MSc Industrial Engineering and Management
Final Project

Decreasing personnel overtime and the hiring of temporary workers in nursing homes

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Preface

This research serves to conclude my Master of Science in Industrial Engineering and Management (IEM) at the University of Twente. While my study journey started with Industrial Engineering at the Eindhoven University of Technology, I transferred to the University of Twente due to my passion for Industrial Engineering in the healthcare sector. I am very glad I made this decision, as I greatly enjoyed the courses in both the Healthcare Technology & Management and the Operations Management in Healthcare specializations of IEM. In addition to that, I took elective courses from the master program in Data Science and Society at Tilburg University, which enriched my student experience as well. I am very grateful for the opportunities I have had over the past six years and for the enriching student life I have been part of. I would like to express my gratitude to everyone who has been a part of this journey and helped me get to where I am now.

In particular, I would like to thank Erwin Hans. Erwin, thank you for all your guidance and support during the process of writing my thesis, both on an educational and personal level, and for your critical but honest feedback on my thesis. Second, I want to thank Sebastian Rachuba for assisting me in the final phase of my thesis.

Furthermore, I am grateful for the opportunity to conduct my thesis at Ximius, a consultancy and software development company founded in 2019 [65], which provides custom software development services to two sectors: the hospital sector and the VVT sector. The services are aimed at improving patient flow and integrated capacity management within these sectors. Ximius was the perfect company for me to apply the theoretical knowledge from my studies into practice. From Ximius, I would like to especially thank my supervisor, Carmen van der Mark, for her enthusiasm and involvement in my project. You always made time in your schedule when I had questions. I would also like to thank Martin Stevense for providing me with data and for connecting me with the necessary personnel.

Lastly, I would like to thank my family, friends, and boyfriend for their unwavering support and for making the past six years the best years of my life (so far). In particular, I want to thank my parents, sister, Délano, and Maud for supporting me every step of the way and for being proud of me no matter what.

With the end of my student life, a new chapter begins. I am going to travel to Thailand and Vietnam, after which I will start working at Ximius.

I hope you enjoy reading my thesis.

Evelien van der Veen
Eindhoven, October 2023

Executive Summary

Problem Definition

There is currently a large number of growing problems in the nursing, care and home care (in Dutch: Verpleging, Verzorging en Thuiszorg) [43] (VVT) sector. We perform a preliminary study to identify the perceived problems by four different VVT institutions (referred to as institutions A, B, C, and D). The findings of this preliminary study reveal one common denominator problem: the VVT institutions cannot meet demand without hiring temporary workers (which occurs both at institutions A and B) or high amounts of overtime hours (which occurs at both institutions C and D). This common denominator problem is the subject of this master thesis. Furthermore, from the findings of the preliminary study, we conclude that institution D has one of the most workable complexities (mainly because everything is centrally controlled), has a high organizational commitment to making changes for the better, and has a wide diversity of problems. Consequently, this master thesis focuses on institution D. Institution D is a small institution with 140 clients in total.

Objective

Following the findings of the preliminary study, the objective of this master thesis is to develop an intervention for institution D that is expected to reduce the personnel overtime hours, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible.

Method

We use a Mixed Integer Linear Programming model (MILP) that creates shifts and assigns shifts to employees in one step, i.e., that rosters from staffing levels. We do this to better account for personnel preferences. The most important model inputs consist of the staffing levels, the staff availability, the qualification level of the personnel, the department the personnel works for, the contract hours of the personnel, and the number of counting absences. The output of the MILP model presents all shifts that are created per week, per department, with the corresponding assigned personnel member and skill type. Additionally, it indicates the associated overtime percentage and the amount of additional employees needed for this weekly schedule. A time horizon of one week is chosen because institution D wants to have separate rosters for even weeks and odd weeks that repeat every other week, respectively.

To assess the effectiveness of the intervention, we conduct a quantitative analysis through experimentation. We explore the effect of 24 different scenarios on the overtime percentage and on the amount of additional employees needed. The scenarios include different combinations of employee availability, department assignments, and skill levels.

Results, Conclusions, and Recommendations

The experimental results show that our MILP model significantly lowers the overtime percentage for all scenarios for which no additional employees are needed, especially when employees are scheduled within their own department and with either their own skill level or a lower one. Institution D claims to plan by giving each employee the freedom to ask for one free day off a week and for either the odd or even weekends off, and by deploying each employee in their own department, with their own or a lower skill level. Our model calculates an overtime percentage of 4.1% for that specific scenario in even weeks and of 8.3% for that specific scenario in odd weeks, compared to overtime percentages of 9.55% and 14.61% respectively with the existing planning method. This implies that by continuing to schedule employees within their own department and with either their own skill level or a lower one, institution D can improve their overtime percentage by using our model.

The experimental results also show that institution D can only achieve feasible schedules with their current care-delivery personnel under contract if their employees are willing to work shifts below their own qualification level. If their employees insist on working only within their own qualification level, institution D would need to hire an additional 9 to 11 zero-hours contract employees.

To conclude, this research benefits institution D as it introduces an automated model for creating optimized weekly schedules that consider employee preferences, skills, and overtime hours, which aids institution D's planners, provides insights into overtime management, and encourages data-driven decision-making. In addition to these contributions to practice, the research also contributes to theory by addressing a gap in the existing literature. We namely demonstrate the effectiveness of our MILP model in creating complete rosters with multiple shifts per employee from staffing levels, a novel approach compared to previous research.

Discussion

The research is constrained by limitations arising from the lack of comprehensive data and the difficulty in accessing the available data. As a result, the development of the intervention and the prospective assessment are conducted under these data availability and accessibility constraints. Additionally, we must acknowledge a limitation concerning the experimental results: a direct one-to-one comparison between our model results and the actual overtime percentages is not feasible due to differences in when overtime percentages are calculated (pre-scheduled vs. post-scheduled), variations in the knowledge of counting absences, and the presence of hard constraints in our model. Nonetheless, the MILP model offers a promising solution for reducing overtime at institution D.

A suggestion for future research is to base the planning model on the actual demand rather than on the staffing levels. We assume that adopting this approach will lead to even lower overtime percentages and will allow the model to better account for wastes and inefficiencies. Another research suggestion to explore is how to manage holiday periods.

Contents

List of Acronyms

AZW research program labor market, care & welfare (in Dutch: onderzoeksprogramma Arbeidsmarkt, Zorg & Welzijn)

CIZ center indication care (in Dutch: Centrum Indicatiestelling Zorg) [32]

CPB Centraal PlanBureau [10]

FTEs Full Time Equivalent employees [66]

GDP Gross Domestic Product

ILP Integer Linear Programming

KPI Key Performance Indicator

MILP Mixed Integer Linear Programming

NLQF Dutch qualification framework (in Dutch: Nederlands kwalificatieraamwerk)

NZa Dutch healthcare authority (in Dutch: Nederlandse Zorgautoriteit)

OR Operations Research

PNIL non-salaried personnel (in Dutch: Personeel Niet In Loondienst)

VVT nursing, care and home care (in Dutch: Verpleging, Verzorging en Thuiszorg) [43]

Wlz law long-term care (in Dutch: Wet langdurige zorg)

ZZP care package (in Dutch: ZorgZwaartePakket) [51]

Chapter 1

Introduction

This research acknowledges that there is currently a large number of growing problems in the VVT sector, and takes a first step in solving these problems. In particular, the research develops an intervention for the problem that VVT institutions cannot meet demand without hiring temporary workers or high amounts of overtime hours. The intervention is designed for institution D, an intramural VVT institution, specifically.

In this chapter, Section 1.1 includes the context of the research: it states both the sector within which the research is conducted and the institution within that sector on which the research focuses. Section 1.2 describes the motivation for conducting the research and the research problem. Section 1.3 gives the objective of the research, followed by Section 1.4 which includes the research questions that we answer in order to achieve the objective.

1.1 Research Context

This research concerns the VVT sector, where VVT stands for nursing, care and home care (in Dutch: Verpleging, Verzorging en Thuiszorg) [43]. The VVT sector assists elderly who can no longer live fully independently and/or at home. The institutions within the VVT sector assist the elderly by providing either intramural care, extramural care, or both. Intramural care refers to care that clients receive during an uninterrupted stay in an institution, and extramural care refers to care provided to clients who do not reside in an institution. Within the VVT, the former thus involves care in a nursing home (in Dutch: verpleeghuis) or care home (in Dutch: verzorgingshuis) [49], and the latter involves care that the care provider delivers to the client's home (in Dutch: thuiszorg) [48].

This research includes VVT institutions A, B, C, and D that (partly) provide intramural care. The focus, though, is on one of them: institution D. Institution D is chosen, as it has one of the most workable complexities (mainly because everything is centrally controlled), has a high organizational commitment to making changes for the better, and has a wide diversity of problems. Institution D is a residential care center that provides mainly intramural care, and is located in the Netherlands [3]. Institution D has in total 140 clients, divided over five departments: departments 1, 2, 3, 4, and 5. In the departments live respectively 21, 34, 39, 34, and 12 clients. The departments 1 and 2 both contain psychogeriatric clients (clients with mental disorders related to old age, such as dementia), and serve as nursing homes. The departments 3 and 4 contain somatic clients (clients suffering from a chronic physical illness such as Parkinson's, rheumatism, cancer or COPD). These departments are more or less similar to independent living, as the clients that live there have their own room/apartment and receive food, drinks, and if necessary care. In department 5, tenants live independently.

1.2 Motivation

1.2.1 Background

Problems within the VVT sector are a hotly debated topic. This is evidenced by the number of news articles that have been posted on this topic over the years, with headlines such as "The VVT sector: care institution or worrisome institution?" [13], "More and more red signals in the VVT due to absenteeism and high personnel costs" [67], and "Heavy weather coming for the (intramural) VVT sector: almost all institutions are in financial trouble" [26].

These headlines can be explained by the following developments in the sector. First of all, because of the aging of the Dutch society [6, 41, 42], there is both an increasing demand for care [41, 42] and an increasing complexity of demand. With increasing complexity of demand we mean that the number of elderly people with complex care needs is increasing [41]. Next to that, the sector deals with labour market shortages [14, 19, 21]. The increasing care, increasing complexity of care, and labour market shortages together result in an ever-increasing workload for staff [38]. In turn, the ever-increasing workload not only increases the risk of errors within the organization [38], but also results in higher absenteeism and the departure of permanent employees [27]. As of 2018, no "industry" has such a high absenteeism rate as healthcare [8]. In healthcare, absenteeism is the highest among employees in nursing and care homes [7].

In addition to capacity problems, the VVT sector also deals with financial problems. The share of loss-making institutions in the VVT sector, for example, increased from 13 percent in 2020 to 16 percent in 2021 [5, 9]. Moreover, the total personnel costs in the VVT sector in 2021 compared to 2020 increased by 2.0 percent to 16,544 billion euros. This increase is mainly caused by an increase in the amount of temporary workers. In 2015, the cost of temporary workers in the sector still accounted for 5.7 percent of personnel costs, while this rose to 9.6 percent in 2021 [5].

According to the literature, the problems in the VVT sector will become even larger in the future. For example, according to the forecast of the research program labor market, care & welfare (in Dutch: onderzoeksprogramma Arbeidsmarkt, Zorg & Welzijn) (AZW), the labour market shortage in the sector will increase immensely in the coming 10 years. We should expect a shortage of over 37,800 workers in nursing and nursing care and 18,800 in home care in 2032, compared to 11,200 and 4,800 in 2022, respectively [14]. In addition, the aging population is only increasing and the pressure on healthcare will also continue to increase due to the aging of the population [41]. Next to that, the October 2022 estimate of the Centraal PlanBureau [10] (CPB) shows that the collective healthcare spending between 2025 and 2060 will increase from nearly 11 to over 18 percent of Gross Domestic Product (GDP) [10]. This is due to, again, the aging of the population, but also because of new, more expensive treatments, and because of the rising wage costs of healthcare workers [10].

1.2.2 Problem Identification and Statement

This research takes an institutional perspective. In Section 2.3, we present the results of a preliminary study into the perceived problems by four different VVT institutions (institutions A, B, C, and D). From this preliminary study emerges the following common denominator problem: VVT institutions cannot meet demand without hiring temporary workers (which occurs both at institutions A and B) or high amounts of overtime hours (which occurs at both institutions C and D). For the remainder of this research, we select institution D as the institution focused on (as stated in Section 1.1).

1.3 Objective

The objective of this master thesis is to develop an intervention for institution D that is expected to reduce the personnel overtime hours, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible. We perform a quantitative analysis for the prospective assessment of the intervention. This research faces a limitation due to the lack of comprehensive data and the difficulty in accessing the available data. Consequently, we conduct both the intervention development and prospective assessment within the constraints posed by data availability and accessibility challenges.

1.4 Research Questions

In order to achieve the research objective, we answer the following research questions.

1. What is the current situation regarding care demand and care supply at VVT institutions?

To answer this research question, we perform a preliminary study. The preliminary study includes interviews with the capacity managers and/or executives of institutions A, B, C, and D. Next to these interviews, we use other sources of information such as publications of the Ministerie van Volksgezondheid, Welzijn en Sport. The research question is answered in Chapter 2.

2. What are possible causes for the problem that VVT institutions cannot meet demand without hiring temporary workers or high amounts of overtime hours?

By means of the interviews in the preliminary study we not only gain information on the current situation at the four institutions, but also on the problems experienced by the institutions, and the connections between these problems. The latter makes it possible to identify the possible causes for the problem that VVT institutions cannot meet demand without hiring temporary workers or high amounts of overtime hours, thus answering this research question. The research question is answered in Chapter 2 as well.

3. What is the current situation at institution D: which cause(s) is (are) actual causes of the problem that institution D cannot meet demand without high amounts of overtime hours?

From this research question onwards we perform a case study at institution D. The first step in the case study is to find the actual cause(s) of the problem specified to institution

D: institution D cannot meet demand without high amounts of overtime hours. The answer to this research question gives a direction for the intervention. The research question is answered in Chapter 3.

4. Which problem-solving approaches exist that tackle a similar problem with (a) similar cause(s) as the identified problem with its under research question three identified cause(s)?

This research question is answered in Chapter 4 by means of a literature review.

5. Which problem-solving approach given under the fourth research question is best suited to tackle the identified problem including the cause(s) identified under the third research question?

The answer to this research question gives a theory-ingrained base for the intervention in this research. The research question is answered in Chapter 4 as well.

6. What model optimizes the resource capacity allocation of the care delivering personnel in a way that lowers the overtime hours at institution D, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible?

We use the findings from our fourth and fifth research question to design a model that is able to construct a weekly schedule that adheres to our research objective. With the help of this research question, the intervention for institution D is thus built. The research question is answered in Chapter 5.

7. How does the developed model work compared to the currently used (manual) method?

The goal of the intervention is to lower the overtime hours at institution D. Therefore, to answer this research question, we compare the overtime percentage of the developed model for several scenario's to the overtime percentage achieved with the current (manual) method. The research question is answered in Chapter 6.

8. How can the developed model be generalized such that it is also applicable to other institutions in the VVT sector?

The answer to this research question gives insight into the model and its possible extensions. The research question is answered in Chapter 7.

9. What are the limitations of this research and which recommendations for future research can we make?

By means of this research question we reflect on our research. The research question is answered in Chapter 8.

10. What are the managerial implications of the proposed model?

The answer to this research question gives the recommendations that we draw from the experimental results. The research question is answered in Chapter 8 as well.

11. What are the contributions of this research to theory and practice?

This last research question gives the contributions to both theory and practice, where the contribution to theory includes to what extent the model is an addition to the models found in the literature and the contribution to practice includes how the proposed model can be applied to institution D. The research question is answered in Chapter 8 as well.

Chapter 2

Preliminary Study

This chapter gives an answer to both research question 1 "What is the current situation regarding the care demand and care supply at VVT institutions?" and research question 2 "What are possible causes for the problem that VVT institutions cannot meet demand without hiring temporary workers or high amounts of overtime hours?" As mentioned in Section 1.4, we answer both research questions by means of a preliminary study. The sections below give the objective, approach, results, and conclusions of the preliminary study. The result section separates the results of research question 1 and 2.

2.1 Objective

The goal of the preliminary study is to retrieve information, that cannot be found in published documents such as annual reports, on both the current situation at institutions A, B, C, and D, and on the problems as experienced by the institutions and the connections between these problems.

2.2 Approach

The preliminary study includes interviews with the capacity managers and/or executives of institutions A, B, C, and D. For these interviews, we use the semi-structured format. The semi-structured format is the most frequently used interview technique in qualitative research [11] and in a healthcare context [17]. It is a popular data collection method as it is both versatile and flexible [25], and as it is successful in enabling reciprocity between the interviewer and participant [16]. Appendix A provides the questions of the semi-structured interviews, where Section A.1 provides the questions of the semi-structured interview for institutions A and B and Section A.2 for institutions C and D. Both semi-structured interviews have the following categories: 'Introduction', 'Organization Profile', 'Planning', 'Supply and Demand Relationship', and 'Problems'. The category 'Organization Profile' is the only category that differs between the interviews of institutions A/B and institutions C/D. The information that we gain in that section of the interview is used amongst others to answer research question 1.

The interviews are transcribed, after which they are coded with the open coding technique. Open coding is the analytic process of attaching concepts (codes) to observed data during qualitative data analysis. The codes can be a single word or a short sequence of words [15]. The codes that we use all identify a problem or cause (see Appendix B).

After the transcripts are coded, we select a common denominator problem appearing from the four interviews as the problem to focus on in this master thesis. For that common denominator problem we perform a root cause analysis with the help of the coded interview transcripts. The root cause analysis is performed to find out why the institutions cannot meet demand without hiring temporary workers or high amounts of overtime hours. The method of analysis used is a cause and effect analysis. This analysis results in an Ishikawa diagram, also known as a cause-and-effect or fishbone diagram [63, 64]. An Ishikawa diagram is used because "it can be used as a method to delve deeply to identify root causes" [22].

2.3 Results

Appendix C provides a paragraph of one of the transcribed and coded interviews to show how the open coding is performed. Based on the information gained from the interviews (and the literature), the current situation at the VVT institutions is stated in Section 2.3.1, and the perceived problems at the VVT institutions are stated in Section 2.3.2.

2.3.1 Current Situation at the VVT Institutions

Care Demand

In the Netherlands, the demand for elderly care is high: there are more people awaiting care than that there are spots available in VVT institutions. People that await care and cannot be placed immediately are placed on a waiting list. In order to enter the waiting list of an intramural VVT institution, a client needs to be indicated with a Wlz-indication, where Wlz stands for law long-term care (in Dutch: Wet langdurige zorg). This is done by the center indication care (in Dutch: Centrum Indicatiestelling Zorg) [32] (CIZ). The CIZ determines the most appropriate care profile and states this in the indication decision. The indicated care profile determines to what extent the client is entitled to personal care, supervision and nursing. Each care profile requires certain care [50]. The care profiles are described globally (see below) and are not expressed in hours of care per week [32]. The care profile of a client also determines the amount of money that an institution receives from the government for that specific client.

The following care profiles exist in the intramural VVT sector according to the Wlz [60]:

ZZP 4	which entails sheltered living with intensive supervision and extended care
ZZP 5	which entails protective living with intensive dementia care
ZZP 6	which entails protective living with intensive care and nursing services
ZZP 7	which entails protective living with very intensive care, due to specific conditions, with emphasis on supervision
ZZP 8	which entails sheltered living with very intensive care, due to specific conditions, with emphasis on care/nursing
ZZP 9b	which entails recovery-oriented treatment with care and nursing services
ZZP 10	which entails protective living with palliative-terminal care

ZZP stands for care package (in Dutch: ZorgZwaartePakket) [51]. Clients with a ZZP 4, ZZP 6 or ZZP 8 indication are somatic clients, clients with a ZZP 5 or ZZP 7 indication are psychogeriatric clients, and clients with a ZZP 9b are rehabilitation clients.

Institutions A and B are large VVT institutions with several intramural nursing and care locations: institution A has 18 intramural locations and institution B has 10 intramural locations. For both institutions A and B holds that each location delivers different combinations of care. In other words, some locations only have departments with somatic clients, others with both somatic and psychogeriatric clients, others only with rehabilitation clients, etc. Institutions C and D are smaller institutions. They both have one location, where they provide care to both somatic and psychogeriatric clients.

When a client from the waiting list can be admitted to an institution/location (because a spot has become available), a norm is used to translate the client's indication to hours of care. After that, a care plan meeting takes place. In this meeting, the client and the institution make concrete agreements about the care to be provided, given the care needs of the individual client [60] and the approximate amount of care hours that are available.

Until 2014, the Dutch healthcare authority (in Dutch: Nederlandse Zorgautoriteit) (NZa) substantiated care profiles in hours [39]. Since then, institutions have to create their own norm to translate the client's indication to hours of care. Institutions A, B, C, and D do not have their own norm yet. They therefore still use the NZa standard.

If a client's health deteriorates during their stay, a new care profile indication may be requested at the CIZ.

Care Supply

Care supply includes both personnel and spaces. The personnel in VVT institutions are of different qualification levels. The Dutch qualification framework (in Dutch: Nederlands kwalificatieraamwerk) (NLQF) provides guidance for the systematic ordering of these existing qualification levels (based on diploma). The different qualification levels with the corresponding job titles are outlined in Table 2.1 below [62].

TABLE 2.1: Care functions with corresponding qualification level and diploma

Diploma	NLQF level	Job title	Job title in Dutch
MBO level 1	1 [33]	Care assistant	Zorghulp
MBO level 2	2 [35]	Helping care and welfare	Helpende zorg en welzijn
MBO level 3	3 [37]	Caregiver IG (Caregiver Individual Healthcare)	Verzorgende IG (Verzorgende Individuele Gezondheidszorg)
MBO level 4	4 [36]	Nurse	Verpleegkundige
HBO	6 [34]	Nurse	Verpleegkundige

Within the VVT, personnel is only allowed to perform tasks of their own or a lower qualification level. If a personnel member has achieved a certificate for a task of a higher level, the personnel member is also allowed to do that task.

Whether or not a VVT institution has personnel of each qualification level depends both on the care profiles that the clients in the institution have, and on whether or not vacancies are filled. At institutions A and B, they have personnel of all stated qualification levels, at institution C they have personnel of all stated qualification levels except for NLQF level 6 and at institution D of all stated qualification levels except for NLQF levels 4 and 6 [57, 58, 56].

Not only the qualification level of the personnel in VVT institutions differs, the amount of Full Time Equivalent employees [66] (FTEs) under contract per qualification level also differs per institution. This is because the sizes of the institutions differ, and because each institution determines the amount of personnel needed per qualification level (the formation) in a different way. At institutions A, B, C, and D, the formation is determined based on historical calculations. These historical calculations are updated once a year based solely on finances. The historical calculations take the demand at the moment of creation into account. Since the institutions deal with an increasing demand and an increasing complexity of demand, the historical calculations do not match the current demand. In order to match the current demand, new calculations are necessary.

As already mentioned, care supply also includes spaces. The buildings of VVT institutions are separated into several departments. In general, each department is arranged for the care that is provided. For example, normally, departments with ZZP 4, ZZP 6 and/or ZZP 8 clients have larger bedrooms and a smaller or no joint living room, because somatic clients can move around the building and meet each other also in other places than the joint living room (e.g. in the restaurant). Departments with ZZP 5 and/or ZZP 7 clients normally have larger joint living rooms and smaller bedrooms because psychogeriatric clients spend most of their time in the joint living room. This is also the case for institutions A, B, and C. At institution D, the departments are not arranged according to this logic, since institution D is located in a building that originally had a different purpose. They therefore have to make do with the spaces they have in the building, even though these are not ideal from a care delivery perspective.

2.3.2 Perceived Problems at the VVT Institutions

From the interviews appears that there is one common denominator problem: the VVT institutions cannot meet their demand. This results in either the hiring of temporary workers (which occurs at both institutions A and B) or to high amounts of overtime hours (which occurs at both institutions C and D). Therefore, this problem is the subject of this research and serves as the "effect" in the Ishikawa diagram. From the interviews, we also conclude that institution D has one of the most workable complexities (mainly because everything is centrally controlled), has a high organizational commitment to making changes for the better, and has a wide diversity of problems. Therefore, the focus of this master thesis is on institution D.

Figure 2.1 below gives the Ishikawa diagram of the problems in the VVT sector. The problems stated in the Ishikawa comply with the ones found in the literature. The problems that are identified as causes can be subdivided into the categories "care supply", "care demand", and "planning". Since this master thesis focuses on institution D, the Ishikawa diagram serves as a frame of reference to test the situation at institution D.

The possible causes stated in red, purple, and blue relate to the main problem in the following way:

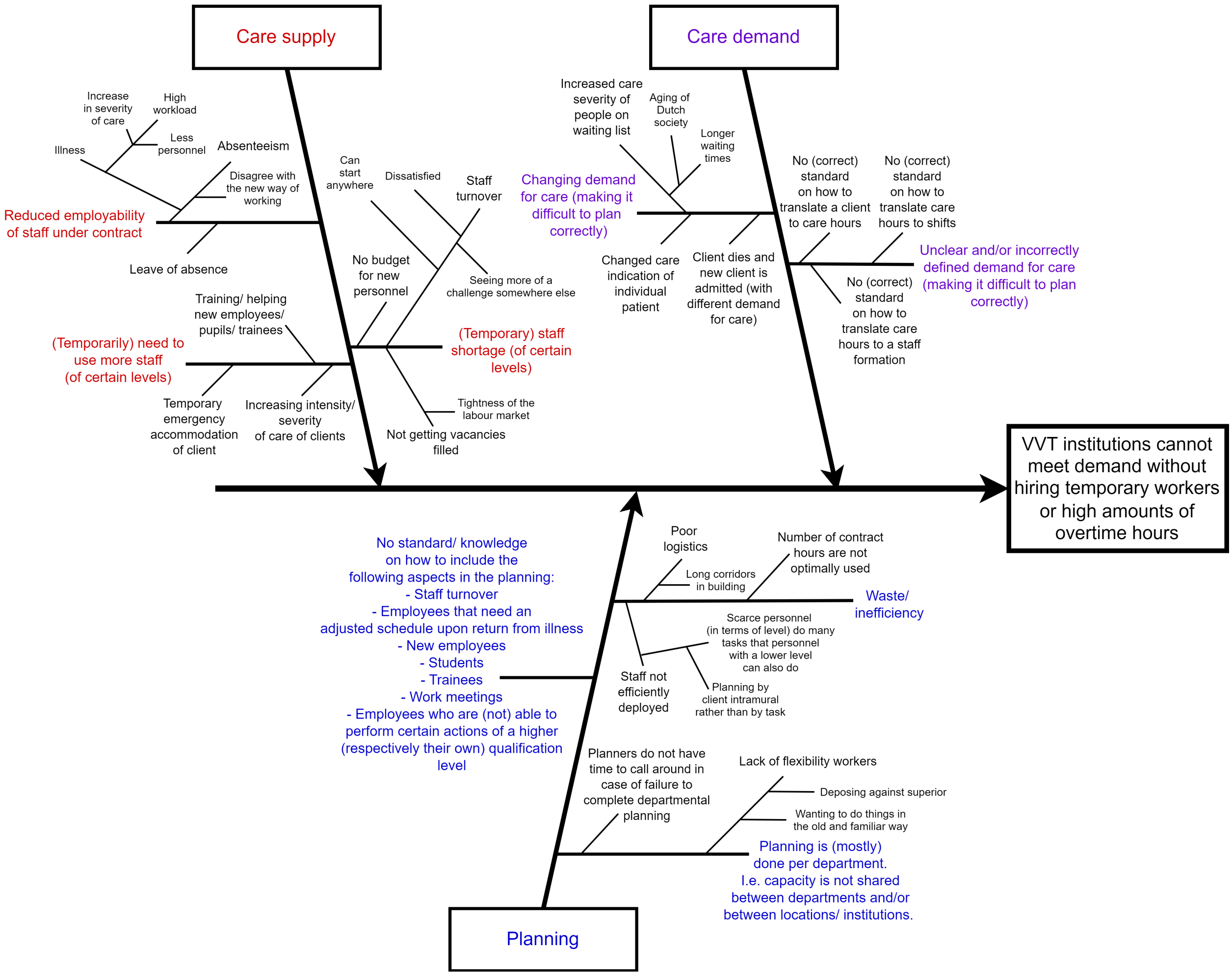

FIGURE 2.1: Ishikawa diagram

Care Supply

1. **Reduced employability of staff under contract**
   When employees under contract have reduced employability in specific weeks, this can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours for those weeks as fewer staff can be scheduled than needed according to the budget. The employability of employees under contract may be reduced due to absenteeism and/or leave of absence.

2. **(Temporarily) need to use more staff (of certain levels)**
   When (temporarily) more staff (of certain levels) need to be deployed, this can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours as more staff is required than initially budgeted for. Reasons why more staff (of certain levels) should be deployed (temporarily) include: training or helping new employees/pupils/trainees, the temporary emergency accommodation of a client, and an increasing intensity/severity of care of clients.

3. **(Temporary) staff shortage (of certain levels)**
   I.e., there are fewer FTEs under contract than that are budgeted. When there is a

(temporary) staff shortage, this can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours because there will be fewer staff to deploy during the period of staff shortage. A staff shortage may occur due to a lack of budget to hire new/additional staff, due to vacancies not being filled (due to scarcity in the labor market), and/or due to staff turnover.

Care Demand

4. **Changing demand for care (making it difficult to plan correctly)**
When there is a changing demand for care, this can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours as heavier care may be needed one week than another. This may be due to a change in the care indication of an individual patient, because a client dies and a new client with a different care demand is admitted, and/or because the care severity of people on the waiting list increases.

5. **Unclear and/or incorrectly defined demand for care (making it difficult to plan correctly)**
When there is an unclear and/or incorrectly defined care demand, this can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours because if the predicted care demand (in hours) is significantly higher than it should be, e.g., more personnel will be planned than is actually needed. An unclear and/or incorrectly defined care demand can occur if there is no (correct) standard on how to translate a client to care hours, no (correct) standard on how to translate care hours to shifts, and/or no (correct) standard on how to translate care hours to a staff formation.

Planning

6. **No standard/knowledge on how to include specific aspects in the planning**
To be precise, there is no standard/knowledge on how to include the following aspects in the planning:

    - Staff turnover
    - Employees that need an adjusted schedule upon return from illness
    - New employees
    - Students
    - Trainees
    - Work meetings
    - Employees who are (not) able to perform certain actions of a higher (respectively their own) qualification level

    This, in turn, can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours as not all employees might be deployed to the fullest extent resulting in more hours of work for other employees.

7. **Waste/inefficiency**
When various wastes and inefficiencies occur (that are not taken into account in the planning), more hours will be worked than planned to complete all the tasks. This leads to personnel overtime. Examples of wastes/inefficiencies include: poor logistics

(lots of running time through long corridors, given that institution D is located in a building that originally had a different purpose), inefficient staff deployment (e.g., when scarce staff levels perform tasks that lower-level staff can also handle), and/or the suboptimal use of the amount of contract hours. With the latter we mean that in weeks with (temporarily) more personnel, it would be beneficial to let personnel work fewer hours than specified in their contract, such that the personnel can work more hours in weeks with fewer personnel.

8. **Planning is (mostly) done per department**
   I.e., capacity is not shared between departments and/or between locations/institutions. If the planning is made per department and departments do not contact each other in case of a staff shortage in certain weeks, this can lead to not being able to meet demand without hiring temporary workers or high amounts of overtime hours as the care demand still needs to be fulfilled.

2.4 Conclusion

The preliminary study presented in this chapter includes interviews with the capacity managers and/or executives of institutions A, B, C, and D. The preliminary study gives insight into both the current situation regarding care demand and care supply at VVT institutions (Section 2.3.1) and the problems, including its connections, as experienced by the institutions (Section 2.3.2). From the preliminary study, it appears that there is one common denominator problem. Namely, that the four VVT institutions cannot meet demand without hiring temporary workers (which occurs both at institutions A and B) or high amounts of overtime hours (which occurs at both institutions C and D). The Ishikawa diagram in Figure 2.1 gives the possible causes for this problem. Furthermore, we conclude that institution D has one of the most workable complexities, has a high organizational commitment to making changes for the better, and has a wide diversity of problems. Therefore, the focus of this master thesis is on institution D, and the Ishikawa diagram serves as a frame of reference to test the situation at institution D. We hypothesize that (a part of) the perceived problems in the VVT institutions, as found in the preliminary study, also occur at institution D.

Chapter 3

Current Situation at Institution D

From this chapter onwards we perform a case study at institution D. The first step in the case study is to state the current situation at institution D in order to determine if and to what extent the possible causes found in Chapter 2 occur at institution D. I.e., to find the actual cause(s) of the problem that institution D cannot meet demand without high amounts of overtime hours. The current situation is described by means of process characteristics and figures (in Section 3.1), the current planning process (in Section 3.2), and Key Performance Indicators (KPIs) (in Section 3.3). "KPIs represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization" [40]. Section 3.4 concludes this chapter.

3.1 Process

As mentioned before in Section 1.1, institution D is a residential care center that provides mainly intramural care. Institution D has in total 140 clients, divided over departments 1, 2, 3, 4, and 5. In the departments live respectively 21, 34, 39, 34, and 12 clients. The departments 1 and 2 contain psychogeriatric clients and serve as nursing homes. The departments 3 and 4 contain somatic clients. These departments are more or less similar to independent living, as the clients that live there have their own room/apartment and receive food, drinks, and if necessary care. In department 5, tenants live fully independently. Institution D has both personnel that provides care (during either the day or night) and personnel that works at for example the restaurant or at the reception.

In total, institution D has 45.9 FTE of care-providing personnel that work during the day. Table 3.1 shows how these FTEs are divided over the qualification levels. In practice,

TABLE 3.1: Number of FTEs under contract per diploma level/qualification level/function (source: [59])

Diploma	**NLQF level**	**Job title**	**Number of FTEs***
MBO level 1	1 [33]	Care assistant	13.0 (-1.6)
MBO level 2	2 [35]	Helping care and welfare	6.9 (-0.8)
MBO level 3	3 [37]	Caregiver IG (Caregiver Individual Healthcare)	26.0 (-0.9)
MBO level 4	4 [36]	Nurse	0.0
HBO	6 [34]	Nurse	0.0

* On the 1st of August 2023 (Calculated ourselves based on the list of employees)

not all FTEs are available, since there are also employees that are for example long-term sick. The number in brackets shows the amount of FTEs of the long-term sick personnel per qualification level. Next to the care-proving personnel that works during the day, institution D has 7.6 FTE of care-providing personnel that works during the night. All of these 7.6 FTE are of the qualification level 'caregiver IG'.

3.2 Control

The current rostering process at institution D consists of 8 phases. The rostering period is one week. The phases, including their time frame and a short description, are given in Table 3.2. Prior to the rostering process, each employee is allowed to ask for a free day a week and/or a free weekend in either the even or the odd weeks. Institution D claims to always oblige by these availability requests.

TABLE 3.2: Rostering process

Phase	Time frame	Description
Phase 1	>- 10 weeks	Requesting vacations and days off
Phase 2	-8 to -6 weeks	Composition of roster
Phase 3	-6 to -4 weeks	Evaluation of draft roster
Phase 4	-5 to -4 weeks	Fill open shifts by flex pool
Phase 5	-4 weeks	Publish final roster
Phase 6	-4 weeks to 0 hour	Communicate open shifts with department
Phase 7	0 hour until the end of the rostering period	Handle ad hoc situations
Phase 8	the end of the rostering period +8 days	Final processing of mutations

The rostering process starts with vacation and leave requests. Vacation and leave requests can be submitted before the 15th of the current month for the period after the next month (phase 1). Between 8 and 6 weeks before the start of the roster period, the roster is created by the planners. This can be done in two ways. If basic rosters are available, they are applied. Basic rosters are available when team leaders, planners, or the administration have decided to create them. They typically make this decision when they notice that rosters are sent out with many open shifts or when there are a significant numbers of plus and/or minus hours. A basic roster shows both the shifts that need to be filled in a certain period (can be a week, a few weeks, a month, etc.) and who are assigned to the shifts. If no basic rosters are available, the rostering is based on historical calculations that state the amount of shifts needed per qualification level per day. The shifts per day are filled by looking at the qualification level, the hours, the availability, and the distribution of the personnel (phase 2). Both the basic and non-basic rosters are created manually and are based on historical calculations instead of on actual demand. Between 6 and 4 weeks before the start of the roster period, the draft roster is discussed with team leaders if necessary (phase 3). After that, shifts that are still open are offered to the flex pool (phase 4). No later than 28 days prior to the roster period, the roster needs to be published (phase 5). After publication, open shifts (e.g., due to sickness absence) should be communicated to the care coordinators and the flex pool (phase 6). Ad hoc situations during the scheduling period are discussed and resolved with team leaders and care coordinators (phase 7).

Before the 8th of the month after the scheduling period, all mutations (such as long-term sickness) must be processed in the scheduling system (phase 8).

The rostering process described above is performed per department. In the rostering process, departments 3 and 4 are combined. We will call the combination of these departments 'department 6'. Department 5 is not included in the rostering process, as the tenants live fully independently. So, the departments that are included in the rostering process are departments 1, 2, and 6. Sometimes departments ask other departments for help if they cannot meet demand without high amounts of overtime hours, but most of the time departments try to fill their rosters with their own personnel (even if that results in overtime).

Next to combining departments, institution D also uses different job title names in the described rostering process. The 'care assistants' are now called 'cliëntondersteuners', the 'helping care and welfare' are called either 'helpende', 'helpende +', or 'medicatie', and the 'caregiver IG' and 'nurse' are combined and called either 'verzorgende' or 'coordinator zorg'. The employees with the job title 'coordinator zorg' perform both caregiver ('verzorgende') tasks and coordinator of care tasks. In other words, not all of their contract hours are spend on providing care. In Section 2.3.1, we already explained that employees are allowed to perform tasks of both their own and lower qualification levels. This means that employees of the type 'verzorgende' can also perform 'medicatie' tasks and 'cliëntondersteuner' tasks, and that employees of the type 'medicatie' can also perform 'cliëntondersteuner tasks'. In the rostering process described above, institution D uses this information to roster their personnel.

The rostering process only specifies who has to work and when, but not what the employees need to do. At the beginning of each shift, the team leaders tell the employees what needs to be done (which clients and what tasks). Next to that, the rostering process does not contain standards on how to include specific aspects in the planning. Think of staff turnover, employees that need an adjusted roster upon return from illness, new employees, students, trainees, work meetings, and employees who are (not) able to perform certain actions of a higher (respectively their own) qualification level. The historical calculations are not updated based on these aspects. Moreover, the historical calculations do not take waste and inefficiencies, such as the poor logistics resulting from the long corridors, into account. Lastly, the planners that perform the rostering process try to roster each employee for as much hours per week as specified by their contract.

3.3 Performance

This section states KPIs that either help to quantify the problem that institution D cannot meet demand without high amounts of overtime hours or help to objectify the extent to which some possible causes are causes of this problem. We have set these KPIs ourselves (based on the available data), since no KPIs were defined by institution D until 2023 because of which barely any data is kept for the in 2023 set KPIs. Table 3.3 gives an overview of the KPIs, and Table 3.4 states whether the KPIs relate to the main problem or to possible causes. During this section, data is provided for either a few years, a single year, several months, or a few weeks. This is due to the limited availability of data and challenges in accessing it.

Table 3.3: KPIs

No.	KPI	Frequency	Unit of Measurement
Financial			
1	Result after tax	Year	Euros €
Clients			
2	The total amount of clients	Month	Numbers #
3	The care profile (ZZP) mix	Month	Numbers #
Internal processes			
4	Absenteeism rate of personnel	Year and Month	Percentage %
5	The difference between the personnel that is needed according to the staffing levels and the personnel that is under contract	Week	Hours
6	The percentage of vacancies that are unfilled	Year	Percentage %
7	The average amount of time vacancies remain unfilled	Week	Weeks
8	The overtime percentage	Year	Percentage %

Table 3.4: Relationship between KPIs and problem or possible causes

No.	Related problem or possible cause
Financial	
1	N/A
Clients	
2	(Temporarily) need to use more staff (of certain levels)
3	Changing demand for care (making it difficult to plan correctly)
Internal processes	
4	Reduced employability of staff under contract
5	(Temporary) staff shortage (of certain levels)
6	(Temporary) staff shortage (of certain levels)
7	(Temporary) staff shortage (of certain levels)
8	Institution D cannot meet demand without high amounts of overtime hours

KPI 1 Figure 3.1 gives the result after tax in Euros of the fiscal years 2017 up until 2022. The figure shows that institution D has had a negative result after tax for the past four years.

KPI 2 Figure 3.2 gives the fluctuations in the total amount of clients staying in the institution for 2022 (so including all departments from 1 to 5). We see an increase in the first two months of 2022. This increase occurred because the backlog, which institution D had accumulated due to the death of many clients in November and December of 2021 as a result of the COVID-19 wave, was recovered. For the rest of the year, we see that the total amount of clients is between 139 and 141.

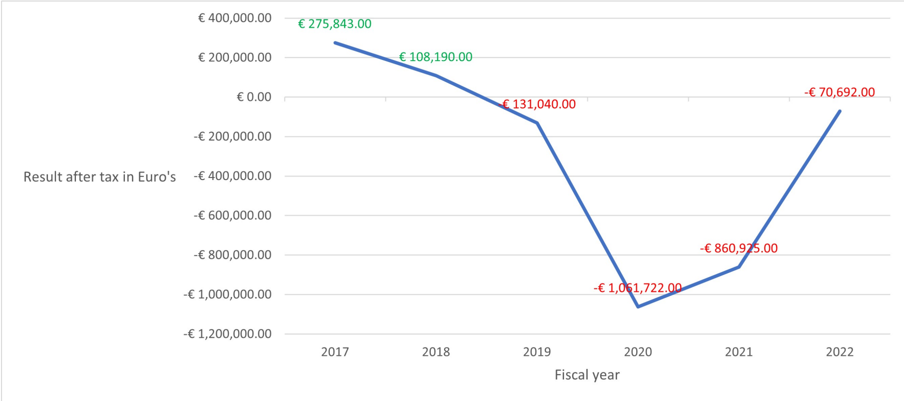

FIGURE 3.1: Result after tax in Euros (sources: [52, 53, 54, 55, 59, 61])

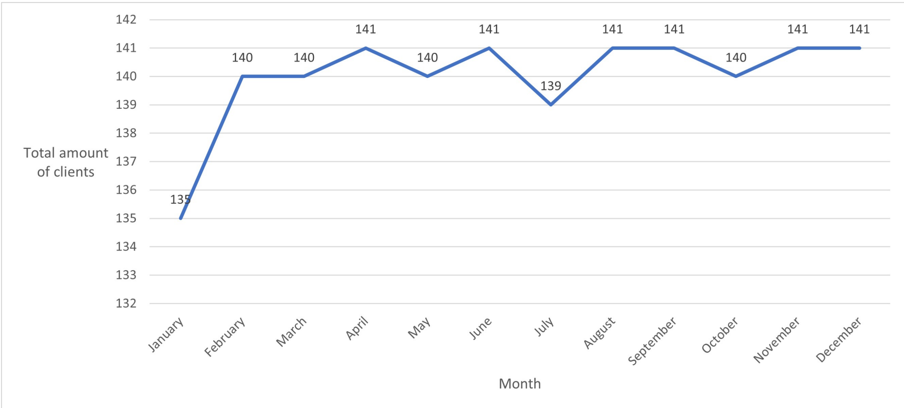

FIGURE 3.2: Fluctuations in the total amount of clients in 2022 (source: manual measurements from institution D)

We know that these are manual measurements of fairly basic production figures. This illustrates the need for proper information systems at institution D.

KPI 3 Figures 3.3 and 3.4 show the ZZP mix for 2022. The ZZP mix is the amount of clients per care profile. In this context, some additional care profiles are introduced, which differ from those discussed in Section 2.3.1. These profiles are defined by institution D rather than conforming to national standards. The figures reveal that there is barely any difference in ZZP mix between the months in 2022.

KPI 4 The absenteeism percentages of the years 2017 to 2022 are shown in Figure 3.5. The figure shows that since 2018 the absenteeism rate at institution D has been higher than the average absenteeism rate of the VVT sector [8]. The quarterly report of Q1 2023 of institution D shows that they have set a norm for the absenteeism percentage since the beginning of 2023. The norm is set on $< 11\%$. The absenteeism percentages of the months April 2022 to March 2023 are shown in Figure 3.6. As can be seen, the absenteeism percentage has not been below the norm in the past 12 months.

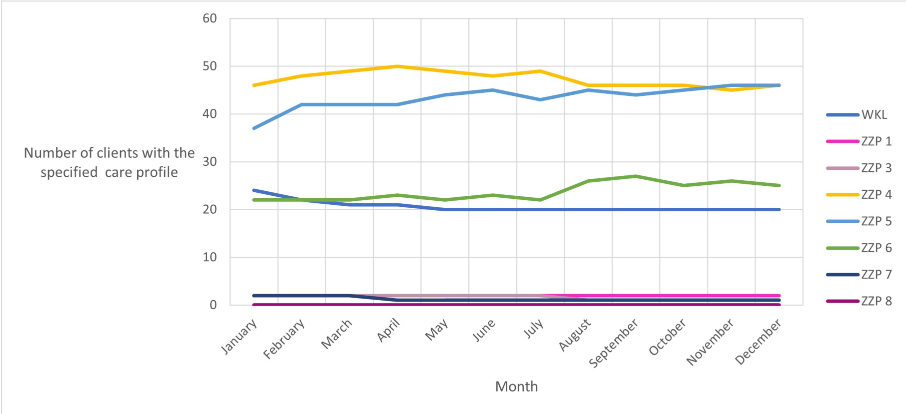

FIGURE 3.3: Care profiles in house 2022 (source: manual measurements from institution D)

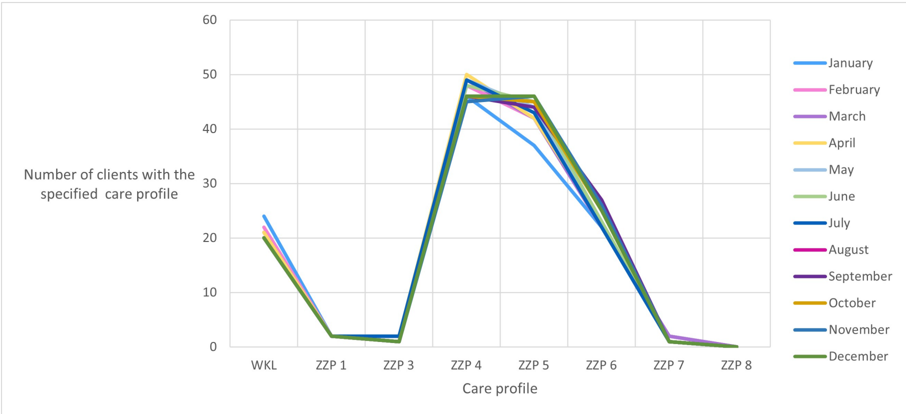

FIGURE 3.4: Care profiles in house 2022 (source: manual measurements from institution D)

KPI 5 Table 3.5 shows the difference between the personnel that is needed according to the staffing levels and the personnel that is under contract (and do not have a long-term sickness). The staffing levels give the required number of employees in each time slot per skill category and per department. The table shows that each department has too few 'cliëntondersteuners' and more than enough 'verzorgende'. Furthermore, it shows that department 6 has too few personnel of the type 'medicatie', while department 2 has more than enough. Combining the personnel per department, department 6 has more than enough personnel, while departments 1 and 2 have too few. Combining the personnel per skill category, institution D has too few 'cliëntondersteuners', and more than enough personnel of the types 'medicatie' and 'verzorgende'. Combining all personnel, institution D currently has too few personnel. Something to note, here, is that there are also employees with a zero-hours contract. These employees are not included in the table. Zero-hours contract employees can work on all departments. There are five 'cliëntondersteuners' with a zero-hours contract and two 'verzorgende'. Assuming that the maximum number of hours a zero-hours contract employee can work per week is equal to 36 hours (so full-time), institution D still has too few 'cliëntondersteuners' and more than enough 'verzorgende'. Including the zero-hours contract employees, institution D has sufficient personnel (7*36 + 1464 = 1716).

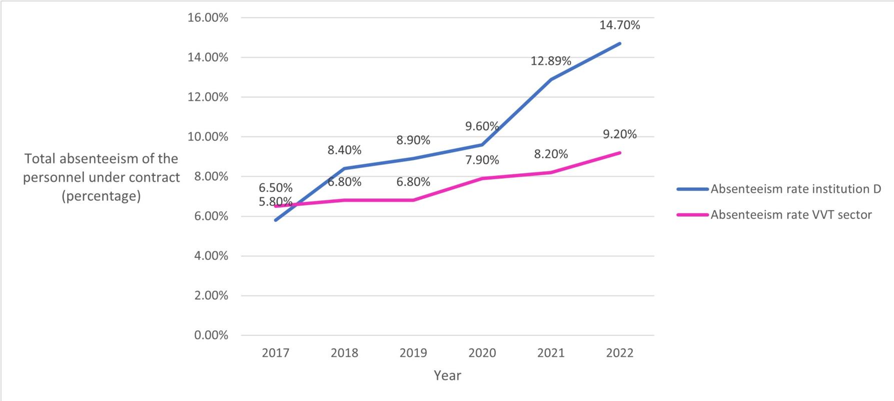

FIGURE 3.5: Absenteeism percentage over the years (sources: [52, 53, 54, 55, 59, 61])

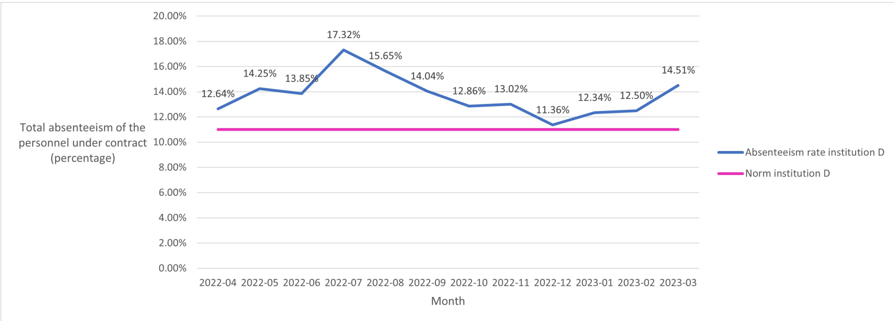

FIGURE 3.6: Absenteeism percentage over the months (source: quarterly report of Q1 2023 of institution D)

TABLE 3.5: The difference between the personnel needed and available

Department	Employee Type	Total needed (in hours)	Total under contract (in hours)
Department 1	Cliëntondersteuners	392	187
	Medicatie	0	0
	Verzorgende	115.5	168
	Total	507.5	355
Department 2	Cliëntondersteuners	392	119
	Medicatie	0	109
	Verzorgende	115.5	225
	Total	507.5	453
Department 6	Cliëntondersteuners	238	104
	Medicatie	119	112
	Verzorgende	231	440
	Total	588	656
Total	Cliëntondersteuners	1022	410
	Medicatie	119	221
	Verzorgende	462	833
	Total	1603	1464

KPI 6 According to institution D's internal systems, 24 job vacancies have been posted online in the period from 2022 to 2023. This number includes vacancies for vacation employees. A total of 20 vacancies were filled during this same period. The number of vacancies filled does not equal the number of employees hired. In fact, some vacancies resulted in more employees being hired. For example, the 'cliëntondersteuners' vacancy led to 8 new employees. The percentage of vacancies that are unfilled is equal to 16.67% (= (24-20)/24 * 100).

KPI 7 Vacancies remain unfilled for on average 6-7 weeks. However, this gives a distorted picture since some vacancies are structurally open. The vacancies regarding 'cliëntondersteuners' and 'verzorgende' are, for example, structurally open as institution D wants to phase out non-salaried personnel (in Dutch: Personeel Niet In Loondienst) (PNIL).

KPI 8 At institution D, they currently do not calculate the overtime percentage. They, however, keep the plus and the minus hours per employee, from which the total overtime percentage can be calculated. The total overtime percentage namely is the total number of plus hours divided by the total number of contract hours times 100. Leave of absence and sickness (i.e., the counting absences) are subtracted from the contract hours. We calculate the overtime percentage for the last period of weeks before the summer holiday in 2023 (week 14, 15, 16, and 17 in April), as these weeks are considered 'normal' with respect to leave of absence figures. Because of data accessibility challenges, we do not give the overtime percentage for the months before April. The calculated overtime percentages are given in Figure 3.7 below. We see that the overtime percentage is higher in odd weeks than in even weeks.

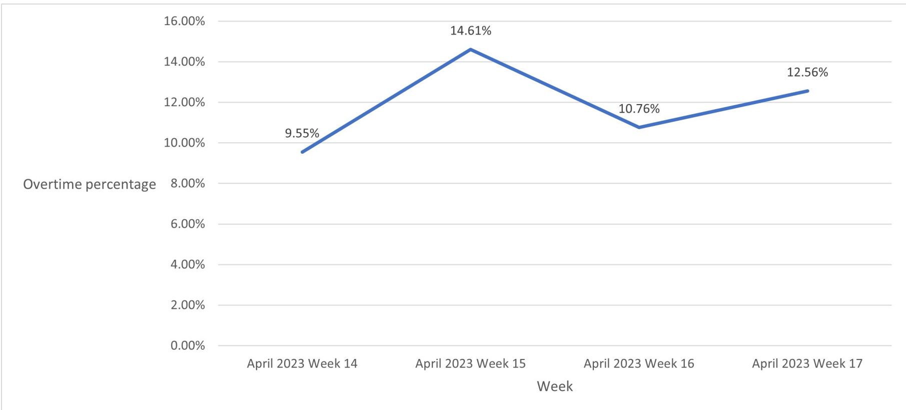

FIGURE 3.7: Overtime percentage over four weeks in April (source: internal system of institution D)

3.4 Conclusion

Based on the current situation at institution D, we state that the possible causes 'Reduced employability of staff under contract', '(Temporary) staff shortage', 'Unclear and/or incorrectly defined demand for care', 'No standard/knowledge on how to include specific aspects in the planning', 'Waste/inefficiency', and 'Planning is (mostly) done per department' as found in Chapter 2 are at play at institution D. Since the employability of the staff under contract and the (temporary) staff shortage are beyond our control, and since we cannot redefine the demand for care for the sake of the available time, the intervention focuses on the remaining three named causes.

Chapter 4

Theoretical Background

In the previous chapter, we concluded that the intervention should focus on the causes 'No standard/knowledge on how to include specific aspects in the planning', 'Waste/inefficiency', and 'Planning is (mostly) done per department'. I.e., the intervention should focus on capacity planning. There are numerous Operations Research (OR) studies on capacity planning in healthcare. Capacity planning in the VVT sector, however, has received hardly any attention as of yet [12]. This chapter discusses the literature devoted so far to capacity planning in the VVT. The chapter starts by explaining tactical and operational capacity planning by means of the framework for healthcare planning and control from Hans et al. [18] in Section 4.1. After that, Section 4.2 discusses the four stages of the care-related capacity planning process for the VVT. In turn, Section 4.3 gives the literature on workload prediction for the VVT, Section 4.4 on staffing for the VVT, Section 4.5 on shift scheduling for the VVT, Section 4.6 on shift rostering for the VVT, and Section 4.7 on the combination of the shift scheduling and shift rostering stages. Section 4.8 describes the research gap, followed by Section 4.9 which gives the conclusions of the chapter. The literature review in this chapter is performed structurally. Appendix D provides more information on the structural approach.

4.1 Framework for Healthcare Planning and Control

Hans et al. [18] propose a reference framework for healthcare planning and control, which hierarchically structures planning and control functions in multiple managerial areas. The framework can be used to identify and position various types of managerial problems, to demarcate the scope of organization interventions and to facilitate a dialogue between clinical staff and managers. We use the framework to demarcate the scope of our intervention. Figure 4.1 gives an example application of the framework of Hans et al. for healthcare planning and control to a general hospital.

The managerial area of focus in this research is, as mentioned before, 'Resource capacity planning'. According to Hans et al., resource capacity planning addresses the dimensioning, planning, scheduling, monitoring, and control of renewable resources. These include equipment and facilities, as well as staff [18].

The hierarchical decompositions of focus in this research are the tactical level and the operational level. Hans et al. [18] state that while strategic planning addresses structural decision making, tactical planning addresses the organization of the operations and/or the execution of the healthcare delivery process (i.e., the "what, where, how, when and who").

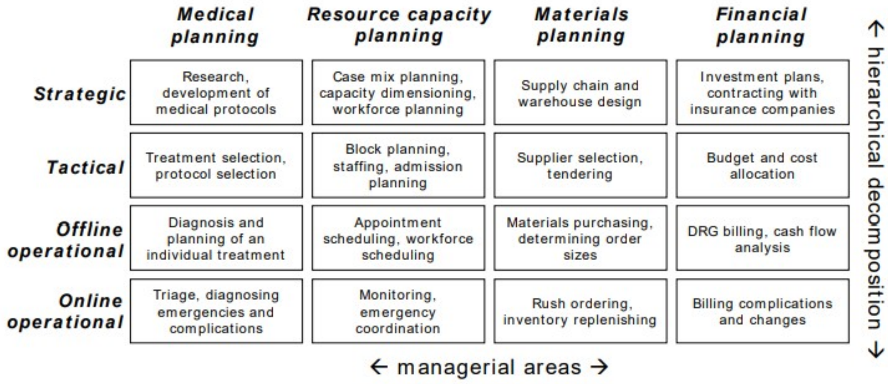

FIGURE 4.1: Example application of the framework of Hans et al. for healthcare planning and control to a general hospital (source: [18])

They furthermore state that, following the concept of hierarchical planning, intermediate tactical planning has more flexibility than operational planning, is less detailed, has less demand certainty, and includes decisions on a longer planning horizon. "For example, while capacity is fixed in operational planning, temporary capacity expansions like overtime or hiring staff are possible in tactical planning" [18]. Conversely, following the concept of hierarchical planning, intermediate tactical planning has less flexibility than strategic planning, is more detailed, has more demand certainty, and includes decisions on a shorter planning horizon. Examples of planning decisions on the tactical level are bed reallocation decisions, temporary bed capacity change decisions, admission control decisions, and staff-shift scheduling decisions [20]. Transmural planning is also an important aspect of tactical management. Transmural care refers to client-centered care, delivered through collaborative efforts and coordination among both general and specialized caregivers who share collective responsibility and allocate specific duties [44]. Transmural planning on the tactical level includes for example the pooling of capacity: nurses can be shared between home care institutions and hospitals or between two home care institutions.

4.2 Care-related Capacity Planning Process

Moeke and Bekker [31] state that the care-related capacity planning process can be divided into four stages: (1) workload prediction, (2) staffing, (3) shift scheduling, and (4) rostering & task assignment, where stages one up until three are at the tactical level and stage four is at the operational level. In stage one, historical demand data is analyzed in order to predict the expected workload over time. The workload predictions form the basis for stage two. Stage two focuses on determining the corresponding staffing levels over time in order to meet the demand, thereby taking uncertainty into account. Stage three aims to develop a shift schedule to meet the staffing levels from the second stage, without over-stretching the available staffing hours. Stage two and three are sometimes combined. Combining stage two and three will often turn out to be convenient for a nursing home setting. From a methodological perspective, shift scheduling deals with the problem of determining the working shifts (start and end times, breaks, etc.), together with the assignment of the number and type of care workers to each shift. Finally, the fourth stage focuses on assigning care workers to specific shifts and tasks. More specifically, it determines both which of the available care workers should be assigned to which shift(s) and which of the available care workers should perform which care tasks at which time of the day in order to meet the demand of the nursing home clients as closely as possible. Not all nursing homes assign tasks to care workers in advance. If they do, the task schedules are often generated for short periods of time (i.e., a few days). If they do not, tasks are being distributed among the team of care workers on the spot (i.e., in real time). Still, the first three steps ensure that supply and demand are sufficiently balanced [31]. Figure 4.2 shows the care-related capacity planning process.

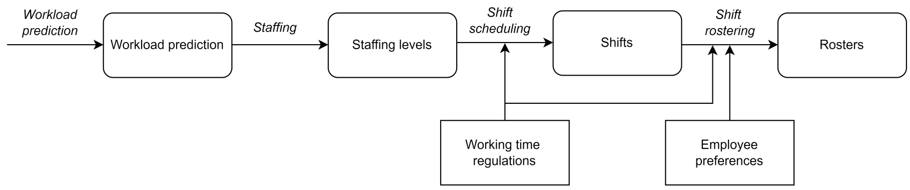

FIGURE 4.2: Care-related capacity planning process (source: [46])

As mentioned in Section 3.2, institution D currently only performs the rostering stage of the care-related capacity planning process. The workload prediction, staffing, and shift scheduling stages are skipped by using historical calculations that state the amount of shifts needed per qualification level per day. These historical calculations are based on a historical demand, and not on the actual (current) demand. For that reason, we assume that the historical calculations are incorrect. Therefore, the intervention in this research will include as much stages of the care-related capacity planning process as is possible according to the available data. Since Section 3.2 states that institution D distributes tasks among the staff on the spot, the task assignment part of stage four is not included in the intervention. Below, all steps of the care-related capacity planning process are described. The last paragraph of each section states whether or not the stage can be performed with the currently available data.

4.3 Workload Prediction

"As the role of capacity planning is to balance capacity with demand, it is crucial to have insight in how the demand behaves over time" [31]. Moeke and Bekker [31] make a distinction between deterministic and random demand. According to them, deterministic demand includes the care activities for which it is possible to make a fairly detailed schedule in advance based on the individual needs and preferences of the clients (think of giving medicine and/or help with getting out of bed in the morning). Random demand includes the non-routine, consequential care activities that cannot be anticipated and planned for in advance (think of providing assistance with toileting). If demand is fully deterministic, the workload, i.e., the number of care workers required to meet the demand, can be predicted by combining the time preferences of clients regarding an activity with the care duration. With respect to random demand, some nursing homes make use of a call button system in which every call button request is registered automatically in a central database. In case a nursing home has such a system or a system in which staff is equipped with a key card which they have to scan in order to enter or leave a room, the workload can be predicted by combining the requests with the duration of the help. If such a system is not available, then an estimate is the best that can be achieved. The estimate should be calibrated based on practical experience [31]. The research of Dieleman et al. [12] gives an example of predicting the workload by means of the time preferences of clients regarding activities and the care durations.

The researches conducted by Moeke and Bekker [31] and Dieleman et al. [12], as referenced in their respective publications, use the preferred starting times and care delivery durations to predict the workload. Since both are currently not known at institution D, and since no other demand data is available than the amount of clients per care profile and the amount of hours determined per care profile according to the NZa standard (as introduced in Section 2.3.1), we are not able to perform this stage. The amount of clients per care profile and NZa standard together are not enough as we also need to know when the care needs to be provided, i.e., the distribution of the care hours, in order to find the amount of employees needed per hour or per half an hour.

4.4 Staffing

Staffing is the process of determining the corresponding staffing levels over time in order to meet the demand [12]. Here, staffing levels include the required number of employees in each time slot. Staffing levels may also specify required skill levels [45]. Staffing levels for example express that two employees of skill level "cliëntondersteuner" should be available on department 1 between 7:30 AM and 10:00 AM, one employee of skill level "verzorgende" should be available on department 2 between 8:30 AM and 9:00 AM, etc.

As already mentioned, the research of Moeke and Bekker [31] makes a distinction between deterministic and random demand. They state that if demand is fully deterministic, the ideal staffing level is equal to the workload. Furthermore, they state that some slack capacity is required for random fluctuations in demand. Regarding a nursing home setting, van Eeden [47] showed that the M/M/s (or Erlang delay) model is applicable to determine the staffing during the night.

Institution D deals with both deterministic and random demand. Consequently, slack capacity needs to be incorporated into the workload predictions to obtain the correct staffing levels. Since we cannot execute the 'workload prediction' stage, we are also unable to perform the 'staffing' stage. Furthermore, even if we were able to carry out the 'workload prediction' stage, additional information would be necessary to allocate the required care hours per care profile to the corresponding hours of care required per qualification level. This information is currently lacking. Nevertheless, institution D has manually established staffing levels, which they have used to create shifts. Therefore, the manually created staffing levels are the most primary workload/staffing level information available. Hence, we will employ these staffing levels as input for the subsequent stages.

4.5 Shift Scheduling

"Shift scheduling is concerned with apportioning the required staffing levels into shifts that are specified by their start times, lengths, the number, and type of employees, and timing of (lunch) breaks" [12]. "A shift schedule should adhere to capacity restrictions, service-level requirements, and (working hours) regulations" [12].

The research of Bekker et al. [4] examines shift scheduling in a nursing home setting. In their study, they develop an Mixed Integer Linear Programming (MILP) model, using a

Lindley-type equation and techniques from stochastic optimisation, that provides optimal staffing patterns across the day. The MILP minimizes the weighted combination of the total average backlog per scenario and the number of shifts. The proposed shift schedules result in a more evenly spread workload for the personnel (and in an improvement of the average waiting time and service level). Moeke and Bekker [31] modify the approach of Bekker et al. by minimizing only the total backlog, since their goal is to optimize performance. In both studies, backlog is defined as the total amount of unfinished work due to not delivering the required care on time. Dieleman et al. [12] extend the approach of Bekker et al. by including differentiated practice. Differentiated practice entails that the available care workers are hierarchically divided into distinct qualification levels (QLs) based on a distinction in education, responsibility, and complexity of care [12, 23]. The research of Dieleman et al. [12] divides the care workers into three QLs, where qualification level one (QL1) is required to perform the least complex tasks and QL3 the most complex tasks.

Next to papers focusing on shift scheduling for Dutch nursing homes, the literature on shift scheduling also exists of papers focusing on nursing homes in other countries. Jiang et al. [24], for example, study a nursing home shift scheduling optimization problem with two nursing staff types, namely regular registered nurses and part-time nurses, under resident demand uncertainty in the USA. They formulate the problem as a two-stage stochastic binary programming model with the objective to minimize the total labor cost (linearly related to work time) incurred by both regular registered nurses and part-time nurses. The analysis offers an operational approach to set the minimum number of nurses on flexible shift schedules to cover the uncertain service needs while maintaining a minimum labor cost. The research of Leung et al. [28] describes the use of cloud computing together with mobile devices for planning the optimal size and mix of nursing teams and scheduling in nursing homes. They state that, in the context of residential care, cloud computing can make the determination and planning of nursing staff demand more efficient and cost effective, while mobile devices can facilitate easy and rapid dissemination of planning information. The research applies the non-dominated sorting genetic algorithm II in cloud computing to solve the integrated nurse staff demand modelling and scheduling problem. A case study of a subvented nursing home in Hong Kong has shown that, by means of this approach, the total overtime work (in hours) was minimized, while the nurse-to-resident ratios were significantly improved. Finally, the research of Liu et al. [30] devotes to the shift design problem and the hierarchical staffing problem, i.e., how to design the time window of each shift to cover the demand periods, and how to allocate the hierarchical staff to the shifts. Liu et al. solve the problem by the two-stage method. In the first stage, according to the characteristics of high time-varying demand, they design the schedule of shifts and determine the number of personnel needed for each shift. In the second stage, they further determine the number of personnel needed for each shift at each level according to the constraints of hierarchical coordination and cooperation.

As our research focuses on a Dutch nursing home in which the care workers are hierarchically divided into distinct qualification levels, the research of Dieleman et al. [12] is the most relevant for our research with respect to the shift scheduling phase. The method of Dieleman et al. needs to be modified to the situation in this research, since our objective differs from Dieleman et al. The focus of our model, namely, is on minimizing the overtime while keeping the amount of temporary workers as low as possible. The research of Dieleman et al. is also the most relevant as there is no uncertainty in our planning situation due to the use of staffing levels as basis.

4.6 Shift Rostering

"Shift rostering is concerned with the assignment of employees to shifts" [45]. The output of the shift rostering process is a work schedule. The work schedules specify for each day and employee the shifts that the employee needs to perform for a planning horizon of typically a couple of weeks or a month. Shift rostering is subject to labor legislation specifying constraints on assignment of both a single shift and combinations of shifts.

Anderson et al. [2] develop a spreadsheet-based rostering tool that automates the generation of rosters and incorporates nurses' preferences for different shifts into the rosters. Nurses' preferences are included as Anderson et al. believe that this will lower the absenteeism rate of staff in nursing homes. At the core of the rostering tool is a hierarchical optimization model that first finds the maximum possible demand that can be satisfied while adhering to all the constraints, and then finds a roster with maximum total preference score which achieves the maximum demand and again satisfies all the constraints. The tool uses an integer programming model to come to near optimal or optimal rosters. The unfilled shifts are than allocated using a heuristic algorithm. The tool is tested in a nursing home in Toronto. It was found that the tool allowed the nursing managers in the nursing home to generate feasible rosters within a fraction of an hour, in contrast to the status-quo manual approach which could take up to tens of hours. In addition, the rosters successfully accounted for preferences with on average above 94% of the allocated shifts ranked as most preferred.

The tool of Anderson et al. includes seniority requirements which the feasible schedules have to abide by. The seniority requirements prioritize more senior nurses when allocating the available shifts. This is not necessary for our intervention. Next to that, the tool of Anderson et al. also has a different objective and is based on the US health system which differs from the Dutch health system. For those reasons, we do not use the tool of Anderson et al. in designing our intervention.

4.7 Combining Shift Scheduling and Shift Rostering

In many personnel scheduling applications, shift scheduling and shift rostering are separate planning decisions (as is depicted in Figure 4.2). Working time regulations constrain the creation of both shifts and rosters, and employee preferences constrain the creation of rosters. A major downside of performing shift scheduling and shift rostering separately is that the shifts that result from the shift scheduling phase might not allow for the creation of good or even valid rosters, since the employee preferences further constrain the feasible shift set. To solve this, the research of van der Veen and Veltman [46] proposes a rostering method that creates rosters directly from staffing levels. See Figure 4.3 for a graphical presentation.

In their study, van der Veen and Veltman restrict themselves to instances where employees are allowed to work at most one shift that consists of one (large) time slot without interruptions. They do this, because the staffing levels include multiple skills, which makes the instances already NP-complete. van der Veen and Veltman study two ways of modelling. The first one is an Integer Linear Programming (ILP) model, in which shifts are modeled implicitly, i.e., they assign a binary decision variable to every combination of employee, time slot, and skill. The second modelling approach is a Branch-and-Bound procedure

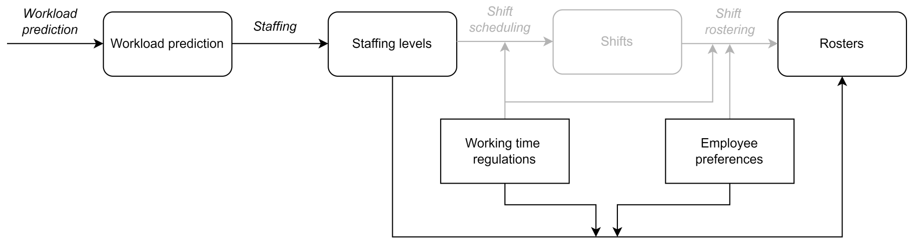

FIGURE 4.3: Care-related capacity planning process as a one-step approach (source: [46])

combined with column generation in the nodes of the branching tree. This approach is commonly referred to as Branch-and-Price (B&P). The research of van der Veen and Veltman assesses the performance of their B&P method by comparing its performance with that of the ILP. The two methods perform almost equally well with respect to solving time. The B&P method, though, turns out to be a far more flexible approach to solve rostering problems. Extending the B&P model with extra rostering constraints is not too hard, while this is much harder (if not impossible) for the ILP model. Next to this, the B&P method is more open to improvements and hence, combined with the larger flexibility, van der Veen and Veltman consider it better suited to create rosters directly from staffing levels in practice.

Since the B&P method is able to create rosters from staffing levels and is flexible in adding extra rostering constraints, the method is relevant for this research. However, the objective of this method is to minimize the total cost, while our objective is to minimize the overtime while keeping the amount of temporary workers as low as possible.

4.8 Research Gap

None of the existing literature that focuses on the VVT sector has a model objective that minimizes the number of overtime hours while keeping the number of temporary workers as low as possible. Furthermore, the research of van der Veen [46] only schedules one shift per employee instead of making a complete roster with multiple shifts assigned to an employee in a week. None of the existing literature actually makes rosters from staffing levels, although this is important as it ensures that employee preferences can be accommodated as well.

4.9 Conclusion

This chapter answers both research question 4 "Which problem-solving approaches exist that tackle a similar problem with (a) similar cause(s) as the identified problem with its under research question three identified cause(s)?" and research question 5 "Which problem-solving approach given under the fourth research question is best suited to tackle the identified problem including the cause(s) identified under the third research question?" The answer to the latter reads: both the research of Dieleman et al. [12] and of van der Veen and Veltman [46] are used as inspiration for our intervention. The former is used as inspiration for our intervention since we also have personnel with three distinct qualification levels, and the latter is used as inspiration since we want to combine shift scheduling and shift rostering in order to account for personnel preferences. Furthermore, as most literature uses an MILP for similar problems, we will also use an MILP.

Chapter 5

Intervention

In this chapter, we build an intervention for institution D that is expected to reduce the personnel overtime hours, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible. We, thus, answer research question 6. Section 5.1 gives the conceptual model of the intervention, including the model inputs and outputs. Section 5.2 thereafter gives each element of the mathematical model of the intervention. The mathematical model is implemented in AIMMS 4.96.2.3, and solved using CPLEX 22.1. To be able to implement the mathematical model in AIMMS, the input data is prepared. Next to that, the output of the AIMMS model is transformed such that it is interpretable and user-friendly. Section 5.3 gives more information on this data preparation in Python, on the model development in AIMMS, and the user-friendly output generation in Python. After that, experiments are done with the model. The experimental design is given in Section 5.4. Section 5.5 gives the conclusions of the chapter.

5.1 Conceptual Model

As already reasoned in Chapter 4, we use an MILP for the specific problem. The MILP creates shifts and assigns them to employees in one step.

5.1.1 Model Inputs

The model inputs of the MILP include:

- The staffing levels (as explained in Section 4.4)
- The staff occupation/availability (for institution D this includes the traffic light method and the requested free days and/or weekends)
- The qualification level of the personnel
- The department the personnel works for
- The contract hours of the personnel
- The number of counting absences (leave of absence and/or sickness) per employee for both an even week (week 14) and an odd week (week 15) in April

Here, the traffic light method gives the staff occupation per personnel member. Red entails that the personnel member cannot work in the specified time slot, orange that the personnel member does not prefer to work in the specified time slot, and green that the personnel member can work in the specified time slot. The requested free days and/or weekends approach entails that every personnel member can ask for both one free day a week and either the odd or even weekends off. As stated in Section 3.2, institution D currently uses the requested free days and/or weekends approach to plan with. They, though, would like to plan with the traffic light method in the future. Therefore, the traffic light method is also included as a model input. For the counting absences, we use data from April as it predates the summer holiday and thus represents the most recent 'typical' month.

5.1.2 Model Outputs

The output of the MILP model presents all shifts that are created per week, per department, with the corresponding assigned personnel member and skill type. Additionally, it indicates the associated overtime percentage and the amount of additional employees needed for this weekly schedule. A time horizon of one week is chosen because institution D wants to have separate rosters for even weeks and odd weeks that repeat every other week, respectively.

5.2 Mathematical Model

This section gives each element of the mathematical model, i.e., the MILP. The section starts by giving the model requirements and assumptions, then gives the sets and indices, the parameters, the decision variables, the constraints, the objective function, and ends by giving the formal problem description.

5.2.1 Model Requirements and Assumptions

The model requirements include:

- The model should reduce the personnel overtime hours
- The model should provide all care that is needed (so it should adhere completely to the staffing levels)
- The model should adhere to all regulations (such as the Dutch labor regulations (in Dutch: de arbeidstijdenwet))
- The model should keep the hiring of temporary workers as low as possible

The model assumptions that are made while defining the problem are:

- Shifts can only start at the beginning of a time slot
- Employees that work as coordinator of care fall under the category 'verzorgende'. However, they have to spend 10 of their contract hours on coordinator tasks
- Personnel that is not assigned to a specific department can work on all departments
- The availability of employee number 68 is not yet added to the traffic light method, and therefore it is assumed that he or she is always available
- An additional employee (if added) has a zero-hours contract, and is available in every time slot of every day and can work on each department with each skill

- No employee can work more than 40 hours a week (so the contract hours and overtime hours together cannot be more than 40)

5.2.2 Sets and Indices

Table 5.1 provides an overview of the sets and indices that we use. The sets I, C, E, and S all represent employees, where the sets C, E, and S are subsets of I. Furthermore, set K represents the feasible shifts. A feasible shift consists of consecutive time slots t. Each time slot t is half an hour. The first time slot of each day is from 7:00 AM till 7:30 AM. The last time slot is from 22:30 PM to 23:00 PM. At institution D, the planning is made per week. Therefore, the set of days D includes Monday to Sunday.

TABLE 5.1: Notation of sets and indices

Set	**Index**	**Definition**	**Subset**
I	i	Set of employees	
I^C	i	Set of employees under contract	$I^C \subset I$
I^E	i	Set of extra employees	$I^E \subset I$
I^S	i	Set of sick employees	$I^S \subset I$
K	k	Set of feasible shifts	
A	a	Set of departments (working areas)	
J	j	Set of skills	
D	d	Set of days	
T	t	Set of time slots	

5.2.3 Parameters

Table 5.2 provides an overview of the parameters of the MILP. All parameter names are equal to the names that are used in AIMMS.

TABLE 5.2: Notation of parameters

Parameter	**Definition**
$b_{\mathrm{i,k,d,t}}$	1 when employee i can work shift k on day d, and when shift k includes time slot t, 0 otherwise
$Characteristics_{\mathrm{i,a,j}}$	1 when employee i can work at department a with skill j, 0 otherwise
$ContractHours_{\mathrm{i}}$	The amount of contract hours for employee i
$NotZeroHourContract_{\mathrm{i}}$	1 when employee i does not have a zero-hours contract, and 0 if the employee does
$CountingAbsences_{\mathrm{i}}$	The amount of counting absences (leave of absence and/or sickness) per employee in hours
$StaffingLevel_{\mathrm{a,j,d,t}}$	Required number of employees per combination of department a, skill j, day d, and time slot t
$TotalContractHours$	The total number of hours the personnel under contract combined need to work

5.2.4 Decision Variables

Table 5.3 provides an overview of the decision variables of the MILP. All decision variable names are again equal to the names that are used in AIMMS. Three types of variables are used: variables concerning planning decisions, auxiliary variables that provide insights into the performance of the model (KPIs), and other auxiliary variables. The first variable, $x_{\mathrm{i,k,a,j,d}}$, is a variable concerning planning decisions. The second and third variables, *OvertimePercentage* and *TotalExtraEmployees*, are auxiliary variables that provides insights into the performance of the model (KPI). All other variables fall under the category 'other auxiliary variables'.

TABLE 5.3: Notation of decision variables

Decision variable	Definition
$x_{\mathrm{i,k,a,j,d}}$	1 if employee i is assigned to shift k at department a, requiring skill competency j, on day d, 0 otherwise
OvertimePercentage	A free variable that states the total overtime as a percentage of the total contract hours
TotalExtraEmployees	A non-negative variable that gives the amount of extra employees that are needed to adhere to the staffing levels
$Breaks_{\mathrm{i}}$	A non-negative variable that states the amount of breaks employee i has in a week
z_{i}	1 or 0
$ActuallyDeployed_{\mathrm{e}}$	1 if extra employee e is actually deployed, 0 otherwise
$WorkedHours_{\mathrm{i}}$	A non-negative variable that states the number of hours employee i has worked in a week
$OverUndertime_{\mathrm{i}}$	A free variable that states the difference between the worked hours and the contract hours of employee i (so the plus and minus hours)
$OvertimeHours_{\mathrm{i}}$	A non-negative variable that gives zero if employee i has made minus hours and states the plus hours/overtime hours if the employee has made those
TotalOvertimeHours	A free variable that gives the combined overtime of all employees

5.2.5 Constraints

In an MILP, constraints help to determine the values of decision variables. There exist both hard constraints and soft constraints. Hard constraints may never be violated. An example of a hard constraint is that an employee can only work one shift per day (on a certain department and with a certain skill). Soft constraints, on the contrary, can be violated if that is necessary. Our model only uses hard constraints. Below, all constraints are explained.

Constraint 1 (Called ObligeToStaffing in AIMMS): This constraint ensures that at least as much employees are working per department, per skill type, per time slot, per day as is stated by the staffing levels. The staffing levels account for breaks. There is thus no need to add extra employees to the staffing levels in the afternoon.

$$\sum_{i \in I} \sum_{k} (b_{\mathrm{i,k,d,t}} \cdot Characteristics_{\mathrm{i,a,j}} \cdot x_{\mathrm{i,k,a,j,d}}) \geq StaffingLevel_{\mathrm{a,j,d,t}} \qquad \forall a, j, d, t$$

Constraint 2 (Called ObligeToLongtermSickness in AIMMS): This constraint ensures that employees that are long-term sick are not assigned to any shifts.

$$x_{\mathrm{i,k,a,j,d}} = 0 \qquad \forall i \in I^S, k, a, j, d$$

Constraint 3 (Called MaxOneShiftPerDay in AIMMS): This constraint ensures that each employee can work at maximum one shift per day.

$$\sum_k \sum_a \sum_j x_{\mathrm{i,k,a,j,d}} \leq 1 \qquad \forall i \in I, d$$

Constraint 4 (Called MaxFiveShiftsPerWeek in AIMMS): This constraint ensures that each employee can work at maximum five shifts per week.

$$\sum_k \sum_a \sum_j \sum_d x_{\mathrm{i,k,a,j,d}} \leq 5 \qquad \forall i \in I$$

Constraint 5 (Called TotalBreaks in AIMMS): This constraint calculates the total number of breaks per employee. This is done by calculating the number of shifts that are assigned to each employee per week.

$$Breaks_i = \sum_k \sum_a \sum_j \sum_d x_{\mathrm{i,k,a,j,d}} \qquad \forall i \in I$$

Constraint 6 (Called WorkedHoursConstraint in AIMMS): This constraint calculates the worked hours per week per employee. Breaks are are not included in the worked hours, and therefore extracted.

$$WorkedHours_i =$$

$$\left(\left(\sum_k \sum_a \sum_j \sum_d \sum_t (b_{\mathrm{i,k,d,t}} \cdot Characteristics_{\mathrm{i,a,j}} \cdot x_{i,k,a,j,d}) \right) - Breaks_i \right) \cdot 0.5 \qquad \forall i \in I$$

Constraint 7 (Called Max40WorkingHours in AIMMS): This constraint ensures that no employee works for more than 40 hours a week.

$$WorkedHours_i \leq 40 \qquad \forall i \in I$$

Constraint 8 (Called ObligeToContractHours in AIMMS): This constraint ensures that each employee that is currently under contract works at least 90% of its contract hours per week (after counting absences are subtracted).

$$WorkedHours_i \geq \frac{90}{100} \cdot (ContractHours_i - CountingAbsences_i) \qquad \forall i \in I^C$$

Constraint 9 and 10 (Called ObligeToContractHoursForExtra and ActuallyDeployedExtraPersonnel in AIMMS): These constraints ensure that an extra employee is only deployed if he/she will then be able to work for at least 90% of a full-time week (of 36 hours) (after counting absences are subtracted). In other words, it ensures that an extra employee is either not deployed or works at least 90% of 36 hours.

$$WorkedHours_i \geq \left(\frac{90}{100} \cdot (36 - CountingAbsences_i)\right) -$$
$$((1 - ActuallyDeployed_i) \cdot M_9) \qquad \forall i \in I^E$$
$$WorkedHours_i \leq ActuallyDeployed_i \cdot M_{10} \qquad \forall i \in I^E$$

Constraint 11 (Called OverUndertimeConstraint in AIMMS: This constraint calculates the over- or under-time per employee. The overtime (under-time) includes the amount of hours an employee has worked more (respectively less) than needed according to their contract.

$$OverUndertime_i = (WorkedHours_i - ContractHours_i + CountingAbsences_i) \cdot$$
$$NotZeroHourContract_i \qquad \forall i \in I$$

Constraint 12, 13 and 14 (Called OverTime, Overtime2 and Overtime3 in AIMMS): These constraints ensures that the $Overtimehours_i$ variable is filled with the maximum of 0 and the $Overundertime_i$ variable. Such that the variable only gives the overtime that is a result from the schedule.

$$OvertimeHours_i \geq OverUndertime_i \qquad \forall i \in I$$
$$OvertimeHours_i \leq OverUndertime_i + z_i \cdot M_{13} \qquad \forall i \in I$$
$$OvertimeHours_i \leq z_i \cdot M_{14} \qquad \forall i \in I$$

Constraint 15 (Called TotalOvertimeHoursConstraint in AIMMS): This constraint calculates the total overtime hours that result from the schedule the model creates.

$$TotalOvertimeHours = \sum_{i \in I} OvertimeHours_i$$

Constraint 16 (Called OvertimePercentageConstraint in AIMMS): This constraint calculates the resulting overtime percentage.

$$OvertimePercentage = \left(\frac{TotalOvertimeHours}{TotalContractHours}\right) \cdot 100$$

Constraint 17 (Called TotalExtraEmployeesNeeded in AIMMS): This constraint calculates the total number of extra employees needed.

$$TotalExtraEmployees = \sum_{i \in I^E} ActuallyDeployed_i$$

Big-M Parameter

In constraints 9, 10, 13, and 14, we use a Big-M parameter. In the context of MILPs, the Big-M parameter, often denoted as "M", is a common technique used to model linear inequalities that involve binary decision variables. It is a way to express logical relationships within the linear programming framework or to linearize non-linear constraints. In our model, we use the Big-M parameter for the latter reason. The Big-M parameter is usually a positive constant that is large enough to guarantee that the constraint is always satisfied when the binary variable is 0 or 1, but not too large such that it does not create numerical instability or a difficulty in solving the MILP. We use a value for the Big-M parameter that is only a bit larger than any expected value of the variables $WorkedHours_i$ and $OvertimeHours_{\mathrm{i}}$. As both $WorkedHours_i$ and $OvertimeHours_{\mathrm{i}}$ can be at most 40, we choose "M" to be 50 for all four constraints.

Symmetry-Breaking Constraints

When running our model, symmetry occurs. "The presence of symmetry in MILP formulations leads to multiple solutions with equal objective function values that force MILP solvers to explore a vast number of nodes of the tree" [29]. One can try to break the symmetry by adding symmetry-breaking constraints. The symmetry, that occurs when running our model, concerns the variable $x_{\mathrm{i,k,a,j,d}}$. This symmetry occurs with respect to indices i, k, a, j, and d. For example, symmetry occurs between $x_{1,54,3,1,1}$ and $x_{1,54,3,2,1}$, which means that the objective function value remains the same whether employee 1 works shift 54 at department 3 on day 1 with skill 1 or with skill 2. When experimenting with symmetry-breaking constraints, we find that all possible symmetry-breaking constraints restrict the MILP model as much that the model outcomes become infeasible for each scenario. Therefore, we decide not to include symmetry-breaking constraints.

5.2.6 Objective Function

The objective of the MILP is to minimize the overtime percentage, while keeping the number of additional employees as low as possible. We choose the values for α and β in a way that complements this objective. By means of experiments, we find that α must be 1 and β must be 5 to meet the objective. See Tables 7.1 and 7.2 for evidence.

$$Min \quad (\alpha \cdot OvertimePercentage) + (\beta \cdot TotalExtraEmployees)$$

5.2.7 Formal Problem Description

We state the complete MILP on the next page.

$$\textbf{Min } (\alpha \cdot \mathrm{OvertimePercentage}) + (\beta \cdot \mathrm{TotalExtraEmployees})$$

$$
\begin{aligned}
&\sum_{i \in I} \sum_{k} (\mathrm{b}_{i,k,d,t} \cdot \mathrm{Characteristics}_{i,a,j} \cdot \mathrm{x}_{i,k,a,j,d}) && \geq \mathrm{StaffingLevel}_{a,j,d,t} && \forall a, j, d, t \\
&\mathrm{x}_{i,k,a,j,d} && = 0 && \forall i \in I^S, k, a, j, d \\
&\sum_{k} \sum_{a} \sum_{j} \mathrm{x}_{i,k,a,j,d} && \leq 1 && \forall i \in I, d \\
&\sum_{k} \sum_{a} \sum_{j} \sum_{d} \mathrm{x}_{i,k,a,j,d} && \leq 5 && \forall i \in I \\
&\mathrm{Breaks}_i && = \sum_{k} \sum_{a} \sum_{j} \sum_{d} \mathrm{x}_{i,k,a,j,d} && \forall i \in I \\
&\mathrm{WorkedHours}_i && = \left(\left(\sum_{k} \sum_{a} \sum_{j} \sum_{d} \sum_{t} (\mathrm{b}_{i,k,d,t} \cdot \mathrm{Characteristics}_{i,a,j} \cdot \mathrm{x}_{i,k,a,j,d}) \right) - \mathrm{Breaks}_i \right) \cdot 0.5 && \forall i \in I \\
&\mathrm{WorkedHours}_i && \leq 40 && \forall i \in I \\
&\mathrm{WorkedHours}_i && \geq \frac{90}{100} \cdot (\mathrm{ContractHours}_i - \mathrm{CountingAbsences}_i) && \forall i \in I^C \\
&\mathrm{WorkedHours}_i && \geq (\frac{90}{100} \cdot (36 - \mathrm{CountingAbsences}_i)) - ((1 - \mathrm{ActuallyDeployed}_i) \cdot \mathrm{M}_9) && \forall i \in I^E \\
&\mathrm{WorkedHours}_i && \leq \mathrm{ActuallyDeployed}_i \cdot \mathrm{M}_{10} && \forall i \in I^E \\
&\mathrm{OverUndertime}_i && = (\mathrm{WorkedHours}_i - \mathrm{ContractHours}_i + \mathrm{CountingAbsences}_i) \cdot \mathrm{NotZeroHourContract}_i && \forall i \in I \\
&\mathrm{OvertimeHours}_i && \geq \mathrm{OverUndertime}_i && \forall i \in I \\
&\mathrm{OvertimeHours}_i && \leq \mathrm{OverUndertime}_i + \mathrm{z}_i \cdot \mathrm{M}_{13} && \forall i \in I \\
&\mathrm{OvertimeHours}_i && \leq \mathrm{z}_i \cdot \mathrm{M}_{14} && \forall i \in I \\
&\mathrm{TotalOvertimeHours} && = \sum_{i \in I} \mathrm{OvertimeHours}_i && \\
&\mathrm{OvertimePercentage} && = \left(\frac{\mathrm{TotalOvertimeHours}}{\mathrm{TotalContractHours}} \right) \cdot 100 && \\
&\mathrm{TotalExtraEmployees} && = \sum_{i \in I^E} \mathrm{ActuallyDeployed}_i &&
\end{aligned}
$$

5.3 AIMMS Model

As mentioned earlier, the mathematical MILP model presented in the previous section is implemented in AIMMS 4.96.2.3, and solved using CPLEX 22.1. AIMMS is a toolkit for rapid optimization modeling and app development [1]. In order to run the MILP in AIMMS, some of the in Section 5.1.1 described input data has to be prepared. Namely, the binary parameters $b_{i,k,d,t}$ and $Characteristics_{i,a,j}$ for each combination of i, k, d, t and i, a, j, respectively, have to be created by means of the employee availability, the qualification level of the employees and the department the employees work for. Snapshots of the inputs and outputs are given in Appendix E.

After preparing the data for use in AIMMS, the model is built. Appendix F shows the model explorer of AIMMS. The AIMMS model gives as output a .out file showing the decision variables $x_{i,k,a,j,d}$, *OvertimePercentage*, and *TotalExtraEmployees*.

To be able to easily interpret the AIMMS output, we transform the .out file to a user-friendly Excel file that states the employee names with their corresponding shifts per day, the department name per shift, and the skill type per shift, instead of coded data. Snapshots of the inputs and outputs are given in Appendix G.

5.4 Experimental Design

The objective of this master thesis is not only to develop an intervention for institution D that is expected to reduce the personnel overtime hours, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible, but also to perform a quantitative analysis for the prospective assessment of the intervention. This section gives the experiments that we perform in Chapter 6. The experiments serve as a prospective assessment, and involve experimentation in three areas:

- The staff occupation/availability (rows of Table 5.4)
- The qualification level of the personnel (columns of Table 5.4)
- The department the personnel works for (columns of Table 5.4)

With respect to staff occupation, we use the availability as is given by the traffic light method (both for even and odd weeks), the availability if each employee can only ask for one free day a week and/or for the even or the odd weekends off, and an availability where each employee is available at all times. With respect to the qualification level of the personnel, we use either that each employee can only work shifts of their own skill or that each employee can work shifts of their own and lower skills. With respect to the department, we use either that each employee can only work at their own department or that each employee can work at all departments. This brings us to the scenarios as described in Table 5.4. Each experiment checks for a different scenario whether it is possible to meet the staffing levels. Scenarios 10 and 14 represent the currently used planning approach.

Note that each availability type yields different values for $b_{i,k,d,t}$, and that each combination of department (own or all) and skill (own or lower also) results in different values for $Characteristics_{i,a,j}$. We expect the 'all departments, own skill' and 'all departments, own or lower skill' scenarios to perform at least as well as the 'own department, own skill'

TABLE 5.4: Scenarios

	Own department, own skill	Own department, own or lower skill	All departments, own skill	All departments, own or lower skill
Traffic light method in even weeks	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Traffic light method in odd weeks	Scenario 5	Scenario 6	Scenario 7	Scenario 8
One free day and/or weekend in even weeks	Scenario 9	Scenario 10	Scenario 11	Scenario 12
One free day and/or weekend in odd weeks	Scenario 13	Scenario 14	Scenario 15	Scenario 16
Full availability in even weeks	Scenario 17	Scenario 18	Scenario 19	Scenario 20
Full availability in odd weeks	Scenario 21	Scenario 22	Scenario 23	Scenario 24

and 'own department, own or lower skill' scenarios, respectively, as the former scenarios provide more freedom than the latter ones.

5.5 Conclusion

This chapter provides an MILP model that models the creation and assignment of shifts in one step. The MILP is built in AIMMS 4.96.2.3, and solved using CPLEX 22.1. In order to run the MILP in AIMMS, pre-processing is needed. Snapshots of the inputs and outputs of the pre-processing Python codes are given in Appendix E. Furthermore, a code is written that transforms the .out output file of AIMMS to a user-friendly Excel file. Snapshots of the input and output of this code are given in Appendix G. In the next chapter, experiments are performed with the AIMMS model. Therefore, this chapter gives the experimental design. The experiments are based on 24 different scenarios, which include different combinations of employee availability, on which department to work (own or all), and which skills to perform (own or also lower skills).

Chapter 6

Results and Analysis

This chapter gives an answer to research question 7 "How does the developed model work compared to the currently used (manual) method?" We give an answer to this research question by performing the experiments as defined in Section 5.4. The results per scenario are presented in Section 6.1. After that, Section 6.2 gives the analysis of the results, including a comparison of the results to the results of April 2023 (as given in Section 3.3). Section 6.3 concludes this chapter.

6.1 Results

Table 6.1 shows the result, i.e., the overtime percentage, for each scenario. The feasible scenarios are colored green and orange. A scenario is feasible if there is a solution to the scenario that meets all constraints. The orange colored scenarios are only feasible if additional employees are added. The number in parentheses tells us how many zero-hours contract employees must be added to make the scenario feasible.

Table 6.1: Overtime percentage per scenario

	Own department, own skill	**Own department, own or lower skill**	**All departments, own skill**	**All departments, own or lower skill**
Traffic light method in even weeks	Infeasible	Infeasible	Infeasible	Infeasible
Traffic light method in odd weeks	Infeasible	Infeasible	Infeasible	Infeasible
One free day and/or weekend in even weeks	Infeasible	Infeasible	Infeasible	Infeasible
One free day and/or weekend in odd weeks	11.4% (10)	8.3% (0)	10.1% (10)	8.8% (0)
Full availability in even weeks	8.9% (9)	3.3% (0)	7.0% (9)	4.8% (0)
Full availability in odd weeks	12.2% (9)	7.3% (0)	11.8% (9)	9.2% (0)

By default, AIMMS lets its solver's solve any mathematical program to (local) optimality. Even though we want the model to find the (local) optimum, for practical purposes we want to limit the solvers runtime to a maximum of 10 minutes. To achieve this, we set a time limit of 600 seconds as the stopping criterion. You can adjust this time limit by navigating to Settings > Project Options > Solvers General > Stop Criteria. Only the scenarios 13 and 18 cannot reach (local) optimality within the 600-second limit. After 600 seconds, scenarios 13 and 18 reach a MIP tolerance for relative optimality of 0.06% and 3.53%, respectively. This means that the solution found after 600 seconds is within 0.06% or 3.53% of the best value.

6.2 Analysis

Before analyzing the overtime percentages, we need to investigate why all scenarios related to the 'traffic light method' and the 'one free day and/or weekend in even weeks' approach are infeasible. When examining both the availability and the number of contract hours for each employee, we observe inconsistencies between their availability and the constraints. For instance, in the 'one free day and/or weekend in even weeks' scenarios, employee 19 has requested both even weekends and Fridays off. This means that in even weeks, he or she can work a maximum of four days (Monday, Tuesday, Wednesday, and Thursday). According to our model, the maximum duration of a shift is 8.5 hours (8 hours when you subtract the break). Consequently, employee 19 can work a maximum of 4 times 8, which equals 32 hours, while their contract requires them to work 36 hours. To meet the condition that each employee must work at least 90% of their contract hours, employee 19 would need to work 0.90 times 36, which equals 32.4 hours. Since 32 is less than 32.4, no feasible solution exists. Therefore, we decide to redo each scenario with the requirement that employees must work at least 85% of their contract hours after deducting counting absences each week.

Table 6.2: Overtime percentage per scenario (work at least 85% of contract hours)

	Own department, own skill	**Own department, own or lower skill**	**All departments, own skill**	**All departments, own or lower skill**
Traffic light method in even weeks	9.2% (10)	4.9% (0)	5.9% (10)	5.1% (0)
Traffic light method in odd weeks	9.8% (11)	8.9% (0)	10.4% (10)	8.9% (0)
One free day and/or weekend in even weeks	7.2% (10)	4.1% (0)	5.5% (10)	4.1% (0)
One free day and/or weekend in odd weeks	11.4% (10)	8.3% (0)	10.1% (10)	8.8% (0)
Full availability in even weeks	8.9% (9)	3.3% (0)	7.0% (9)	4.8% (0)
Full availability in odd weeks	12.2% (9)	7.3% (0)	11.8% (9)	9.2% (0)

Table 6.2 demonstrates that all scenarios are feasible if employees must work at least 85% of their contract hours after deducting absences each week. Additionally, it reveals that institution D can only achieve feasible schedules with their care-delivery personnel under contract (so without adding additional employees) if their employees are willing to work

shifts below their own qualification level. If employees insist on working only within their own qualification level, institution D would need to hire an additional 9 to 11 zero-hours contract employees.

To compare the overtime percentages in Table 6.2 with those achieved by the currently used (manual) planning method, we rely on the overtime percentage data from week 14 (an even week) and week 15 (an odd week) as provided in Section 3.3. We selected these weeks, as we also use the counting absences from these weeks. In week 14, institution D had an overtime percentage of 9.55%, while in week 15, it was 14.61%. All scenarios resulting in zero additional employees needed show significantly lower overtime percentages compared to these figures. Institution D claims to follow scenarios 10 and 14 in their planning. Our model calculates an overtime percentage of 4.1% for scenario 10 (for even weeks) and 8.3% for scenario 14 (for odd weeks). This implies that by continuing to schedule employees within their own department and with either their own skill level or a lower one, institution D can improve their overtime percentage by using our model.

While our model results demonstrate an improvement in the overtime percentage, a direct one-to-one comparison is not possible for several reasons. First, our model calculates overtime percentages before the scheduled period, whereas the April overtime percentages reflect the situation after the schedule has been implemented. Discrepancies between these pre-scheduled and post-scheduled percentages can arise, for example when the staffing levels do not accurately align with demand, leading to overtime even when the schedule appears to fully meet the staffing requirements. Second, institution D's scheduling personnel have knowledge of when the counting absences take place, whereas we have only received information about the total hours of counted absences per personnel member. Lastly, our model exclusively incorporates hard constraints, such as the maximum number of hours an employee can work in a week, including overtime, and on a single day. These constraints are introduced because the schedules repeat every two weeks, making it unrealistic to structurally schedule work weeks exceeding 40 hours for an employee. In practice, though, exceptions can be made when creating the schedule. The presence of three holidays in April (Good Friday, Easter, and King's Day) does not impact the difference between the actual overtime percentages and the model outcomes. Institution D, namely, treats holidays as regular days. So, they apply the same staffing levels, and employees can request leave of absence, although approval is not guaranteed.

When analyzing the data in Table 6.2, we observe that the overtime percentages are consistently lower in the even weeks compared to the odd weeks. This discrepancy can be attributed to the counting absences, which are lower in the selected even week (week 14) when compared to the chosen odd week (week 15). Specifically, the total counting absences in week 14 amount to 288.10 hours, while they total 354.05 hours in week 15. The 'full availability' scenarios provide this insight since all other factors remain the same between the 'full availability in even weeks' and 'full availability in odd weeks' scenarios. When we examine the data related to the requests for free days and/or weekends, we find that a total of 30 employees request even weekends off, while 27 employees request odd weekends off. Interestingly, this seems to have little impact on the overall outcome, as the overtime percentages of the 'one free day and/or weekend in even weeks' and 'one free day and/or weekend in odd weeks' scenarios exhibit a similar level of variation as seen in the 'full availability' scenarios.

The results in Table 6.2 also show that, in four out of six cases, the overtime percentage for the 'all departments, own or lower skill' scenarios is higher than for the 'own department, own or lower skill' scenarios. This outcome is unexpected, since the former scenarios provide more freedom than the latter. Consequently, we initially anticipated the 'all departments, own or lower skill' scenarios to perform at least as well as the 'own department, own or lower skill' scenarios. One possible reason for this discrepancy may be that CPLEX 22.1 finds local optimality rather than global optimality. Additionally, in some cases, the time limit of 600 seconds is reached, preventing the achievement of local optimality.

6.3 Conclusions

This chapter evaluates the outcome, i.e., the overtime percentage and the amount of additional employees needed, of the developed MILP model in comparison to the existing manual method at institution D. The analysis of the results reveals that the model consistently delivers lower overtime percentages, particularly when scheduling employees within their own department and with either their own skill level or a lower one. While our model results demonstrate lower overtime percentages, a direct one-to-one comparison with the manual method is challenging. Several factors contribute to this challenge, including differences in when overtime percentages are calculated (pre-scheduled vs. post-scheduled), variations in the knowledge of counting absences, and the presence of hard constraints in our model. Nevertheless, the developed MILP model offers a promising solution for reducing the overtime at institution D.

Chapter 7

Generalization of the Model

This chapter gives an answer to research question 8 "How can the developed model be generalized such that it is also applicable to other institutions in the VVT sector?" Each section presents an addition or change to the model that helps to generalize the model built in Chapter 5.

7.1 Different Planning Objective

One factor that may distinguish institution D from other institutions is its planning objective. Institution D prioritizes minimizing the need for additional employees first, with a secondary focus on reducing overtime percentages. The reason for this distinction lies in their financial constraints, as they lack the resources to hire additional personnel. Additionally, there is a labour market shortage in the sector, making it hard for them to fill all vacancies. Some institutions, though, may be open to hiring additional staff, as long as it results in a lower overtime percentage. In such cases, the objective function described in Section 5.2.6 requires different values for α and β. To explore this, we conduct a sensitivity analysis involving α and β. The results of the sensitivity analysis are presented in Tables 7.1 and 7.2. In all scenarios within the sensitivity analysis, a runtime of 600 seconds is applied as the time limit.

For scenarios 1 and 2, so the 'traffic light method in even weeks - own department, own skill' and the 'traffic light method in even weeks - own department, own or lower skill' respectively, we explore various combinations of values for α and β. The findings in Table 7.1 indicate that when α is set to 1, the outcomes remain the same regardless of whether β is 3, 4, 5, or 10. Similarly, when β is set to 1, the outcomes are consistent for α values of 3, 4, 5, or 10. We assume that this trend extends to all other scenarios as well. Therefore, to streamline our experiments and reduce their total number, we narrow our focus to α equals 1 and β equals 1, 2, or 5, as well as β equals 1 and α equals 2 or 3.

From Tables 7.1 and 7.2, we observe that the α - β combination chosen for institution D ($\alpha = 1$ and $\beta = 5$) indeed results in the lowest number of additional employees when compared to the other α - β combinations. This reaffirms the choice made in Chapter 5. The situation for institution D is depicted in purple. Furthermore, the tables show that the more employees you are willing to add, the lower the overtime percentage becomes. Additionally, they show that for all scenarios the lower the value for β and the higher the value for α, the lower the overtime percentage. The opposite holds true for the number of additional employees.

Table 7.1: Overtime percentage per scenario per factor combination (work at least 85% of contract hours)

		Own department, own skill	**Own department, own or lower skill**
Traffic light method in even weeks	$\alpha = 1, \beta = 1$	0.6% (14)	1.0% (2)
	$\alpha = 1, \beta = 2$	2.0% (13)	2.8% (1)
	$\alpha = 1, \beta = 3$	9.2% (10)	4.9% (0)
	$\alpha = 1, \beta = 4$	9.2% (10)	4.9% (0)
	$\alpha = 1, \beta = 5$	9.2% (10)	4.9% (0)
	$\alpha = 1, \beta = 10$	9.2% (10)	4.9% (0)
	$\alpha = 2, \beta = 1$	0.6% (14)	0.2% (3)
	$\alpha = 3, \beta = 1$	0.1% (15)	0.2% (3)
	$\alpha = 4, \beta = 1$	0.1% (15)	0.2% (3)
	$\alpha = 5, \beta = 1$	0.1% (15)	0.2% (3)
	$\alpha = 10, \beta = 1$	0.1% (15)	0.2% (3)
Traffic light method in odd weeks	$\alpha = 1, \beta = 1$	1.7% (15)	1.6% (4)
	$\alpha = 1, \beta = 2$	3.1% (14)	4.4% (2)
	$\alpha = 1, \beta = 5$	9.8% (11)	8.9% (0)
	$\alpha = 2, \beta = 1$	1.7% (15)	1.6% (4)
	$\alpha = 3, \beta = 1$	1.3% (16)	1.6% (4)
One free day and/or weekend in even weeks	$\alpha = 1, \beta = 1$	0.9% (13)	0.4% (2)
	$\alpha = 1, \beta = 2$	2.4% (12)	1.8% (1)
	$\alpha = 1, \beta = 5$	7.2% (10)	4.1% (0)
	$\alpha = 2, \beta = 1$	0.1% (14)	0.4% (2)
	$\alpha = 3, \beta = 1$	0.1% (14)	0.4% (2)
One free day and/or weekend in odd weeks	$\alpha = 1, \beta = 1$	1.5% (15)	2.1% (3)
	$\alpha = 1, \beta = 2$	4.5% (13)	3.7% (2)
	$\alpha = 1, \beta = 5$	11.4% (10)	8.3% (0)
	$\alpha = 2, \beta = 1$	1.5% (15)	1.4% (4)
	$\alpha = 3, \beta = 1$	1.5% (15)	1.4% (4)
Full availability in even weeks	$\alpha = 1, \beta = 1$	0.6% (13)	0.3% (2)
	$\alpha = 1, \beta = 2$	1.8% (12)	3.3% (0)
	$\alpha = 1, \beta = 5$	8.9% (9)	3.3% (0)
	$\alpha = 2, \beta = 1$	0.6% (13)	0.3% (2)
	$\alpha = 3, \beta = 1$	0.1% (14)	0.4% (2)
Full availability in odd weeks	$\alpha = 1, \beta = 1$	2.0% (14)	1.8% (3)
	$\alpha = 1, \beta = 2$	5.0% (12)	5.0% (1)
	$\alpha = 1, \beta = 5$	12.2% (9)	7.3% (0)
	$\alpha = 2, \beta = 1$	1.4% (15)	1.8% (3)
	$\alpha = 3, \beta = 1$	1.4% (15)	1.3% (4)

Changes to α and β must be made in the 'ObjectiveFunction' constraint in AIMMS. See Appendix F for the AIMMS model explorer.

Table 7.2: Overtime percentage per scenario per factor combination (work at least 85% of contract hours)

		All departments, own skill	**All departments, own or lower skill**
Traffic light method in even weeks	$\alpha = 1, \beta = 1$	0.5% (13)	0.5% (2)
	$\alpha = 1, \beta = 2$	1.6% (12)	2.5% (1)
	$\alpha = 1, \beta = 5$	5.9% (10)	5.1% (0)
	$\alpha = 2, \beta = 1$	0.5% (13)	0.5% (2)
	$\alpha = 3, \beta = 1$	0.1% (14)	0.6% (2)
Traffic light method in odd weeks	$\alpha = 1, \beta = 1$	2.2% (14)	1.8% (3)
	$\alpha = 1, \beta = 2$	3.8% (13)	3.7% (2)
	$\alpha = 1, \beta = 5$	10.4% (10)	8.9% (0)
	$\alpha = 2, \beta = 1$	1.3% (15)	1.8% (3)
	$\alpha = 3, \beta = 1$	1.3% (15)	1.8% (3)
One free day and/or weekend in even weeks	$\alpha = 1, \beta = 1$	1.3% (12)	0.6% (2)
	$\alpha = 1, \beta = 2$	3.1% (11)	1.8% (1)
	$\alpha = 1, \beta = 5$	5.5% (10)	4.1% (0)
	$\alpha = 2, \beta = 1$	0.3% (13)	0.4% (2)
	$\alpha = 3, \beta = 1$	0.3% (13)	0.3% (2)
One free day and/or weekend in odd weeks	$\alpha = 1, \beta = 1$	2.1% (14)	1.9% (3)
	$\alpha = 1, \beta = 2$	3.5% (13)	3.6% (2)
	$\alpha = 1, \beta = 5$	10.1% (10)	8.8% (0)
	$\alpha = 2, \beta = 1$	1.3% (15)	2.0% (3)
	$\alpha = 3, \beta = 1$	1.3% (15)	1.7% (4)
Full availability in even weeks	$\alpha = 1, \beta = 1$	1.0% (12)	0.5% (2)
	$\alpha = 1, \beta = 2$	2.4% (11)	2.1% (1)
	$\alpha = 1, \beta = 5$	7.0% (9)	4.8% (0)
	$\alpha = 2, \beta = 1$	0.2% (13)	0.5% (2)
	$\alpha = 3, \beta = 1$	0.2% (13)	0.4% (2)
Full availability in odd weeks	$\alpha = 1, \beta = 1$	1.8% (14)	2.2% (3)
	$\alpha = 1, \beta = 2$	4.7% (12)	4.0% (2)
	$\alpha = 1, \beta = 5$	11.8% (9)	9.2% (0)
	$\alpha = 2, \beta = 1$	1.8% (14)	2.1% (3)
	$\alpha = 3, \beta = 1$	1.3% (15)	2.0% (4)

7.2 Adding One Or More (Specific) Employees

If an institution is in contact with one or more specific employees who want to work at the institution, the institution can add the employee(s) to the MILP and run scenarios to assess the effect of hiring the employee(s) on the overtime percentage. If an institution wants to add one or more additional employees to the MILP, they should follow these steps:

1. Add the employee(s) to both the 'employees' and 'characteristics' files
2. Include them in the sets I and I^C
3. Execute the code provided in Appendix E
4. Run the initialization procedures of the scenarios they want to test

The 'employees' file contains availability information, while the 'characteristics' file contains relevant characteristics of the employees under contract. More information on the 'employees' and 'characteristics' files is given in Appendix E. These same changes apply if an institution wants to experiment with a completely new staff mix.

7.3 Maximum Amount of New Personnel Per Day Per Department

When an institution has hired new staff, it may choose to utilize a maximum of 40% of these new employees per day, per department, to ensure that clients encounter enough familiar faces. Relying solely on new staff at a department can also lead to overtime, as these individuals may not yet be fully acclimated to their roles. If we want to include this in our model, we must add a set of newly added employees I^N, which is a subset of I ($I^N \subset I$). Furthermore, we need to add the following constraint:

$$\sum_{i \in I^N} \sum_{k} \sum_{j} x_{\mathrm{i,k,a,j,d}} \leq 0.40 \sum_{i \in I} \sum_{k} \sum_{j} x_{\mathrm{i,k,a,j,d}} \qquad \forall a, d$$

7.4 Knowledge on Remaining Capacity

Some institutions may want to determine the amount of unused capacity for each schedule, i.e., the amount of minus hours per employee. This information is valuable because staff members with minus hours can be contacted first in case of unexpected absences during a given week. To extract this data from our model, we must introduce a decision variable called $UndertimeHours_{\mathrm{i}}$, which is a non-negative. It is set to zero if employee i has made plus hours and gives the amount of minus hours if the employee has any. Additionally, we need to add the following constraints:

$$UndertimeHours_{\mathrm{i}} \geq -OverUndertime_{\mathrm{i}} \qquad \forall i \in I$$

$$UndertimeHours_{\mathrm{i}} \geq 0 \qquad \forall i \in I$$

7.5 Making the Even and Odd Schedules Co-dependent

Some institutions may want to establish a dependency between schedules for even and odd weeks. To accomplish this, a new set needs to be introduced, and almost all parameters and decision variables require an additional index. Specifically, a set 'W' representing weeks must be created, with an index 'w', where 'w = 1' corresponds to odd weeks, and 'w = 2' corresponds to even weeks. The parameters $b_{\mathrm{i,k,d,t}}$, $CountingAbsences_{\mathrm{i}}$, and $StaffingLevel_{\mathrm{a,j,d,t}}$, along with all decision variables, must incorporate the index 'w'. This also means that the data preparation codes need to be adjusted. Additionally, the objective function needs to be modified to:

$$Min \quad \left(\alpha \cdot \sum_{w} OvertimePercentage_{\mathrm{w}}\right) + \left(\beta \cdot \sum_{w} TotalExtraEmployees_{\mathrm{w}}\right)$$

In addition to that, all constraints in which a parameter or decision variable with the index 'w' occurs need to include '$\forall w$' as well. Besides, Constraint 11 needs to be modified:

$$OverUndertime_{\text{i,w=1}} =$$

$$(WorkedHours_{\text{i,w=1}} - ContractHours_{\text{i}} + CountingAbsences_{i,w=1}) \cdot$$

$$NotZeroHourContract_{i} \qquad \forall i \in I$$

Furthermore, the following constraint needs to be added:

$$OverUndertime_{\text{i,w=2}} =$$

$$(WorkedHours_{\text{i,w=2}} - ContractHours_{\text{i}} + CountingAbsences_{i,w=2}) \cdot$$

$$NotZeroHourContract_{i} + OverUndertime_{\text{i,w=1}} \qquad \forall i \in I$$

Now, the minus and/or plus hours from odd weeks are included in the calculation for even weeks, which has as result that employees with minus (plus) hours in the odd weeks will be scheduled more (less) in the even weeks.

7.6 Exact Dates and Times of Leave of Absence

If we know not only the total hours of counted absences per personnel member (as we know now) but also when the counting absences take place, we can ensure that the personnel members are not scheduled on the days of, for example, their leave of absence. In this case, we need to create another binary parameter called $CountingAbsencesDateTime_{\text{i,k,d,t}}$, which is 1 when employee i cannot work shift k on day d, and when shift k includes time slot t, due to a counting absence, and is 0 otherwise. Additionally, we need to create a binary decision variable called $EventualAvailability_{\text{i,k,d,t}}$ that represents the eventual availability. Lastly, the following constraint needs to be added:

$$EventualAvailability_{\text{i,k,d,t}} = b_{\text{i,k,d,t}} - CountingAbsencesDateTime_{\text{i,k,d,t}}$$

7.7 Conclusions

In this chapter, we give several suggestions for changes and/or additions that can be made to the MILP model in Chapter 5 to make the model applicable to other institutions in the VVT sector. The suggestions include changing the planning objective, adding one or more (specific) employees, adding a maximum to the number of new personnel assigned per day and per department, gaining knowledge regarding unused capacity, making the even and odd schedules co-dependent, and adhering to leave of absence and sick requests on specific days.

Chapter 8

Conclusions and Future Work

This chapter starts by stating the conclusions that we draw from the experimental results in Section 8.1. After that, this chapter gives an answer to the last three research questions: "What are the limitations of this research and which recommendations for future research can we make?" (in Section 8.2), "What are the managerial implications of the proposed model?" (in Section 8.3), and "What are the contributions of this research to theory and practice?" (in Section 8.4). Section 8.2 answers its research question by reflecting on the research. Section 8.3 answers its research question by giving recommendations to institution D based on the conclusions and limitations of the research. Finally, Section 8.4 answers its research question by giving the contributions to both theory and practice, where the contribution to theory includes to what extent the model is an addition to the models found in the literature and the contribution to practice includes how the proposed model can be applied to institution D and/or other institutions.

8.1 Conclusions

The objective of this master thesis was to develop an intervention for institution D aimed at reducing the personnel overtime hours, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible. This objective has been achieved, as the intervention indeed reduces the overtime for institution D, while providing all the care needed, adhering to regulations, and keeping the hiring of temporary workers as low as possible. We draw the following conclusions from the quantitative analysis for the prospective assessment of the intervention:

- Institution D can only achieve feasible schedules with their care-delivery personnel under contract (so without adding additional employees) if their employees are willing to work shifts below their own qualification level.
- If their employees insist on working only within their own qualification level, institution D would need to hire an additional 9 to 11 zero-hours contract employees.
- All scenarios resulting in zero additional employees needed show significantly lower overtime percentages when compared to the existing manual scheduling method at institution D.
- Institution D claims to follow scenarios 10 and 14 in their planning, i.e., they claim to plan by giving each employee the freedom to ask for one free day off a week and for either the odd or even weekends off, and by deploying each employee in their

own department, with their own or a lower qualification level. Our model calculates an overtime percentage of 4.1% for that specific scenario in even weeks and of 8.3% for that specific scenario in odd weeks, compared to overtime percentages of 9.55% and 14.61% respectively with the existing planning method. This implies that by continuing to schedule employees within their own department and with either their own skill level or a lower one, institution D can improve their overtime percentage by using our model.

- Counting absences have a direct effect on the overtime percentage: the higher the counting absences, the higher the overtime percentage.
- A (small) difference in the number of requests for even or odd weekends off appears to have little impact on the overtime percentage. The difference we face in this thesis is that 30 people have requested the weekends off in even weeks, while 27 people have requested the weekends off in odd weeks.
- Changes and/or additions can be made to our model such that it is also applicable to other institutions in the VVT sector. Some examples are given in Chapter 7.

8.2 Limitations and Future Work

Section 8.2.1 discusses the limitations of the research, whereas Section 8.2.2 discusses the recommendations for future work.

8.2.1 Limitations

The research in this master thesis has several limitations. The most significant limitation the research faces is the lack of comprehensive data and the difficulty in accessing the available data. Consequently, both the preliminary study and the case study, including the intervention development and prospective assessment, are conducted within the constraints posed by data availability and accessibility challenges. A result of this data shortage is that we had to define and calculate the KPIs used in Section 3.3 ourselves. Institution D, namely, did not define any KPIs until 2023, because of which barely any data was kept for the in 2023 set KPIs. Additionally, the absence of data prevented us from basing our model on actual demand (so on the clients with their respective client profiles), as institution D does not have any data with respect to which tasks need to be done per client type, how much time these tasks take (including its variance), the minimum qualification level needed per task, and the amount of additional tasks that need to be done due to unexpected occurrences. Therefore, performing task scheduling was not possible. Instead, we based our model on the staffing levels created by institution D, since that is the most primary available workload/staffing level information. Furthermore, again due to the lack of data, the counting absences used in the model only represent the number of absences per employee per week, without specifying the actual dates and time slots of absence. In Section 7.6, we outline the necessary adjustments and additions that would be required if we were to have access to actual dates and times of leave of absence.

In addition to limitations related to the availability and accessibility of data, this research has some other limitations. First, the preliminary study includes interviews with only four different VVT institutions, whereas a more comprehensive understanding could be achieved by interviewing a larger number of institutions. Second, the literature review exclusively focuses on the VVT sector, while valuable insights might be obtained from the literature on capacity planning in other industries. Regarding the experiments, a limitation arises from the fact that not all experiments reach (local) optimality due to the set time limit of 600 seconds. Lastly, we must acknowledge a limitation concerning the experimental results: a direct one-to-one comparison between our model results and the actual overtime percentages is not feasible. This is due to the following reasons:

- Our model calculates overtime percentages before the scheduled period, whereas the April overtime percentages reflect the situation after the schedule has been implemented.
- Institution D's scheduling personnel have knowledge of when the counting absences take place, whereas we have only received information about the total hours of counted absences per personnel member.
- Our model exclusively incorporates hard constraints, such as the maximum number of hours an employee can work in a week, including overtime, and on a single day. These constraints are introduced because the schedules repeat every two weeks, making it unrealistic to structurally schedule work weeks exceeding 40 hours for an employee. In practice, though, exceptions can be made when creating the schedule.

8.2.2 Future Work

A suggestion for future research is to base the planning model on the actual demand rather than on the staffing levels. We assume that adopting this approach will lead to even lower overtime percentages and will allow the model to better account for wastes and inefficiencies. Another research suggestion to explore is how to manage holiday periods.

8.3 Recommendations

Considering all the findings and limitations in this thesis, we recommend that institution D adopts our planning model. Within our planning model, we recommend institution D to continue scheduling by means of the 'one free day and/or weekend' approach rather than transitioning to the 'traffic light method' approach. This choice results in lower overtime percentages while it still gives some availability freedom to the personnel. Additionally, we recommend institution D to begin monitoring KPIs, such that the institution's performance is more accurately represented. This will facilitate the fast identification and resolution of problems. Furthermore, we recommend institution D to determine which tasks need to be done per client type, how much time these tasks take (including its variance), the minimum qualification level needed per task, and the amount of additional tasks that need to be done due to unexpected occurrences. If this information is available, a planning tool can be developed that plans based on the actual demand rather than on the predetermined staffing levels.

8.4 Contributions to Theory and Practice

Section 8.4.1 below discusses the theoretical contributions of the research, and Section 8.4.2 the practical contributions.

8.4.1 Contribution to Theory

During the literature review, we found no paper that makes a complete roster by creating and assigning shifts in one step. The research of van der Veen [46] namely only schedules one shift per employee instead of making a complete roster with multiple shifts assigned to an employee in a week. Furthermore, the research of van der Veen employs a B&P model, whereas we use an MILP model. Our study has demonstrated that an MILP model is also well-suited for directly creating rosters based on staffing levels. Lastly, none of the literature we found has a model objective that minimizes the number of overtime hours while keeping the number of temporary workers as low as possible.

8.4.2 Contribution to Practice

This research has several contributions to institution D. First, the model created in this study constructs a complete weekly schedule that optimally deploys the personnel while taking the employee preferences regarding their availability into account. The schedule includes all shifts per department, specifies the employees assigned to each shift, and outlines the required skill type for each shift. This automated scheduling process is a valuable aid to the planners at institution D, who currently create the schedules manually. Furthermore, the developed model provides insights into the associated overtime percentage and the number of additional employees needed for the weekly schedule. This information enables the institution to experiment further with the model and make data-driven decisions. Lastly, the research findings can be used by the management to demonstrate to employees that the traffic light method results in higher overtime percentages and that it is not beneficial to the institution to give each employee only shifts of their own skill level.

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Appendix A

Semi-structured Interview

Section A.1 provides the semi-structured interview for both institutions A and B and Section A.2 provides the semi-structured interview for both institutions C and D. Prior to each semi-structured interview, the interviewee is asked if the conversation can be recorded. All interviewees agreed to this. Moreover the interviewees are thanked before and after the interview for their time.

A.1 Semi-structured Interview with institutions A and B

Introduction

- Could you provide some background information about yourself? Such as your role within the organization and the extent to which you deal with personnel capacity planning issues?

Organization Profile

- According to the website, institution A (institution B) has ... locations in .... Are these ... locations comparable? For example, in terms of size and types of clients:
  - Do the locations have an equal number of departments?
    - If yes, how many departments do they have?
  - Do the locations have equal-sized departments or an equal number of clients per department?
    - If yes, how many clients or what is the size of each department?
  - Do the locations serve the same types of clients?
    - If yes, what types of clients do they serve?
    - If no, what types of clients are served by institution A as a whole?
  - Do all departments have a single type of client, or are there departments where multiple types of clients coexist?
- Does the number of clients (both overall, per facility, and per department) remain constant, or does it vary?
- How is the workforce (formation) determined, and is the workforce updated annually?
- How are the staff qualification level needs of clients distributed (%)?

- Is there a fixed assignment of staff members to a department or a flexible assignment?
  - If there is a fixed assignment, is there a relationship between staff qualification level and department? In other words, do some departments have more staff at higher qualification levels?

Planning

- How is planning currently done? Is the VVT-tool from Ximius used?
  - If not, what planning aspects are currently considered? For example, department: staffing needs, number of clients, clients' care needs; Staff: day shift, night shift, part-time, full-time, days off, sick leave, meeting hours, etc.
- Do staff members adhere to the planning?
- How do staff members perceive the quality of the planning? What do they consider important regarding the planning?
- How are last-minute changes in the planning handled? For example, due to illness. Is there a flexible pool of staff available?

Supply and Demand Relationship
Staff

- Do they think they have enough staff at the required qualification levels to meet the demand?
  - If not, at what qualification level do they think they are lacking staff?
  - Is there a relationship with a specific department or varying client populations?
  - If not, how do they address this issue?
- Do staff members occasionally perform tasks/activities above their own qualification level (i.e., tasks/activities for which they are not qualified based on their educational level)?
  - If yes, at which staff qualification level(s) does this occur? And what percentage of the available time does it represent?
- To what extent are external personnel hired to meet the care demand (and what percentage of the total expenses does this represent)?
- Approximately what percentage of the time do staff members perform tasks/activities below their own qualification level?

Client

- What happens when a bed becomes available? How is the new client added to the schedule? Does the new client go to the department where the bed becomes available, or is it also possible to swap another client to a different department to accommodate the new client?

- Do all clients within their facility receive the necessary care (i.e., are there instances where not all activities in their care profile are performed)?
  - If no, what prioritization is applied?
- How is the required care for a new client determined? Is this done through an indication resulting from the intake?
  - If so, is this indication later evaluated?
  - When a client desires more care than what is funded by the healthcare system, how is this handled?
- How is the required care for a client translated into hours of care?

Problems

- What are the problems they encounter?
- Why do they think they encounter these problems?
- Do the problems occur in all departments or only in some? If yes, which departments?
  - If yes, why do some departments experience these problems while others do not?

A.2 Semi-structured Interview with institutions C and D

The semi-structured interview for institutions C and D is the same as the semi-structured interview for institutions A and B except for the questions regarding the organization profile. We therefore only state the section of questions related to the organization's profile for institutions C and D below.

Organization Profile

- How many departments do you have?
- How many clients reside in each of these departments?
- What types of clients do you assist?
- Do individual departments have a single type of client, or are there departments where multiple types of clients coexist?
- Is the number of clients (both overall and per department) always the same, or does it vary?
- How is the staff establishment determined, and is it updated annually?
- How are the staffing qualification level needs of clients distributed percentage-wise?
- Is there a fixed assignment of staff members to a department, or is it flexible?
  - If there is a fixed assignment, is there a correlation between staff qualification level and department? In other words, do some departments have more staff at higher qualification levels?

Appendix B

The Codebook

The table below shows the codes that are identified and the number of interviews (out of four) in which the code is identified.

Category	**Code**	**Amount of times identified**
Care supply	Reduced employability of staff under contract	3
	(Temporarily) need to use more staff (of certain levels)	4
	(Temporary) staff shortage (of certain levels)	4
Care demand	Changing demand for care	4
	Unclear and/or incorrectly defined demand for care	4
Planning	No standard/knowledge on how to include specific aspects in the planning	3
	Waste/inefficiency	4
	Planning is (mostly) done per department	3
Other	Cannot meet demand without hiring temporary workers	2
	Cannot meet demand without high amounts of overtime hours	2

Table B.1: The codebook

Appendix C

Example of the Open Coding of the Semi-structured Interviews

(Q1) Moderator: Is there a fixed linkage of staff members to a department or a flexible linkage?
Interviewee: There is currently a fixed linkage of staff members to a department: they work in teams. However, flexibility is a hot topic. In fact, a lot of staff members only want to work in their own department because it is safe and because they are nervous to help new clients. The latter, in turn, is because each client has his/her own habits and staff members are unaware of new clients' habits. Helping a new client thus implies that the staff member has to read into the client. In capacity management, this lack of flexibility is a problem. The more flexible employees are, the easier it would be for the institution to set up rosters properly and to deliver the right care. They would like to make that clear to staff.

Code: Planning is (mostly) done per department. I.e., capacity is not shared between departments and/or between locations/institutions
Subcode: Lack of flexibility workers

Appendix D

Structured Literature Review

As a first step of our structured literature review, we defined keywords. The keywords are used to define search syntaxes. The defined keywords are:

- stages of tactical capacity planning
- personnel planning and scheduling
- differentiated practice
- random demand
- staffing
- shift scheduling
- shift rostering
- nursing home
- nursing homes
- long term care
- overtime

Table D.1 shows the search syntaxes that are used in the database Google Scholar. In all cases, the following search settings are chosen:

- Each period
- Sort based on relevance
- Each language
- Each type
- Excluding both patents and citations
- Only the first page of search results is looked at (so the first 10 articles)

The found sources are evaluated for usefulness based on their title and abstract. The middle column gives the total number of hits caused by the search syntax. The most right column shows the useful sources that are found by means of the search syntax.

Search syntax	**Hits**	**Useful sources**
(stages of tactical capacity planning) AND "nursing home"	17,800	[4, 12, 18, 31]
(personnel planning and scheduling) AND (long term care)	372,000	[2, 45]
"differentiated practice" AND ("nursing home" or "nursing homes")	198	[23]
(random demand) AND (staffing) AND (nursing homes)	30,100	[47]
"shift scheduling" AND ("nursing home" OR "nursing homes")	280	[4, 12, 24, 28, 30, 31]
"staffing" AND "shift scheduling" AND "shift rostering"	49	[46]

Table D.1: Structural literature review

Appendix E

Data Pre-Processing

This appendix gives the transformations that are made using Python to prepare the available input data for use in the MILP. The first used Python code uses a file named 'employees' as input, and gives a file named 'possibleshifts' as output. The 'employees' input file contains all employees (one employee per tab) including the time slots that they are (un)available per day. See Figure E.1 for a snap shot. The 'possibleshifts' output file contains all employees (one employee per tab) including their feasible set of shifts per day (where shifts are allowed of either 6, 6.5, 7, 7.5, 8, or 8.5 hours). See Figure E.2 for a snap shot of this file. We run the code for each availability type (traffic light method in even weeks, traffic light method in odd weeks, free day and/or weekend availability in even weeks, free day and/or weekend availability in odd weeks, optimal availability).

Tijdsloten	Monday	Tuesday	Wednesd	Thursday	Friday	Saturday	Sunday
Time slot 1 = 07:00 – 07:30	0	1	1	1	0	1	1
Time slot 2 = 07:30 – 08:00	0	1	1	1	0	1	1
Time slot 3 = 08:00 – 08:30	0	1	1	1	0	1	1
Time slot 4 = 08:30 – 09:00	0	1	1	1	0	1	1
Time slot 5 = 09:00 – 09:30	0	1	1	1	0	1	1
Time slot 6 = 09:30 – 10:00	0	1	1	1	0	1	1
Time slot 7 = 10:00 – 10:30	0	1	1	1	0	1	1
Time slot 8 = 10:30 – 11:00	0	1	1	1	0	1	1
Time slot 9 = 11:00 – 11:30	0	1	1	1	0	1	1
Time slot 10 = 11:30 – 12:00	0	1	1	1	0	1	1
Time slot 11 = 12:00 – 12:30	0	1	1	1	0	1	1
Time slot 12 = 12:30 – 13:00	0	1	1	1	0	1	1
Time slot 13 = 13:00 – 13:30	0	1	1	1	0	1	1
Time slot 14 = 13:30 – 14:00	0	1	1	1	0	1	1
Time slot 15 = 14:00 – 14:30	0	1	1	1	0	1	1
Time slot 16 = 14:30 – 15:00	0	1	1	1	0	1	1
Time slot 17 = 15:00 – 15:30	0	1	1	1	0	0	0
Time slot 18 = 15:30 – 16:00	0	1	1	1	0	0	0
Time slot 19 = 16:00 – 16:30	0	1	1	1	0	0	0
Time slot 20 = 16:30 – 17:00	0	1	1	1	0	0	0
Time slot 21 = 17:00 – 17:30	0	1	1	1	0	0	0
Time slot 22 = 17:30 – 18:00	0	1	1	1	0	0	0
Time slot 23 = 18:00 – 18:30	0	1	1	1	0	0	0
Time slot 24 = 18:30 – 19:00	0	1	1	1	0	0	0
Time slot 25 = 19:00 – 19:30	0	1	1	1	0	0	0
Time slot 26 = 19:30 – 20:00	0	1	1	1	0	0	0
Time slot 27 = 20:00 – 20:30	0	1	1	1	0	0	0
Time slot 28 = 20:30 – 21:00	0	1	1	1	0	0	0
Time slot 29 = 21:00 – 21:30	0	1	1	1	0	0	0
Time slot 30 = 21:30 – 22:00	0	1	1	1	0	0	0
Time slot 31 = 22:00 – 22:30	0	1	1	1	0	0	0
Time slot 32 = 22:30 – 23:00	0	1	1	1	0	0	0

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FIGURE E.1: Snap shot of the 'employees' file (example from the traffic light method in odd weeks)

	Tuesday 1st time slot of shift	Tuesday 2nd time slot of shift	Tuesday 3rd time slot of shift	Tuesday 4th time slot of shift	Tuesday 5th time slot of shift	Tuesday 6th time slot of shift	Tuesday 7th time slot of shift	Tuesday 8th time slot of shift	Tuesday 9th time slot of shift	Tuesday 10th time slot of shift	Tuesday 11th time slot of shift	Tuesday 12th time slot of shift	Tuesday 13th time slot of shift	Tuesday 14th time slot of shift	Tuesday 15th time slot of shift	Tuesday 16th time slot of shift	Tuesday last time slot of shift
0	1	2	3	4	5	6	7	8	9	10	11	12	13				
1	2	3	4	5	6	7	8	9	10	11	12	13	14				
2	3	4	5	6	7	8	9	10	11	12	13	14	15				
3	4	5	6	7	8	9	10	11	12	13	14	15	16				
4	5	6	7	8	9	10	11	12	13	14	15	16	17				
5	6	7	8	9	10	11	12	13	14	15	16	17	18				
6	7	8	9	10	11	12	13	14	15	16	17	18	19				
7	8	9	10	11	12	13	14	15	16	17	18	19	20				
8	9	10	11	12	13	14	15	16	17	18	19	20	21				
9	10	11	12	13	14	15	16	17	18	19	20	21	22				
10	11	12	13	14	15	16	17	18	19	20	21	22	23				
11	12	13	14	15	16	17	18	19	20	21	22	23	24				
12	13	14	15	16	17	18	19	20	21	22	23	24	25				
13	14	15	16	17	18	19	20	21	22	23	24	25	26				
14	15	16	17	18	19	20	21	22	23	24	25	26	27				
15	16	17	18	19	20	21	22	23	24	25	26	27	28				
16	17	18	19	20	21	22	23	24	25	26	27	28	29				
17	18	19	20	21	22	23	24	25	26	27	28	29	30				
18	19	20	21	22	23	24	25	26	27	28	29	30	31				
19	20	21	22	23	24	25	26	27	28	29	30	31	32				
20	1	2	3	4	5	6	7	8	9	10	11	12	13	14			
21	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
22	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
23	4	5	6	7	8	9	10	11	12	13	14	15	16	17			
24	5	6	7	8	9	10	11	12	13	14	15	16	17	18			
25	6	7	8	9	10	11	12	13	14	15	16	17	18	19			
26	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
27	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
28	9	10	11	12	13	14	15	16	17	18	19	20	21	22			
29	10	11	12	13	14	15	16	17	18	19	20	21	22	23			
30	11	12	13	14	15	16	17	18	19	20	21	22	23	24			
31	12	13	14	15	16	17	18	19	20	21	22	23	24	25			
32	13	14	15	16	17	18	19	20	21	22	23	24	25	26			

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FIGURE E.2: Snap shot of the 'possibleshifts' file (example for the traffic light method in odd weeks)

After running the code for the previous described transformation, we run another Python code for each availability type. This code uses only the 'possibleshifts' file as input, and gives a filed named 'parameter b' as output. The 'parameter b' output file gives the parameter $b_{i,k,d,t}$ for each combination of i, k, d, and t with shifts of 6, 6.5, 7, 7.5, 8 and 8.5 hours. See Figure E.3 for a snap shot of the 'parameter b' file.

Additionally, we run four other Python codes, which all use a file called 'characteristics' as input file, and give a file called 'characteristics (own department own skill)', 'characteristics (own department lower skills also)', 'characteristics (all departments own skill)' and 'characteristics (all departments lower skills also)', respectively, as output file. The 'characteristics' file gives amongst others for each employee: the department he or she mainly works for, the skill that the employee has, the contract hours of the employee, and the counting absences. Only the department and skill are used by the codes. See Figure E.4 for a snap shot of the 'characteristics' file. The output files give the parameter $characteristics_{i,a,j}$ for each combination of i, a, and j. See Figure E.5 for a snap shot of such a file. The four different codes can be seen as scenarios, where:

- Code 1 gives the combinations for the parameter $characteristics_{i,a,j}$ if employees can only work on their own department and with their own skill
- Code 2 gives the combinations for the parameter $characteristics_{i,a,j}$ if employees can only work on their own department but with both their own skill and lower skills
- Code 3 gives the combinations for the parameter $characteristics_{i,a,j}$ if employees can work on all departments but only with their own skill
- Code 4 gives the combinations for the parameter $characteristics_{i,a,j}$ if employees can work on all departments and with both their own skill and lower skills

	i	k	d	t	Value
b_1,0,1,1	1	0	1	1	1
b_1,0,1,2	1	0	1	2	1
b_1,0,1,3	1	0	1	3	1
b_1,0,1,4	1	0	1	4	1
b_1,0,1,5	1	0	1	5	1
b_1,0,1,6	1	0	1	6	1
b_1,0,1,7	1	0	1	7	1
b_1,0,1,8	1	0	1	8	1
b_1,0,1,9	1	0	1	9	1
b_1,0,1,10	1	0	1	10	1
b_1,0,1,11	1	0	1	11	1
b_1,0,1,12	1	0	1	12	1
b_1,0,1,13	1	0	1	13	1
b_1,1,1,2	1	1	1	2	1
b_1,1,1,3	1	1	1	3	1
b_1,1,1,4	1	1	1	4	1
b_1,1,1,5	1	1	1	5	1
b_1,1,1,6	1	1	1	6	1
b_1,1,1,7	1	1	1	7	1
b_1,1,1,8	1	1	1	8	1
b_1,1,1,9	1	1	1	9	1
b_1,1,1,10	1	1	1	10	1
b_1,1,1,11	1	1	1	11	1
b_1,1,1,12	1	1	1	12	1
b_1,1,1,13	1	1	1	13	1
b_1,1,1,14	1	1	1	14	1

parameterinput_part1 parameterinput_part2

FIGURE E.3: Snap shot of the 'parameter b' file (example from the traffic light method in odd weeks)

i	Department	Skill	Contract hours		NotZeroHour	Counting absenses week 14 (even)	Counting absenses week 15 (odd)
1	2	1	28		1		
2	1	3	26	Van 36 naar 26 want ZoCo	1		
3	1	3	22	Van 32 naar 22 want ZoCo	1		
4	4	1	0	Van 24 naar 0 gezet want langdurig ziek	1		
5	2	1	0	Van 20 naar 0 gezet want langdurig ziek	1		
6	2	1	20		1		20
7	2	1	15		1		
8	2	1	28		1		
9	1	1	20		1		
10	2	3	32		1		
11	1	3	32		1	4	4
12	2	1	24		1	16	24
13	1	3	28		1	4.5	8
14	1	3	28		1		
15	4	1	0	0-uren kan op alle afdelingen werken	0		
16	1	2	32		1	8	
17	4	3	0	0-uren kan op alle afdelingen werken	0		
18	1	1	36		1		
19	1	2	32		1		
20	3	1	32		1		
21	3	2	0	Van 28 naar 0 gezet want langdurig ziek	1		
22	1	2	24		1	16	3.35
23	1	1	20		1	4	4
24	1	2	24		1		
25	1	3	32		1	8	21.65
26	3	3	32		1		
27	1	3	32		1	24.8	34.4
28	1	3	32		1	16	12.15
29	1	3	16		1	16	16
30	1	3	32		1	24	
31	1	3	20		1		
32	1	3	28		1		16.8
33	3	2	25		1		
34	2	3	32		1		
35	2	3	20		1	16	32
36	3	3	28		1		

Characteristics

FIGURE E.4: Snap shot of the 'characteristics' file

Lastly, we run two final codes, where one of the codes only uses the 'possibleshifts' file for the optimal availability as input, and gives a filed named 'Extra Employees' as output. The 'Extra Employees' output file gives the parameter $b_{\mathrm{i,k,d,t}}$ for each combination of i, k, d, and t with shifts of 6, 6.5, 7, 7.5, 8 and 8.5 hours, where i represents the fictitious, additional personnel members. The output file looks similar to the file in Figure E.3. The other code uses only the 'characteristics - extra employees' file as input. This file looks

	i	a	j	Value
characteristics_1,2,1	1	2	1	1
characteristics_2,1,3	2	1	3	1
characteristics_3,1,3	3	1	3	1
characteristics_4,1,1	4	1	1	1
characteristics_4,2,1	4	2	1	1
characteristics_4,3,1	4	3	1	1
characteristics_5,2,1	5	2	1	1
characteristics_6,2,1	6	2	1	1
characteristics_7,2,1	7	2	1	1
characteristics_8,2,1	8	2	1	1
characteristics_9,1,1	9	1	1	1
characteristics_10,2,3	10	2	3	1
characteristics_11,1,3	11	1	3	1
characteristics_12,2,1	12	2	1	1
characteristics_13,1,3	13	1	3	1
characteristics_14,1,3	14	1	3	1
characteristics_15,1,1	15	1	1	1
characteristics_15,2,1	15	2	1	1
characteristics_15,3,1	15	3	1	1
characteristics_16,1,2	16	1	2	1
characteristics_17,1,3	17	1	3	1
characteristics_17,2,3	17	2	3	1
characteristics_17,3,3	17	3	3	1
characteristics_18,1,1	18	1	1	1
characteristics_19,1,2	19	1	2	1
characteristics_20,3,1	20	3	1	1

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FIGURE E.5: Snap shot of the 'characteristics (own department own skill)' file

similar as the file in Figure E.4. The output file is called 'characteristics (extra personnel)', and looks similar to the file in Figure E.5.

Appendix F

AIMMS Model Explorer

Below, we show all sets (S), parameters (P), decision variables (V), constraints (C), and procedures (P) added to the AIMMS model explorer. Figure F.1 and Figure F.2 give the declaration section of AIMMS, and Figure F.3 the initialization procedures.

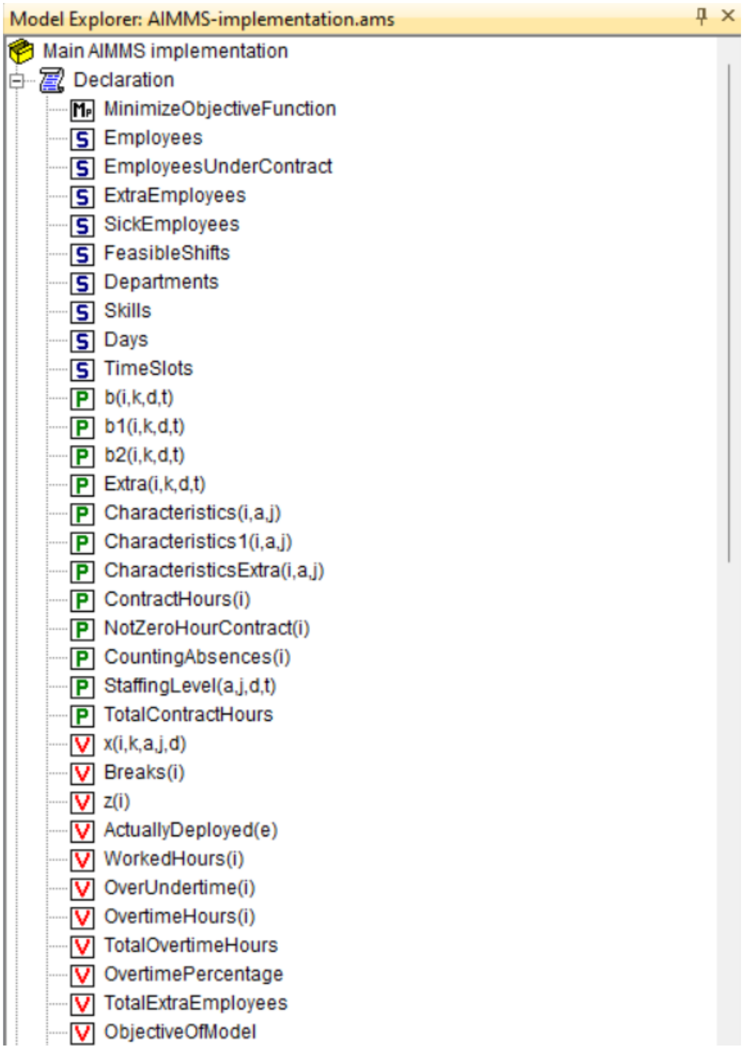


FIGURE F.1: AIMMS declaration section

FIGURE F.2: AIMMS declaration section

FIGURE F.3: AIMMS initialization procedures section

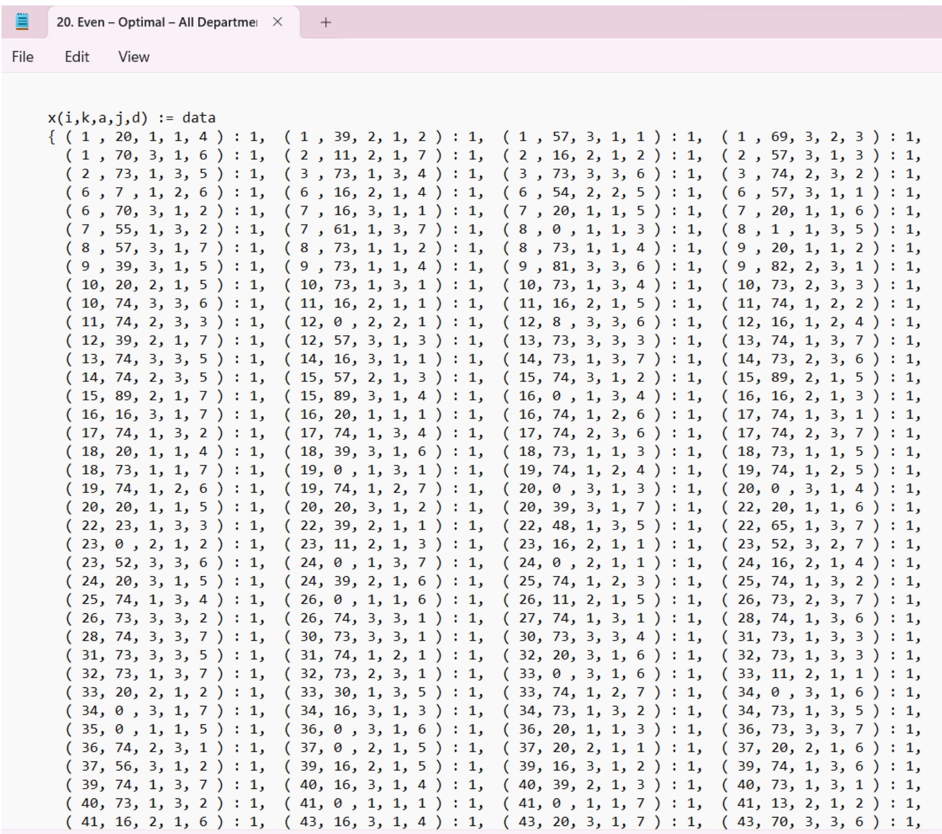
In order to run the scenarios, you have to:

- Run either Initialization_General_Even or Initialization_General_Odd procedures
- Run either Initialization_TrafficLightEven, Initialization_TrafficLightOdd, Initialization_FreeEven, Initialization_FreeOdd, or Initialization_Optimal procedures
- Run either Initialization_OwnDepartment_OwnSkill, Initialization_OwnDepartment_LowerSkillsAlso, Initialization_AllDepartments_OwnSkill, or Initialization_AllDepartments_LowerSkillsAlso procedures
- Run the Initialization_Extra_Personnel procedure
- Run the MainExecution

Appendix G

AIMMS Output Interpretation

This appendix gives the transformation of the AIMMS output file (of type .out) to a user-friendly Excel file. The transformation is performed by means of Python. The output file that is created by means of a Python code is perceived user-friendly as Excel is a commonly used program at institution D, and as the Excel file gives the names of the employees, the starting and ending time of the shifts, the names of the departments, the names of the skills, and the names of the days, instead of numbers. See Figure G.1 for a snap shot of the input file (i.e., the AIMMS output file), and see Figure G.2 for a snap shot of the user-friendly Excel output file. For privacy reasons, the names of the employees are transformed to numbers again in the figure.




```
x(i,k,a,j,d) := data
{ ( 1 , 20, 1, 1, 4 ) : 1,  ( 1 , 39, 2, 1, 2 ) : 1,  ( 1 , 57, 3, 1, 1 ) : 1,  ( 1 , 69, 3, 2, 3 ) : 1,
  ( 1 , 70, 3, 1, 6 ) : 1,  ( 2 , 11, 2, 1, 7 ) : 1,  ( 2 , 16, 2, 1, 2 ) : 1,  ( 2 , 57, 3, 1, 3 ) : 1,
  ( 2 , 73, 1, 3, 5 ) : 1,  ( 3 , 73, 1, 3, 4 ) : 1,  ( 3 , 73, 3, 3, 6 ) : 1,  ( 3 , 74, 2, 3, 2 ) : 1,
  ( 6 , 7 , 1, 2, 6 ) : 1,  ( 6 , 16, 2, 1, 4 ) : 1,  ( 6 , 54, 2, 2, 5 ) : 1,  ( 6 , 57, 3, 1, 1 ) : 1,
  ( 6 , 70, 3, 1, 2 ) : 1,  ( 7 , 16, 3, 1, 1 ) : 1,  ( 7 , 20, 1, 1, 5 ) : 1,  ( 7 , 20, 1, 1, 6 ) : 1,
  ( 7 , 55, 1, 3, 2 ) : 1,  ( 7 , 61, 1, 3, 7 ) : 1,  ( 8 , 0 , 1, 1, 3 ) : 1,  ( 8 , 1 , 1, 3, 5 ) : 1,
  ( 8 , 57, 3, 1, 7 ) : 1,  ( 8 , 73, 1, 1, 2 ) : 1,  ( 8 , 73, 1, 1, 4 ) : 1,  ( 9 , 20, 1, 1, 2 ) : 1,
  ( 9 , 39, 3, 1, 5 ) : 1,  ( 9 , 73, 1, 1, 4 ) : 1,  ( 9 , 81, 3, 3, 6 ) : 1,  ( 9 , 82, 2, 3, 1 ) : 1,
  ( 10, 20, 2, 1, 5 ) : 1,  ( 10, 73, 1, 3, 1 ) : 1,  ( 10, 73, 1, 3, 4 ) : 1,  ( 10, 73, 2, 3, 3 ) : 1,
  ( 10, 74, 3, 3, 6 ) : 1,  ( 11, 16, 2, 1, 1 ) : 1,  ( 11, 16, 2, 1, 5 ) : 1,  ( 11, 74, 1, 2, 2 ) : 1,
  ( 11, 74, 2, 3, 3 ) : 1,  ( 12, 0 , 2, 2, 1 ) : 1,  ( 12, 8 , 3, 3, 6 ) : 1,  ( 12, 16, 1, 2, 4 ) : 1,
  ( 12, 39, 2, 1, 7 ) : 1,  ( 12, 57, 3, 1, 3 ) : 1,  ( 13, 73, 3, 3, 3 ) : 1,  ( 13, 74, 1, 3, 7 ) : 1,
  ( 13, 74, 3, 3, 5 ) : 1,  ( 14, 16, 3, 1, 1 ) : 1,  ( 14, 73, 1, 3, 7 ) : 1,  ( 14, 73, 2, 3, 6 ) : 1,
  ( 14, 74, 2, 3, 5 ) : 1,  ( 15, 57, 2, 1, 3 ) : 1,  ( 15, 74, 3, 1, 2 ) : 1,  ( 15, 89, 2, 1, 5 ) : 1,
  ( 15, 89, 2, 1, 7 ) : 1,  ( 15, 89, 3, 1, 4 ) : 1,  ( 16, 0 , 1, 3, 4 ) : 1,  ( 16, 16, 2, 1, 3 ) : 1,
  ( 16, 16, 3, 1, 7 ) : 1,  ( 16, 20, 1, 1, 1 ) : 1,  ( 16, 74, 1, 2, 6 ) : 1,  ( 17, 74, 1, 3, 1 ) : 1,
  ( 17, 74, 1, 3, 2 ) : 1,  ( 17, 74, 1, 3, 4 ) : 1,  ( 17, 74, 2, 3, 6 ) : 1,  ( 17, 74, 2, 3, 7 ) : 1,
  ( 18, 20, 1, 1, 4 ) : 1,  ( 18, 39, 3, 1, 6 ) : 1,  ( 18, 73, 1, 1, 3 ) : 1,  ( 18, 73, 1, 1, 5 ) : 1,
  ( 18, 73, 1, 1, 7 ) : 1,  ( 19, 0 , 1, 3, 1 ) : 1,  ( 19, 74, 1, 2, 4 ) : 1,  ( 19, 74, 1, 2, 5 ) : 1,
  ( 19, 74, 1, 2, 6 ) : 1,  ( 19, 74, 1, 2, 7 ) : 1,  ( 20, 0 , 3, 1, 3 ) : 1,  ( 20, 0 , 3, 1, 4 ) : 1,
  ( 20, 20, 1, 1, 5 ) : 1,  ( 20, 20, 3, 1, 2 ) : 1,  ( 20, 39, 3, 1, 7 ) : 1,  ( 22, 20, 1, 1, 6 ) : 1,
  ( 22, 23, 1, 3, 3 ) : 1,  ( 22, 39, 2, 1, 1 ) : 1,  ( 22, 48, 1, 3, 5 ) : 1,  ( 22, 65, 1, 3, 7 ) : 1,
  ( 23, 0 , 2, 1, 2 ) : 1,  ( 23, 11, 2, 1, 3 ) : 1,  ( 23, 16, 2, 1, 1 ) : 1,  ( 23, 52, 3, 2, 7 ) : 1,
  ( 23, 52, 3, 3, 6 ) : 1,  ( 24, 0 , 1, 3, 7 ) : 1,  ( 24, 0 , 2, 1, 1 ) : 1,  ( 24, 16, 2, 1, 4 ) : 1,
  ( 24, 20, 3, 1, 5 ) : 1,  ( 24, 39, 2, 1, 6 ) : 1,  ( 25, 74, 1, 2, 3 ) : 1,  ( 25, 74, 1, 3, 2 ) : 1,
  ( 25, 74, 1, 3, 4 ) : 1,  ( 26, 0 , 1, 1, 6 ) : 1,  ( 26, 11, 2, 1, 5 ) : 1,  ( 26, 73, 2, 3, 7 ) : 1,
  ( 26, 73, 3, 3, 2 ) : 1,  ( 26, 74, 3, 3, 1 ) : 1,  ( 27, 74, 1, 3, 1 ) : 1,  ( 28, 74, 1, 3, 6 ) : 1,
  ( 28, 74, 3, 3, 7 ) : 1,  ( 30, 73, 3, 3, 1 ) : 1,  ( 30, 73, 3, 3, 4 ) : 1,  ( 31, 73, 1, 3, 3 ) : 1,
  ( 31, 73, 3, 3, 5 ) : 1,  ( 31, 74, 1, 2, 1 ) : 1,  ( 32, 20, 3, 1, 6 ) : 1,  ( 32, 73, 1, 3, 3 ) : 1,
  ( 32, 73, 1, 3, 7 ) : 1,  ( 32, 73, 2, 3, 1 ) : 1,  ( 33, 0 , 3, 1, 6 ) : 1,  ( 33, 11, 2, 1, 1 ) : 1,
  ( 33, 20, 2, 1, 2 ) : 1,  ( 33, 30, 1, 3, 5 ) : 1,  ( 33, 74, 1, 2, 7 ) : 1,  ( 34, 0 , 3, 1, 6 ) : 1,
  ( 34, 0 , 3, 1, 7 ) : 1,  ( 34, 16, 3, 1, 3 ) : 1,  ( 34, 73, 1, 3, 2 ) : 1,  ( 34, 73, 1, 3, 5 ) : 1,
  ( 35, 0 , 1, 1, 5 ) : 1,  ( 36, 0 , 3, 1, 6 ) : 1,  ( 36, 20, 1, 1, 3 ) : 1,  ( 36, 73, 3, 3, 7 ) : 1,
  ( 36, 74, 2, 3, 1 ) : 1,  ( 37, 0 , 2, 1, 5 ) : 1,  ( 37, 20, 2, 1, 1 ) : 1,  ( 37, 20, 2, 1, 6 ) : 1,
  ( 37, 56, 3, 1, 2 ) : 1,  ( 39, 16, 2, 1, 5 ) : 1,  ( 39, 16, 3, 1, 2 ) : 1,  ( 39, 74, 1, 3, 6 ) : 1,
  ( 39, 74, 1, 3, 7 ) : 1,  ( 40, 16, 3, 1, 4 ) : 1,  ( 40, 39, 2, 1, 3 ) : 1,  ( 40, 73, 1, 3, 1 ) : 1,
  ( 40, 73, 1, 3, 2 ) : 1,  ( 41, 0 , 1, 1, 1 ) : 1,  ( 41, 0 , 1, 1, 7 ) : 1,  ( 41, 13, 2, 1, 2 ) : 1,
  ( 41, 16, 2, 1, 6 ) : 1,  ( 43, 16, 3, 1, 4 ) : 1,  ( 43, 20, 3, 1, 7 ) : 1,  ( 43, 70, 3, 3, 6 ) : 1,
```

FIGURE G.1: Snap shot of the AIMMS output file

	A	B	C	D	E
1	Naam werknemer	Dienst	Afdeling	Vaardigheid	Dag
2	1	07:00 - 15:30	6	Helpende/ helpende plus/ medicatie	Monday
3	1	07:00 - 15:30	6	Helpende/ helpende plus/ medicatie	Tuesday
4	1	07:00 - 15:30	6	Verzorgende	Wednesday
5	1	07:00 - 15:30	2	Verzorgende	Thursday
6	1	07:00 - 15:30	6	Verzorgende	Friday
7	2	07:00 - 15:30	2	Cliëntondersteuners	Tuesday
8	2	14:30 - 23:00	6	Cliëntondersteuners	Wednesday
9	2	07:00 - 15:30	2	Cliëntondersteuners	Thursday
10	2	14:30 - 23:00	2	Cliëntondersteuners	Friday
11	2	07:00 - 15:30	1	Cliëntondersteuners	Saturday
12	3	11:00 - 19:30	1	Verzorgende	Monday
13	3	07:00 - 14:00	6	Cliëntondersteuners	Tuesday
14	3	15:00 - 23:00	6	Cliëntondersteuners	Thursday
15	3	07:00 - 14:30	2	Cliëntondersteuners	Friday
16	3	10:30 - 19:00	2	Verzorgende	Saturday
17	4	15:00 - 23:00	6	Verzorgende	Tuesday
18	4	15:00 - 21:30	2	Cliëntondersteuners	Wednesday
19	4	15:00 - 23:00	6	Verzorgende	Friday
20	4	07:00 - 13:30	2	Cliëntondersteuners	Saturday
21	4	07:00 - 13:30	2	Cliëntondersteuners	Sunday
22	5	07:00 - 15:30	1	Verzorgende	Monday
23	5	07:00 - 14:00	6	Cliëntondersteuners	Wednesday
24	5	07:00 - 13:30	2	Cliëntondersteuners	Saturday
25	5	15:00 - 23:00	2	Verzorgende	Sunday
26	6	07:00 - 15:30	2	Cliëntondersteuners	Tuesday
27	6	07:00 - 15:00	1	Cliëntondersteuners	Wednesday

Sheet

FIGURE G.2: Snap shot of the user-friendly Excel output file