraint ensuring that the unmet demand is only considered if it is larger than 0.

$$U\_cost_i \geq 0 \qquad (5)$$

$$U\_cost_i \geq d_i - capacity_i \qquad (6)$$

3. Constraint ensuring that the over capacity is only considered if it is larger than 0.

$$O\_cost_{i,s} \geq 0 \qquad (7)$$

$$O\_cost_{i,s} \geq capacity_i - d_i \quad (8)$$

4. Constraint to ensure that no shifts of 8 hours are scheduled at noon.

$$x_{Noon,8} = 0 \qquad (9)$$

5. Sign restrictions

$$x_{s,i} \geq 0 \quad \forall i, \forall s \qquad (10)$$

5.4 IMPLEMENTATION

The simulated annealing algorithm and the IP model were both implemented in Python. The shift determining MIP solved optimally, using linear programming. A solution to this problem was implemented in Python using version 3.11.3, by using the PuLP library, with the solver CBC. An implementation was also made of the simulated annealing algorithm (2020).

5.4.1 Approach

The solution is able to, given a certain demand during morning, noon, and evening, to determine the optimal number of shifts. The total demand will of course vary for each combination of parameters. This means that this LP needs to be solved for each combination of parameters in the solution. Furthermore, as the simulated annealing heuristic is evaluating the different alternative solutions, the LP needs to be executed again, in order to find the optimal solution for each of these combinations of parameters. However, this only needs to be done for the combination of parameters that are relevant for the changed solution, i.e., the combination of parameters on which the move or swap operator is acting. The costs of the other combination of parameters will all stay the same, which means that the new cost value will not be affected by these. Avoiding re-evaluating this LP for the entire solution will give significant savings in run time for the implementation of the heuristic.

5.5 PARAMETERS

Before determining the simulated annealing outcome, the parameters of the heuristic need to be determined. To find the maximum temperature $Temp^0$, the approach of Ropke and Pisinger (2006) was used. Through this approach, the initial temperature can be determined based on the objective value x^0. The method determines an initial temperature such that a solution $1 + w^{start}$ worse than the original solution is chosen as the objective function with a probability p (Guericke et al., 2016). Based on the probability calculation for simulated annealing, the formula linking p with w^{start}, $Temp^0$, and, x^0 can be defined as follows.

$$e^{-\frac{(1+w^{start})*x^0-x^0}{Temp^0}} = p$$

This can be rearranged to solve for $Temp^0$

$$Temp^0 = \frac{(1 + w^{start}) * x^0 - x^0}{-\ln p}$$

For these results, a $w^{start} = 0.5$ and $p = 0.5$ are chosen. Given an objective value of the original solution $x^0 = 2130$, we get a starting temperature of

$$Temp^0 = \frac{(1 + 0.5) * 134 - 134}{-\ln 0.5} \approx 97$$

In addition to this, a stopping temperature of $c^{stop} = 0.0001$ was estimated.

Based on the starting and stopping temperatures, as well as on the expected run-time per iteration, total allowed run time, and Markov chain length, an appropriate alpha can be computed. Firstly, the number of possible temperature levels can be computed. Let τ^{iter} is the necessary computation time for one iteration, τ^{total} is the total allowable computation time, and k is the Markov chain length, or the total number of iterations done before lowering the temperature. Then, the total number of temperature levels T can be found according to the following formula.

$$T = \frac{\tau^{total}}{\tau^{iter} * k}$$

The decreasing factor α can hence be described according to the following formula.

$$\alpha^T * c^{start} = c^{stop}$$

Which can be rearranged as follows, to solve for α.

$$\alpha = \sqrt[T]{\frac{c^{stop}}{c^{start}}}$$

In our case, we assume an allowable runtime of 600 seconds, and a runtime per iteration of 0.08 seconds. For simplicity, we choose a Markov chain length of 1, meaning that the α will be adjusted after each iteration. Hence,

$$T = \frac{600}{0.08 * 1} = 7500$$

And,

$$\alpha = \sqrt[7500]{\frac{0.0001}{97}} \approx 0.998$$

These parameters were used in the execution of the heuristic.

5.6 CONCLUSION

A simulated annealing-based heuristic was designed and implemented to solve the problem as has been defined in chapter 4. The aim of the heuristic is to determine how many and which appointments should be moved to other combination of parameters in the problem, to minimize the over-capacity and under capacity. An LP is then used to determine, given a certain list of appointments that need to be scheduled on a certain combination of parameters (and hence a demand for each part of the day), and determines the optimal number of shifts to schedule at this combination of parameters. As the simulated annealing algorithm moves appointments to different combination of parameters, the demand at this combination of parameters should converge so that the LP optimal solution found by the LP results in less over- and under capacity respectively.

6. RESULTS

In this chapter, the results of the research will be reported. In doing this, both the results of the LP model, as well as that of the simulated annealing algorithm will be discussed. This question is hence related to phase 5 of the MPSM, the solution choice phase, and will attempt to answer the research question 7, *How are the KPIs improved or influenced by the heuristic?* In section 6.1, the data used for the experimentation will be discussed, and in section 6.2, the behaviour of the simulated annealing algorithm will be reported. In section 6.3, the results will be reported, and in section 6.4 the schedules resulting from the algorithm will be discussed. Lastly, section 6.5 will contain a conclusion.

6.1 DATA

The algorithm was run on the instance of the data from the TWB database. Actual appointment data was used. The data used is collected at the actual times of the appointments, and contains information about what care is needed, what location the appointment is in (i.e., what team and cluster it belongs to), as well as what date the appointment is and what time it is. The appointments also contain information about how much care is needed for this specific appointment. In the data, there are several appointments scheduled traveling time. This travelling time has been removed from the data in this research. Instead, a fixed travelling time of 15 minutes per appointment has been assumed.

To make the size more manageable, a smaller data set covering only one week, and only one cluster (which includes three teams) was used for the simulated annealing algorithm. This data was used to get an idea of the ability of the algorithm to improve a solution, and hence to give an indication of the feasibility of introducing block scheduling. For the experimentation, only one dataset was used, but several runs of the experimentation were conducted.

The algorithm was used with three different experimental settings, to see how the costs influence the resulting outcomes of the schedule. Firstly, an experiment was conducted with equal weights for all the costs. This was conducted twice, once with three runs and once with ten runs. Then, a cost multiplier of 10 and 50 was used for the over- and under capacity, in experiments 2 and 3 respectively. The other cost multipliers were kept at one in all experiments. Because the introduction of this cost factor is unequal between the different experiments, the objective value of the solutions from the different settings cannot be directly compared.

6.2 SIMULATED ANNEALING BEHAVIOUR

In the first experiment, the weights of the different costs were all equal. This resulted in that the simulated annealing algorithm improved the schedule only barely, or not all. As can be seen from the accepted solutions shown in figure 6.1, the objective value of the accepted solutions almost continually increases; the accepted solution grows continually worse. This explains why the best solution is the original solution, or a solution very similar to it. A similar result could be seen when the same experiment was repeated with 10 runs.

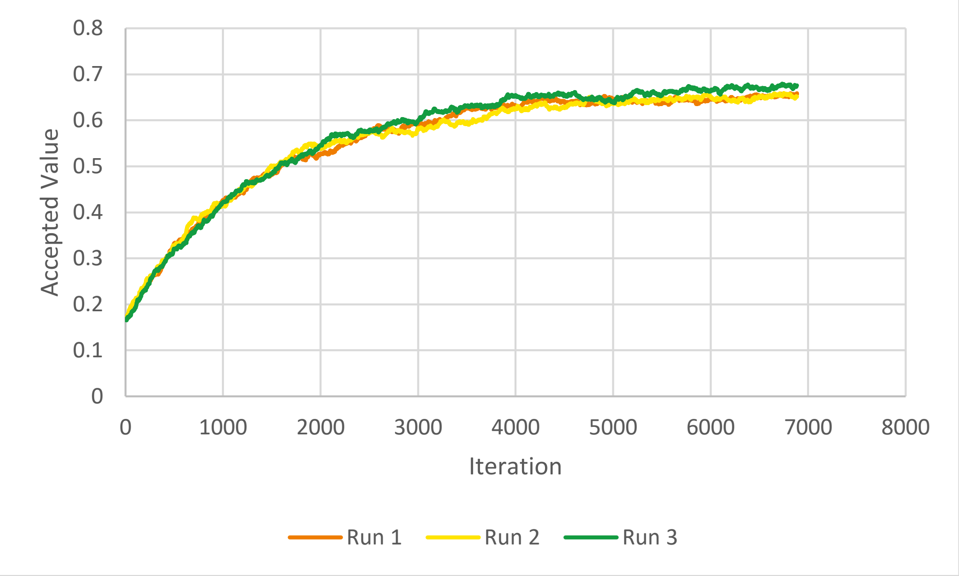

Figure 6.1. Change of the objective value of the accepted solution for experiment 1.

In the second and third experiments, a cost multiplier was introduced for over- and under capacity, the results showed some improvement. The costs of 10 and 50 were used, and with each of these costs some improvement was seen. For the cost of 10, an average of 33% decrease of the objective value was recorded. In figure 6.2, the objective value of the best solution can be seen plotted against the iterations of the simulated annealing algorithm for all three runs.

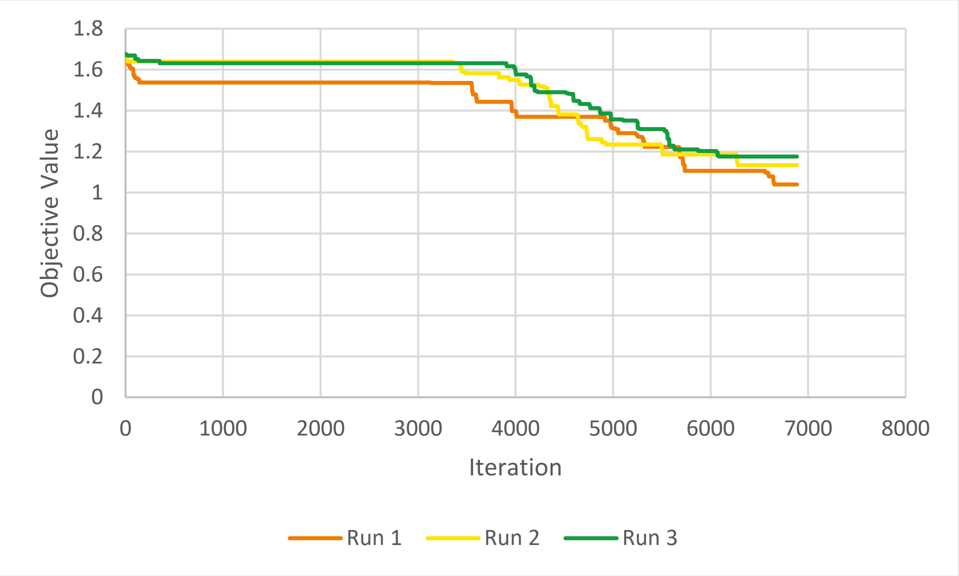

Figure 6.2. Change of objective value of the best solution for experiment 2.

In figure 6.3, the decrease for the cost of 50 can be seen. It is clear that this decrease is much greater, about 60%. However, because of the larger cost multiplier, a similar change in over- and under capacity will have a larger impact on the objective value. Neither of the curves from experiment 1 or 2 seem to be converging, so it is possible that a longer run time can lead to a better solution. However, due to time limitations, this was not tried.

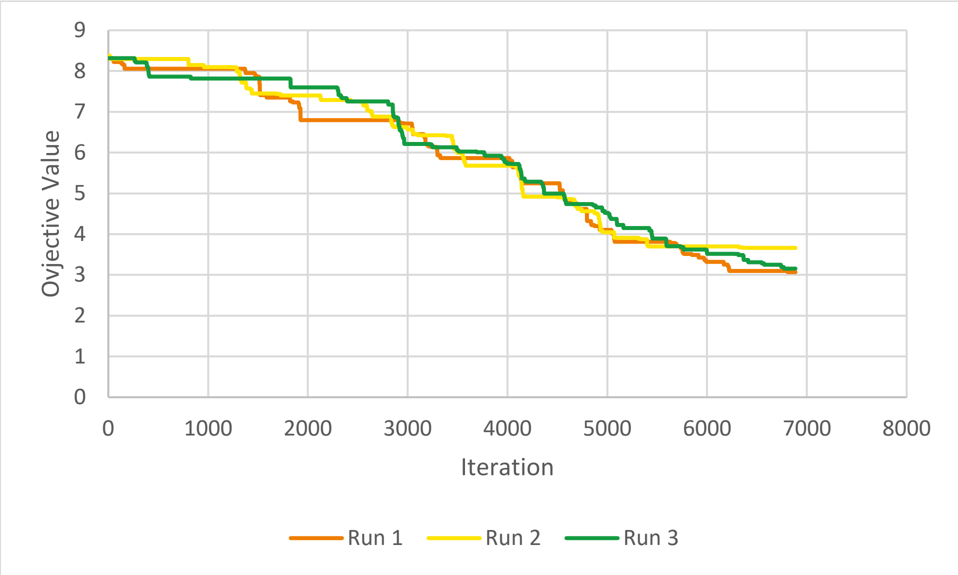

Figure 6.3. Objective value change with iterations.

6.3 SOLUTION ANALYSIS

Firstly, an initial solution to the problem was created. This solution also served as the starting solution for the simulated annealing algorithm. This solution makes use of the LP model used to determine appropriate shifts given a certain demand. In Figure 6.4, the number of shifts of each length can be seen. From this graph, it can be seen that the pattern of having mostly 4-hour shifts is retained. This is not surprising, as there is no flexibility for what times the appointments are scheduled during the day, and because there are in general fewer hours scheduled during midday.

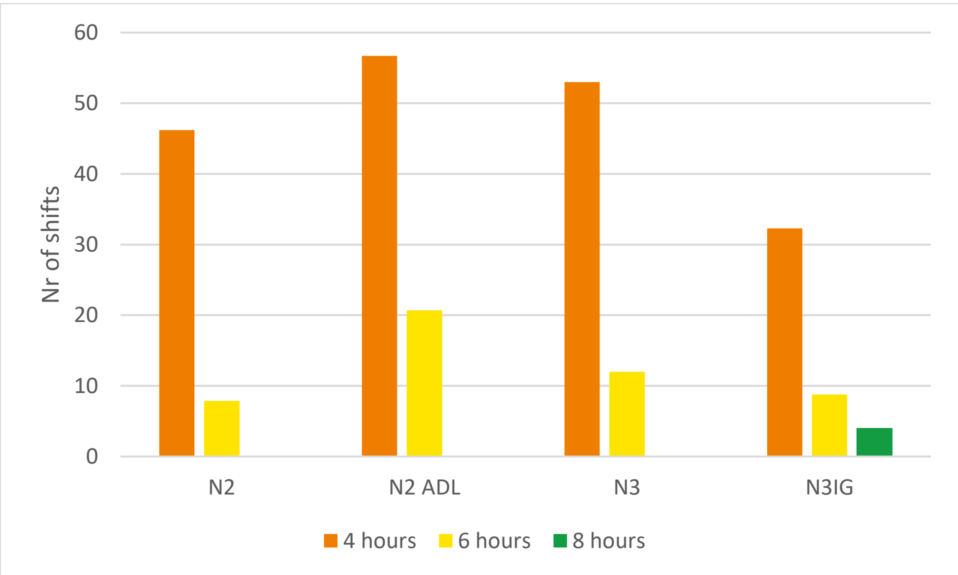

Figure 6.4. Number of shifts of each length per level (average of 10 replications).

In figure 6.5, the outcomes of the different simulated annealing runs can be seen for experiment 1, where all normalized KPIs were given the same weight. Each of these runs were done with the same settings. As can be seen from the figure, only a few of the runs could see any improvement at all in the amount of over- and under capacity, and all of the runs resulted in over- and under capacity that is significantly higher than it would be if no block scheduling has been used. This result is to be expected given that the simulated annealing only barely improved the solution given these settings.

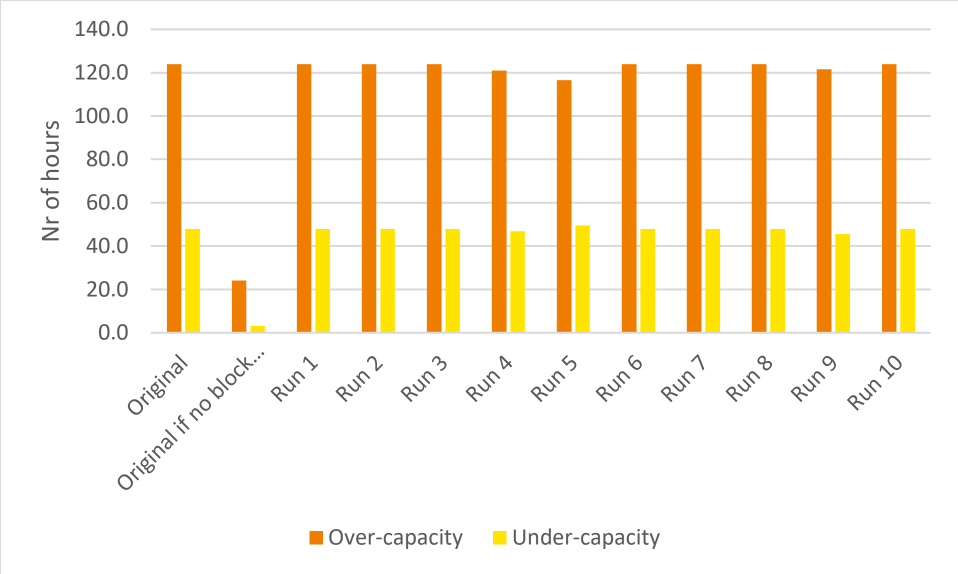

Figure 6.5. Over- and under capacity of the schedules resulting from experiment 1, compared with the original solution and the situation if block scheduling is not used.

In figure 6.6, the results from the different experiments can be seen, also compared with the original solution, and the original solution if no block-scheduling is used. This is used as a comparison to see to what extent the improvements will cover the consequences of the shift to block-scheduling. As can be seen in the figure, the improvements are not sufficient to reach this level, but is not too far from it.

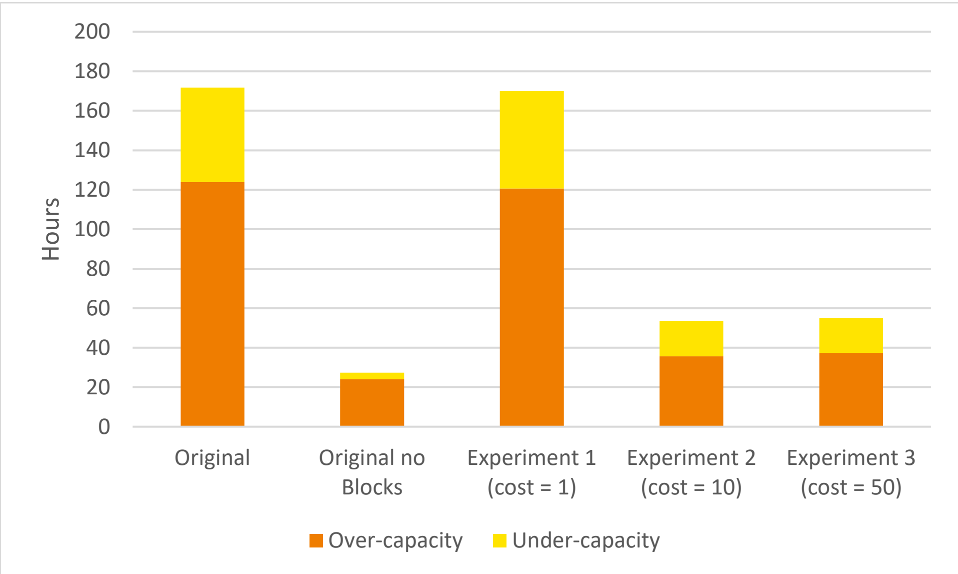

Figure 6.6. Over- and under capacity of the three experiments (average of 3 replications) compared with the original solution and the situation if block scheduling is not used.

In table 6.1, the outcomes of these experiments can be seen in more detail. Three runs were conducted with each experimental setting. The new objective value is compared with that of the original solution. This varies between the experiments, because of the cost multiplier that is used to weight the normalized KPIs.

Table 6.1. Results of the three experiments, compared with their respective objective value for the original solution.

Experiment	Run	Original	Objective Value	Decrease
1	1	0.17	0.17	0%
	2	0.17	0.17	0%
	3	0.17	0.17	1.4%
2	1	1.68	1.04	38.0%
	2	1.68	1.13	32.4%
	3	1.68	1.18	29.8%
3	1	8.38	3.07	63.4%
	2	8.38	3.66	56.3%
	3	8.38	3.15	62.4%

In table 6.2, a more detailed view of the experimental results can be seen. In this table, the normalized KPIs have been translated back into hours for over- and under capacity, and moves for days, teams, and levels. This means that they can be compared between levels, and also with the original solution. From this table, it is clear that while the second and third experiments show great improvements in terms of over- and under capacity, they also lead to a significant number of appointments being shifted from their original day, team, and level. The over- and under capacity hours are per week, which means that already the initial solution show a large improvement from the data analysis in chapter 2.

Table 6.2. Results from the three experiments, translated back into hours and moves, and compared with the initial solution.

	Run	Over-capacity (Hours)	Under-capacity (Hours)	Day Moves	Team Moves	Level Moves
Original	1	123.9	47.9	0	0	0
Original if no block scheduling is used	1	24.2	3.2	0	0	0
Experiment 1	1	123.9	47.9	0	0	0
	2	123.9	47.9	0	0	0
	3	114.3	52.2	15	8	0
Experiment 2	1	25.3	20.2	1435	1075	2635
	2	38.2	17.2	1447	1097	2558
	3	43.6	16.5	1421	1129	2481
Experiment 3	1	32.7	17.6	1444	1148	2646
	2	46.5	16.4	1440	1090	2604
	3	33.1	19.1	1451	1120	2649

6.4 SCHEDULE

In this section, an example of the resulting schedules is shown. Because the tables are very long, the example only contains one day and one team. In table 6.3, the original schedule can be seen for this specific day and team. In this schedule, the demand at a certain day part is shown, as well as how many shifts of 4, 6, and 8 hours are suggested by the algorithm to fill this demand. In the table, the total over- or under capacity that results from this schedule at this specific time is also shown.

Table 6.3. Original schedule for one day, one team

Level	Day Part	Demand (hours)	4-hour shifts	6-hour shifts	8-hour shifts	Over-capacity	Under-capacity
N2 ADL	Morning	11.42	3	0	0	0.58	0
N2 ADL	Noon	0.75	0	0		0.25	0
N2 ADL	Evening	9.00	1	1	0	1.00	0
N2	Morning	11.42	3	0	0	0.58	0
N2	Noon	0.33	0	0		0.67	0
N2	Evening	4.92	0	1	0	1.08	0
N3	Morning	12.12	3	0	0	0	0.12
N3	Noon	0	0	0		0	0
N3	Evening	8.83	2	0	0	0	0.83
N3IG	Morning	10.17	3	0	0	1.83	0
N3IG	Noon	0	0	0		0	0
N3IG	Evening	3.53	1	0	0	0.47	0

In table 6.4, the schedule from the same day and team can be seen after the simulated annealing algorithm has been used. This particular case is from the first run with the second experimental settings. As can be seen in this schedule, the algorithm is removing the appointments from certain days, especially from the lower levels, and aggregate them on other days, teams, and levels. This is often the higher levels, as they can handle all appointments from the lower levels.

Table 6.4. Schedule for one day, and one team.

Level	Day Part	Demand	4 hours	6 hours	8 hours	Over capacity	Under capacity
N2 ADL	Morning	0	0	0	0	0	0
N2 ADL	Noon	0	0	0		0	0
N2 ADL	Evening	0	0	0	0	0	0
N2	Morning	0	0	0	0	0	0
N2	Noon	0	0	0		0	0
N2	Evening	0	0	0	0	0	0
N3	Morning	5.00	0	1	0	0	0
N3	Noon	0.42	0	0		1.58	0
N3	Evening	10.25	1	1	0	0	0.25
N3IG	Morning	24.67	5	1	0	0.33	0
N3IG	Noon	0.75	0	0		0.25	0
N3IG	Evening	15.83	4	0	0	0.17	0

6.5 CONCLUSION

In these results, it can be seen that the algorithm can improve the objective value of the solution, if enough weight is put on over- and under capacity. Naturally, the KPIs of mismatches in day, team, and level get significantly worse through the simulated annealing algorithm, because the original solution already has the optimal value in terms of these KPIs, as it starts by assuming that no such shifts have been made. This means that if a high relative cost is assigned to this type of mismatches, the original solution is already optimal or near optimal, and the simulated annealing algorithm is not able to make any significant improvements to the solution. If these mismatch costs are lover compared with the over- and under capacity costs, however, the algorithm can make significant improvements to the results. To a large extent these improvements consist of entirely emptying certain combination of parameters, and rather reschedule the existing appointments to the other combination of parameters as well as is possible.

7. CONCLUSIONS AND RECOMMENDATIONS

This chapter will offer a discussion around the conclusions and recommendations that can be drawn from this research, as well as what opportunities there are for further research. In section 7.1, the answer to the main research question, '*How can the capacity planning and scheduling at TWB be improved to allow the use of block scheduling?',* as well as the sub-research questions, will be discussed, and some conclusions will be drawn. Next, in section 7.2, there will be a discussion the results; on their quality and reliability, as well as the scientific and practical relevance of them and the potential for future research. Lastly, in section 7.3, there will be a section about recommendations for TWB and how the results of this research can be implemented. This section will answer research question 8, '*How should a successful implementation and evaluation of the solution be ensured?'.*

7.1 CONCLUSION

The main research question posed, '*How can the capacity planning and scheduling at TWB be improved to allow the use of block scheduling?'* is concerned with to what extent, and whether, the scheduling at TWB can be improved so as to allow the introduction of block scheduling. To answer this question, eight sub-research questions were defined. In the following paragraphs, the answers to each of these research questions will be discussed in turn. The last research question, research question 8, will not be addressed here as it will be considered later on in this chapter.

Research question 1: How is the capacity management currently organized at TWB?

The appointment scheduling at TWB is complex, both from a care perspective and from an organizational perspective. This complexity has two main origins: qualification levels, and geographic location. There are six different levels of qualification at TWB, which each corresponds to a type of care that needs to be given. Employees can perform all tasks that require a lower level of qualification than they have, but not tasks that require a higher level of qualification. In addition to the qualifications, there complex geographic divisions of the work at TWB, into clusters and teams. Each cluster is organized somewhat independently, with their own planner and allocated staff. A cluster can consist of several teams, and these teams correspond to a certain geographic area. The staff working in this team then serve this geographic area. In addition to the clusters, there are specialized teams, such as the emergency team, that is specialized on emergencies. The scheduling problem at TWB is complex, because the restrictions between different teams and different levels are generally soft, meaning that the different possible ways a schedule can be made is very large.

Research question 2: What is the potential impact on capacity of the change to block-scheduling?

A data analysis was made of the current shift scheduling at TWB, to identify what potential there is to introduce some form of block scheduling at TWB. From this data analysis, it was concluded that introducing block scheduling without making any changes to the schedule would result in an increase of 200 hours in over-capacity, or 82 hours of overcapacity, and 36 hours of under capacity, depending on how much under capacity is tolerated. However, potential was identified for the improvement of the alignment of the shifts to the block schedule, which shows a potential for the introduction of block scheduling.

Research question 3: What are existing methods and heuristics in optimizing capacity planning?

To answer this research question, a literature review was conducted, through which we identified two similar problems: The Nurse Scheduling Problem (NSP), which is generally considered in a hospital setting, and the Home Healthcare Problem (HHCP), which is defined in the home care setting. Because our research is related to home healthcare, it should be considered as an HHCP, and there are several constraints that are relevant in the HHCP that are not considered in the NSP. Nevertheless, this problem has similarities with both of these problems, and hence solution methods for both were considered. There is a wide variety of problem formulations and solution methods for these problems, both exact and heuristic. For this research, an approach using the simulated annealing heuristic algorithm was chosen, because it has shown to give good results in similar settings (Ceschia et al., 2023).

Research question 4: Which KPIs are relevant in determining the quality of a schedule for TWB?

For this research question, relevant KPIs for the problem were selected. The main KPIs selected were over capacity and under capacity, because these two KPIs together give an idea of how well a shift has been fitted to the schedule, which corresponds to the accuracy with which the nurses get to know their schedule, or to the additional cost of introducing block scheduling, depending on whether block scheduling is used or not. In addition to these two KPIs, the KPIs of date of scheduling, team to give the care, and qualification level to give the care were chosen, and defined as soft constraints. These KPIs are relevant measures of the consistency of a schedule and are hence chosen. These five KPIs can hence be used to determine what is a good schedule.

Research question 5: How can these KPIs be evaluated to investigate the feasibility of a solution?

The first two KPIs, about capacity, and the last three KPIs, of schedule mismatch, are generally contradictory, because in order to improve the capacity fit, the schedule needs to be changed. Hence, a model was developed which minimizes all of these KPIs, and through which a comparison between them can be achieved. With the help of this model and depending on the parameters chosen for the different costs, it can be determined whether it is feasible to find a schedule that allows for a more accurate shift scheduling if less accuracy is allowed in terms of when and to whom the appointments are scheduled.

Research question 6: What heuristic can be designed for the capacity planning at TWB?

As discussed for research question 3, a simulated annealing approach was chosen to solve this problem. The algorithm developed started with an original schedule, where each appointment was scheduled at the originally intended combination of day, team, and level. This schedule was then improved through move or swap operators, guided by the simulated annealing meta-heuristic. To determine the best number of staff to schedule, an LP was defined to be solved independently for each combination of parameters, which took a certain demand as input, and found the optimal number of shifts of different types to schedule given this demand. This LP also took into account at which part of the day the appointments were scheduled.

Research question 7: How are the KPIs improved or influenced by the heuristic?

The heuristic improved the KPIs of over- and under capacity, if large changes in the days, teams, and levels of the appointments were allowed. From a starting value of 124 hours of over-capacity per week, and 49 hours of under capacity per week, the heuristic improved the KPI of over-capacity to 36 hours per week, and that of under capacity to 18 hours per week. However, to achieve this improvement, a large number of appointments had to be moved, in terms of day, team, and level. These KPIs were not improved by the heuristic, because the initial solution was made so that they were all zero. From the settings used in the experimentation, the heuristic did not improve the over- and under capacity enough to result in a lower over- or under capacity than would have been present if no block scheduling had been used.

7.2 DISCUSSION

The main objective of the research was to design a heuristic which can investigate the potential of to introduce block-scheduling at TWB, and hence to answer the research question '*How can the capacity planning and scheduling at TWB be improved to allow the use of block scheduling?'*. To achieve this aim, a simulated annealing algorithm was developed, which tried to improve an existing schedule, to make it more suitable to be a block schedule. With the help of this heuristic, the initial schedule was changed to contain less over- and under capacity, and hence be better fitted as a block schedule. This improvement, however, was caused by a large number of appointments being moved from their original day, team, and level. Because this heuristic is minimizing multiple KPIs, the result of the model depends on which cost parameters, or weights are chosen for the different KPIs. For certain weights of the KPIs, as for instance in experiment 1, the initial solution was near-optimal, or at least the heuristic did not manage to make any large improvements within the assigned run time. For other weights, however, as in experiment 2 and 3, the heuristic made large improvements to the objective value, and hence decreased the over- and under capacity of the schedule. These improvements did, however, also lead to a large increase in the number of appointments that were scheduled at a different day, team, or level. Hence, the ability of the heuristic to improve the schedule depends on which weights are chosen, which in turn depends on to what extent over- and under capacity can be tolerated, and what flexibility can be offered in terms of how much an appointment can be moved between days, teams, and levels. Thus, the heuristic, can serve as a reference for decision-making related to the introduction of block scheduling, but the feasibility of introducing it depends on the priorities TWB.

For pre-defined weights of the different KPIs, the heuristic is hence able to transform a given schedule into a schedule that is better suited as a block schedule. There are, however, certain assumptions that impact the quality of this created schedule. Firstly, the schedule does not consider that some appointments need to be had at specific days or times. This is very important for the actual use of the schedule because it means that some appointments need to be served at specific times. However, it would probably not have a very large impact on the overall outcome of the heuristic, other than serving as an additional constraint. The results of experiment 2 and 3 caused several appointments to be moved from their original day, time, and level to a different one, which caused several of these combinations of parameters to be entirely empty. This is not surprising, as if there are no appointments at a certain combination of parameters, there is neither over- nor under capacity then. However, if there are mandatory appointments at this day for this team, there would be no one to serve them. This also means that many of the combinations of parameters that were used contained very many appointments, so it might have been necessary to include some maximum capacity for them.

Furthermore, because of the large number of different factors that influence the outcomes of the model, there are several areas that can be investigated further. Firstly. A more extensive experimentation can give more certainty in how the simulated annealing algorithm works, and how the solution can be improved. Furthermore, because of the complexity of the scheduling problem at TWB, the model can easily be expanded, to better represent reality. There are a number of aspects that can easily be included to increase the representation of the model. Firstly, there is a possibility to move appointments from one part of the day to a different part of that same day, which has the potential to significantly improve the solution. Especially if a large priority is given to the longer shifts, this would have a great potential to give better results. Secondly, the pattern between days can be investigated, to consider some appointments as fixed, and some appointments as needing to be scheduled at fixed intervals. In general, this model is more focused on amount of care than on the actual scheduling of specific appointments into certain shifts. This would open up a whole new set of research that can be investigated, such as the pattern of appointments over the week, the best starting times of shifts, etc. However, if the appointments are considered on such a detailed level, the actual routing of the appointments starts to become more relevant, which would significantly complicate the problem.

One of the most relevant possibilities for future research is to consider impact of the variability of the planned schedule compared with the actual schedule. To do this, some changes would have to be made to the current model. Firstly, the LP used to determine the shifts, could be used to determine the shifts based only on the predicted data. Then, the simulated annealing algorithm could be used to determine the how to best schedule the actual appointments, given this schedule. The cost parameters for moving an appointment could then be tuned, to allow for some interesting insight into how the possibility to move appointments influence the flexibility of schedules. There could even be a comparison made between a block-scheduling situation and a situation that does not use block scheduling.

Lastly, further sensitivity analysis should be made on the model, mainly to ensure that the cost parameters are well tuned. If experiments are created in which each cost is adjusted separately, it will be possible to determine the impact of each of these costs on the quality of the schedule, and hence be able to determine a good strategy based on the importance of each of the criteria considered.

7.2.1 Contribution of the research

As has been discussed in chapter 3, to the best of our knowledge there has not been much previous attention given to the problem of the type of block scheduling that has been discussed in this research. Often, the nurses in home care only work shifts that cover the appointments they have in a certain day, which means that the actual length of the shifts they work can vary. This means that they get very little stability in their work, as they do not know how long they will work on a specific day until shortly before, in the case of TWB one day before. A type of block-scheduling that ensures that the nurses can work their full shifts would hence be better. However, this requires a better predictability of the scheduling of the employees. This is because by introducing block scheduling any over- or under capacity will be more significant. This research attempted to solve this problem by investigating how more flexible scheduling can be used to allow this form of block-scheduling in a home care context. This question is very relevant, because it has the potential of improving the working conditions in home care. As such, this paper has contributed by suggesting that block scheduling can feasibly be used in home health care, especially if more flexibility is given in the scheduling process. However, to be able to introduce this scheduling, more research ought to focus on, for instance, including more hard and soft constraints in the scheduling, as well as including the time perspective to see how the entire scheduling process can be affected to better accommodate the changes resulting from this form of block scheduling, for instance by focusing on the stability of the schedule. The research is also relevant from a practical perspective, as it has suggested that it is feasible to introducing this type of block-scheduling for TWB, as well as organisations with similar scheduling challenges.

7.3 RECOMMENDATIONS

Introducing block scheduling is, in its own right, not an optimal decision from a capacity perspective, because it means that it is no longer possible to vary the supply to match the demand. Hence, it will always lead to increased over- and under capacity. However, in this research, we have shown that it is much more feasible to make this introduction if more freedom is given in terms of being able to move appointments to different levels and different teams. Whether or not TWB should introduce block scheduling depends on the cost they are willing to take for this change. Hence, we recommend TWB to consider which cost parameters are feasible, and then conduct a sensitivity analysis using, possibly an adapted version of, this model. This would allow them to determine accurately whether the impact of block scheduling can be alleviated using variability in the scheduling of appointments to a sufficient degree to allow block scheduling to be introduced.

The LP, that it used to determine how many shifts to schedule given a certain demand, can be used as a way to determine the number of shifts to schedule given an expected demand for TWB. If needed, more constraints can be used to better represent the reality at TWB, and how the appointments are scheduled. However, as the demand is only known as an estimate, the current model might be sufficient to give TWB insight into approximately how many appointments they should schedule at each time period. It is also possible for TWB to make use of the larger simulated annealing-based model to gain further insights into their scheduling process, as well as to model how an existing schedule can be changed into a block schedule. This would, however, require a flexibility also in which shifts are to be scheduled. We hope that this research will contribute to a better scheduling situation at TWB, as well as give relevant insight for scheduling processes in a larger health care research context.

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9. APPENDICES

9.1 APPENDIX A: PROBLEM CLUSTER AND CORE PROBLEMS

9.1.1 Potential core problems

Problem	Influenceable	Within Scope	Justification
Many mutations	To some extent	No	Only some mutations can be prevented. However, the research could be focused on showing the impact of these mutations and advising TWB on how to prevent them.
Work organized in small units	Yes	Yes	Our research could be focused on showing the impact pooling would have at TWB and giving suggestions on how to implement it.
Capacity and scheduling is mainly done manually	Yes	Yes	Our research could focus on how to define a better and more consistent scheduling system for TWB.

9.2 APPENDIX B: RESEARCH DESIGN

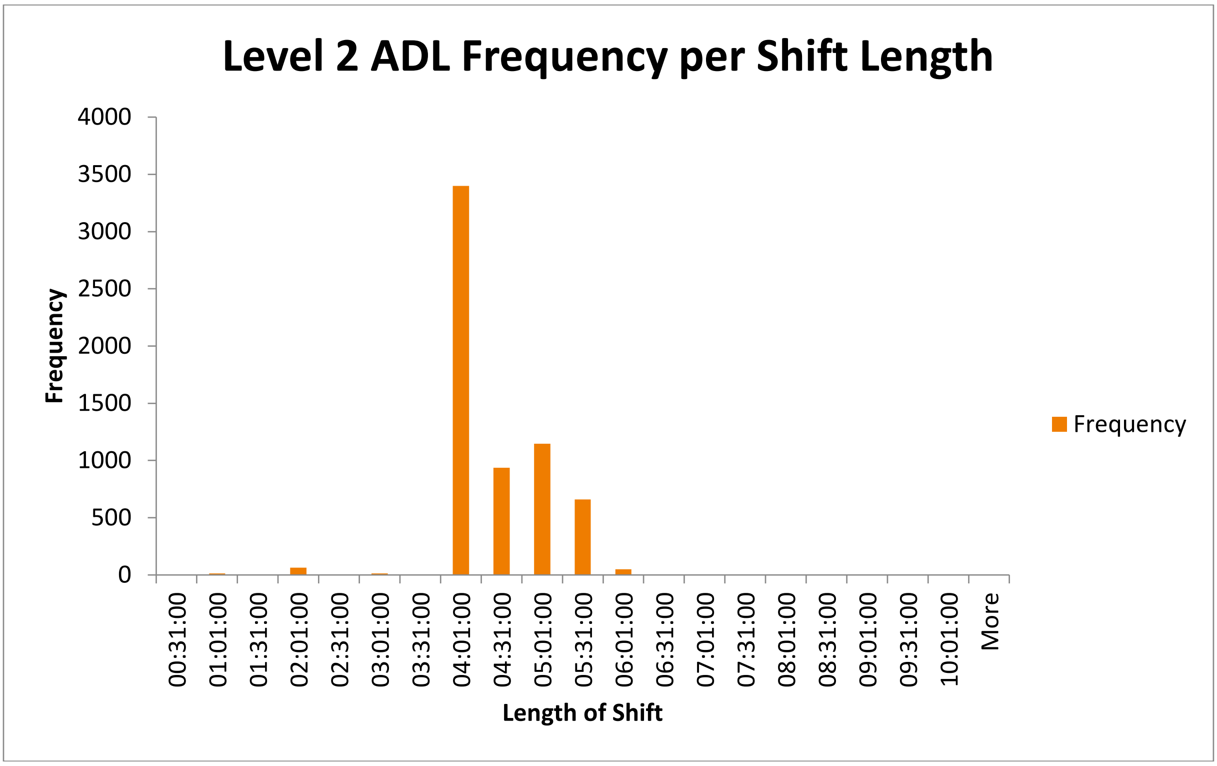
Research Question	How can the capacity planning be improved at TWB to allow the use of block scheduling					
Knowledge Problem	**Phase of MPSM**	**Type of Research**	**Research Population**	**Research Strategy**	**Data Gathering**	**Outcome presentation**
How is the capacity management currently organized at TWB	3	Descriptive	TWB Employees and Management	Qualitative	Interviews	Overview of current schedule and scheduling systems
What is the potential impact on capacity of the change to block-scheduling?	3	Explanatory	TWB Database data	Quantitative	TWB Database Data	Comparison old/new situation
What are existing methods and heuristics in optimizing capacity planning?	4	Descriptive	Literature, Databases	Qualitative	Literature study	Table with common methods

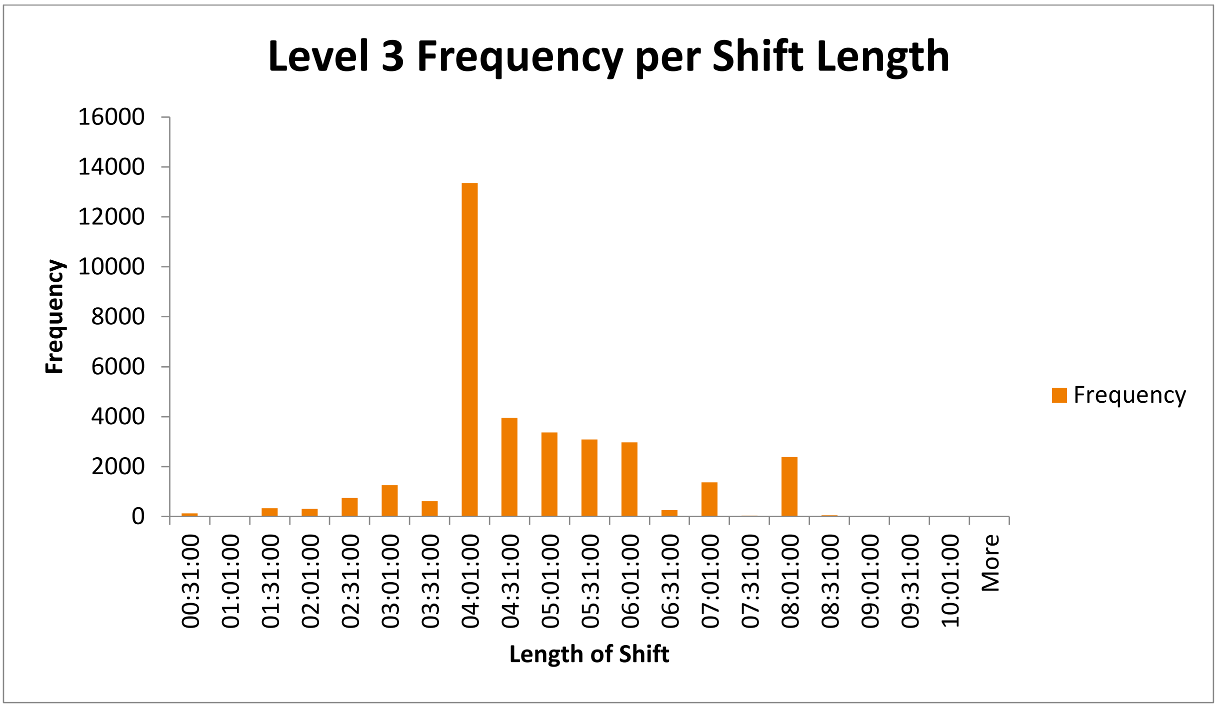
Which KPIs are relevant in determining the quality of a schedule for TWB?	4	Descriptive	TWB Employees and Management, Literature	Qualitative	Semi-structured Interviews, Literature study	List of KPIs
How can these KPIs be evaluated to investigate the feasibility of a solution?	4	Descriptive	TWB Employees and Management	Qualitative	Semi-structured Interviews	List of feasibility criteria
What heuristic can be designed for the capacity planning at TWB?	4 & 5	Descriptive	TWB Planning Dataset	Quantitative	Modelling	Heuristic
How are the KPIs improved or influenced by the heuristic?	5	Explanatory	TWB Planning Dataset, TWB stakeholders	Quantitative	TWB Database data, heuristic	Evaluation of solutions from the heuristic
How should a successful implementation and evaluation of the solution be ensured?	6 & 7	Descriptive	TWB Employees and Management	Qualitative	Observation of organization changes	Plan of action

9.3 APPENDIX C: DATA ANALYSIS

Qualification	**Number of Appointments**
ADL	6292
Level 2	28201
Level 3	34208
Level 3ig	29598
Level 4	7450
Level 5	7117
Null	737
Other	2776

9.4 APPENDIX D: FREQUENCY PER SHIFT LENGTHS




Level 3 Frequency per Shift Length
16000
14000
12000
10000
8000
6000
4000
2000
0
Frequency
00:31:00
01:01:00
01:31:00
02:01:00
02:31:00
03:01:00
03:31:00
04:01:00
04:31:00
05:01:00
05:31:00
06:01:00
06:31:00
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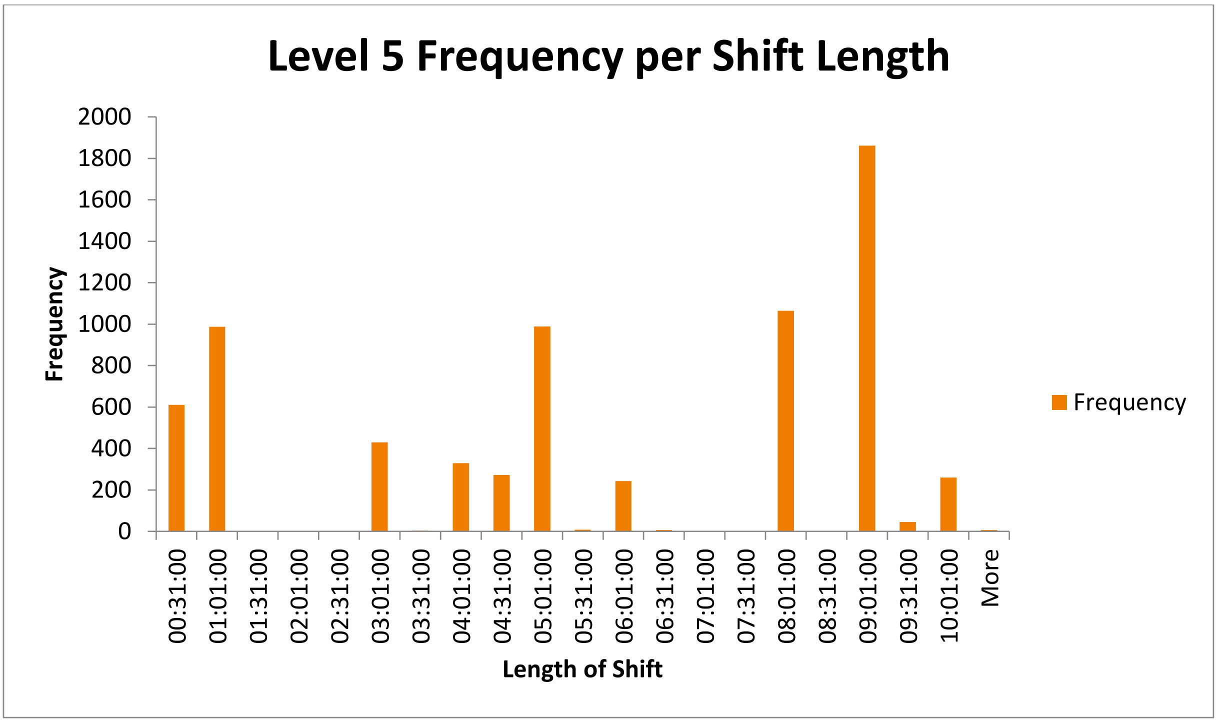
10:01:00
More
Length of Shift
Frequency


Level 5 Frequency per Shift Length
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Frequency
00:31:00
01:01:00
01:31:00
02:01:00
02:31:00
03:01:00
03:31:00
04:01:00
04:31:00
05:01:00
05:31:00
06:01:00
06:31:00
07:01:00
07:31:00
08:01:00
08:31:00
09:01:00
09:31:00
10:01:00
More
Length of Shift
Frequency

UNIVERSITY OF TWENTE
Drienerlolaan 5
7522 NB Enschede

P.O.Box 217
7500 AE Enschede

P +31 (0)53 489 9111

info@utwente.nl
www.utwente.nl