MASTER THESIS

Appointment insertion in home care scheduling

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UNIVERSITY OF TWENTE.

Preface

Beste lezer,

Met dit onderzoek rond ik mijn master Industrial Engineering & Management af aan de Universiteit Twente.

Eind 2020 startte ik mijn afstudeeronderzoek bij TWB. Helaas kon ik door de huidige pandemie (Covid-19) weinig op locatie zijn. Ik ben er tijdens mijn studie achter gekomen dat ik programmeren echt geweldig vind.

Na een hele leuke en leerzame tijd te hebben gehad bij TWB presenteer ik in dit rapport de resultaten van mijn afstudeeronderzoek. Een onderzoek naar verbeteringen op het gebied van efficiëntie in het planningsproces. Mijn conclusie is dat TWB de efficiëntie van het planningsproces aanzienlijk kan verhogen door gebruik te maken van slimme algoritmes.

Ik heb dit onderzoek niet alleen uitgevoerd. Allereerst wil ik mijn afstudeerbegeleiders, Erwin Hans en Gréanne Maan-Leeftink, hartelijk danken voor hun wijsheid en sturing tijdens het onderzoek. Zowel inhoudelijk als onderzoekstechnisch heb ik veel baat gehad bij hun feedback.

Bij TWB wil ik iedereen danken die ik heb mogen spreken en die beschikbare informatie met mij heeft willen delen. Uiteraard wil ik graag mijn bedrijfsbegeleider, Germaine Fokke, danken voor onze (leuke!) overleggen, haar meedenken en alle mensen die ik heb mogen spreken via haar. Ik wil graag ook alle andere medewerkers bedanken van TWB voor het meedenken, meewerken en het beschikbaar stellen van alle informatie voor het onderzoek. Tot slot wil ik Christ-Jan Danen danken voor de mogelijkheid om mijn afstudeeropdracht bij TWB te doen.

Zonder hun hulp was dit onderzoek niet zo compleet geworden als dat het nu is.

Veel leesplezier!

Rick Uijlen

De Steeg, 23 Maart 2021

Managementsamenvatting

Motivatie

TWB heeft geconstateerd dat het planningsproces erg veel tijd kost. Er wordt veel met de hand gepland, zonder de hulp van slimme algoritmes. The meest tijdrovende taak van een planner is het invoegen van een nieuwe klantafspraak binnen de huidige routes. Alleen deze taak kost TWB al €178.000 per jaar.

Goal

Daarom zijn wij tot het volgende onderzoekdoel gekomen:

"Een methode verzinnen waarmee een nieuwe klantafspraak kan worden ingevoegd in de huidige routes, binnen een paar seconden, waarbij de huidige routes zo veel mogelijk hetzelfde blijven."

Aanpak

We zijn gestart met een literatuurstudie, die resulteerde in het vinden van verschillende mogelijkheden om soortgelijke problemen binnen de thuiszorg op te lossen. Vervolgens hebben we gekeken wat de randvoorwaarden zijn voor het plaatsen van een klantafspraak binnen de huidige routes. Uiteindelijk is er naar voren gekomen dat de keuze om een client op een bepaalde plek in een route te plaatsen afhangt van een drietal indicatoren: de reiskosten, de over-kwalificatiekosten en hoe goed een client geholpen wordt binnen zijn of haar voorkeurstijdsvenster. We hebben vervolgens een exact algoritme geschreven die aan de hand van deze 3 indicatoren de optimale plek vindt binnen de huidige routes om de nieuwe afspraak van de client te plaatsen. De huidige routes kunnen behoorlijk verschillen in het aantal afspraken en/of reistijden, afhankelijk van het team en het tijdstip van de routes. Daarom hebben we een experimentsimulator gemaakt. Met deze experimentsimulator hebben we verschillende startsituaties getest om te kijken hoe het algoritme presteert als de routes veranderen. Ook hebben we gekeken of de planning verbetert kan worden als er meer dan één aanpassing gemaakt mag worden.

Conclusie

Met ons algoritme kan de nieuwe klantafspraak, binnen 14 seconden, geplaatst worden binnen één van de huidige routes op de meest gunstigste plek. Dit zorgt voor een tijdsbestedingsvermindering van 90% voor de meest tijd consumerende taak van de planner. Dit zorgt voor een besparing van 82 uur per week, wat resulteert in een besparing van €159.900 per jaar. De conclusie van onze experimenten is dat ook al veranderen de routes aanzienlijk, zelfs dan kan ons algoritme binnen acceptabele tijd de meest optimale plek vinden voor de nieuwe klantafspraak. Als de hoeveelheid cliënten bijna verdubbelt op een route dan loopt de draaitijd van het algoritme op tot een maximum van 29 seconden. Onze experimentsimulator kan in de toekomst gebruikt worden om te testen hoe ons algoritme presteert wanneer de routes flink veranderen qua bijvoorbeeld de afspraakduur, aantal cliënten per route of de reisafstand. In 20% van de gevallen kan er een betere oplossing gevonden binnen 160 seconden als er meer dan één aanpassing gemaakt mag worden aan de planning. De indicatoren van de planning verbeteren gemiddeld 4.5% als er een betere oplossing wordt gevonden.

Wat is de volgende stap voor TWB?

We adviseren om ons algoritme te implementeren, zodat nieuwe klantafspraken op een efficiënte en snelle manier kunnen worden ingevoegd in de huidige routes. Een nieuw project zal hiervoor gestart moeten worden. Momenteel is het algoritme geschreven in “Python” en dient het straks te communiceren met “Nedap ONS”. Het hoofddoel van dit project is om de verschillende computerprogramma’s met elkaar te laten communiceren. Dit betekent dat de programma’s informatie met elkaar moeten kunnen delen, zoals bijvoorbeeld de routes.

De eerste stap voor TWB is om na te denken over de drie onderstaande opties:

a. *Samenwerken met Nedap ONS.* Het doel van deze optie is om het algoritme te implementeren binnen de huidige Nedap ONS applicatie. Nieuwe klantafspraken zouden dan met 1 klik op de knop ingevoegd moeten worden.
b. *Een omhulsel om Nedap ONS heen bouwen.* Er wordt dan een interface over de huidige Nedap ONS applicatie gebouwd. Vanuit de interface komt dan een voorstel waar de planner de nieuwe afspraak het beste kan plaatsen, de planner moet dan nog wel binnen Nedap ONS zelf de client naar de voorgestelde positie toe slepen.
c. *Een nieuwe applicatie bouwen.* In deze nieuwe applicatie wordt de nieuwe clientafspraak ook met 1 klik op de knop ingevoegd, alleen dan zonder de hulp van Nedap ONS. Alle informatie van Nedap ONS wordt gekopieerd naar deze nieuwe applicatie, waar vanaf dan de planning in gemaakt wordt.

Verder hebben we nog een aantal suggesties voor interessante toekomstige projecten:

- Wij denken dat als de planning op een hoger niveau gemaakt wordt, op cluster niveau, dat dit zal resulteren in een betere capaciteitsbesteding. Routes zullen korter zijn en er zal een betere kwaliteitsmatch zijn tussen de client en de verpleegkundige.

- In ons onderzoek hebben wij ons vooral gefocust op de tijdsduur van het invoegen van een nieuwe klantafspraak. Toekomstig onderzoek zou zich ook kunnen focussen op het verminderen van de frequentie van het moeten toevoegen van een nieuwe klantafspraak. Onderzoek naar een robuustere planning kan ervoor zorgen dat er minder aanpassingen nodig zijn aan de huidige routes.
- Tijdens dit onderzoek hebben wij ons vooral gericht op de meest tijdrovende taak van de planner. Toekomstig onderzoek zou zich ook kunnen focussen op één van de andere tijdrovende taken van de planners.
- Experimenten hebben aangetoond dat in 20% van de gevallen er een nog betere oplossing gevonden kan worden binnen 160 seconden als er meer dan één aanpassing aan de huidige planning gemaakt mag worden. De gemiddelde performance van de planning neemt met 4.5% toe als er een betere oplossing gevonden wordt.

Management summary

Motivation

TWB has noted that the planning process of the client schedule of TWB is costs a lot of time. A lot of tasks are done manually, without the help of any algorithms. The most time consuming task is the insertion of new client appointments within the current client master schedule. This task alone costs TWB €178.000 per year.

Goal

Therefore the goal of our research is to:

"Determine a method to insert a new appointment into the schedule for the client appointments within seconds, with as few adjustments to the current schedule as possible."

Approach

We started with a literature study, which resulted in finding various ways of solving similar problems in home health care. Next we gathered information regarding the requirements of the insertion of the client appointments. It became clear that travel costs, over qualification costs and how well a client is served within its time window were very important indicators. We wrote an exact algorithm that finds the optimal insertion position for a new client appointment based on these 3 indicators. The current client master schedule can differ quite a lot in appointments and/or travel times depending on the team and time. Therefore we have also built an experiment generator. With this experiment generator we were able to test how the algorithm performs when the starting parameters vary. We have also compared the indicators of the client schedule when multiple adjustments can be made to the client schedule.

Conclusion

Our algorithm can find the optimal insertion position within the current client schedule within 14 seconds on average. This is a reduction of 90% of the most time consuming tasks of the planners. In total this can save up to 82 hours each week, which saves up to €159.900 per year. The conclusion of the experiments, done with the experiment generator, is that the algorithm does find the optimal solution, based on the starting scenario, within reasonable time. As the amount of clients increase on a route, the computation time increases to a maximum of 29 seconds. This scenario generator could be used to test how the algorithm performs in various scenarios, like a team in a different region or maybe even another home care company. In 20% of the cases a better solution can be found, within

160 seconds, when multiple adjustments to the client schedule are allowed. In case a better solution is found, the performance of the client schedule increases by 4.5%.

What to do next?

We recommend to implement our algorithm in order to insert a client appointment in the existing client schedule in an effective and fast way. A new project has to be started to execute all implementation steps. The main goal of this project is to let different computer programs communicate with each other. This means that they should be able to exchange information like client schedules. The algorithm is currently written in the computer program "Python" and it needs to communicate with "Nedap ONS".

The first step for TWB is to think about the 3 implementation options:

a. *Work together with Nedap ONS.* The goal of this option is to integrate the insertion method into the current Nedap ONS application. New client appointments should be inserted with 1 click.
b. *Build a shell around Nedap ONS.* An interface is built over the current Nedap ONS application, it will give a suggestion where to place the client, but the planner has to drag the client to the insertion position himself within Nedap ONS.
c. *Build a new application.* In this new application the client appointment is inserted with 1 click as well, but without any help from Nedap ONS. All information of Nedap ONS will be copied to this new application and a new client master schedule should be made in this application.

We also have some suggestions for future research of which we think that can make a big difference in the planning process of TWB:

- We believe that client scheduling on a higher level, cluster level, instead of team level could result in shorter travel distances and a better qualification match between the client and the nurse. Because employee capacity will be used in a more efficient way.
- In our research we focused on minimizing the time cost of a task needed to get every client in a route. Future research could also focus on minimizing the frequency of the occurrences of why the client schedule needed an adjustment. Research should be done on how to build a robust client schedule, so that the amount of changes to the client schedule can be reduced.
- During this research we have focused on the most time consuming task of the planners. Research could be done on how to solve some of the other time consuming tasks as well.

- Experiments have shown us that in 20% of the cases a better solution can be found within 160 seconds when multiple adjustments are allowed. The average objective function improves by 4.5% when a better solution is found.

Table of contents

1 Introduction

1.1 Company description

Thuiszorg West Brabant is a Dutch company, specialized in home care and very well known in the region. They offer appropriate home care and support so clients can live longer and safely in their familiar environment. They are the home care specialist in West Brabant. They have over 1800 employees who get to know the client's loved ones, work together with their GPs, other core providers and specialist. Their district nurses are the link between their clients, other professionals and partners in the district. This way they are able to respond to signals at an early stage and they are able to immediately deliver the right care to the right place. Their clients are located in every core and neighborhood of every municipality, and so is TWB.

Together with the University of Twente, TWB has started a collaboration in order to tackle logistic and planning problems. In this master thesis we will focus on planning problems in the client schedule.

Client scheduling and employee rostering in the V&V department (Nurses & Care givers)

The V&V department consist of 900 employees. Neighborhoods are served by a specific team. In order to make the client schedule, different teams are grouped into a geography cluster. Each cluster has one FTE planner which is responsible for the planning and rostering of the cluster.

The client scheduling and rostering process is basically split up in two smaller processes. First the client schedule is made. Each client is assigned to a specific route for a specific nursing level. When all clients are assigned to a specific route, employees are linked to the routes. The employees do have a basic roster for the upcoming 4 weeks, so they know when they have to work.

The planners do work with a system called 'Nedap ONS', sometimes in combination with an own excel-file. Every week there is a cyclic basic client schedule, which is adjusted every day. Changes can be structural (new client) or temporary (illness). The planners currently focus on the following priorities: the matching of care taker and care giver level, combination of routes/clusters, client wishes and route efficiency.

1.2 Research plan

1.2.1 Problem description

1. TWB perceives that the creation of the client schedule and employee roster is done very inefficiently. Everything is planned by hand with the knowledge and experience of the planners. Currently 11 FTE of planners are used to make a client schedule for the clients and a

roster for the employees. The V&V department is making big losses (+- €400.000 per year). Also the Customer Satisfaction Research of 2019 has shown that the clients rate TWB worse than earlier years. TWB scores especially worse on the questions: 'do you get care form the same care giver' and 'do the care takers arrive at the agreed time'. Also the amount of employees that has quit their job at TWB has increased due to dissatisfaction with the current roster and client schedule. Employees have to work short shifts, sometimes early in the morning and late at night on the same day. Concluding all these problems it is clear that a lot of improvements can and should be made with regards to the current way of making the client schedule and the roster. Figure 1 shows the problem cluster, which shows how problems are related to each other.

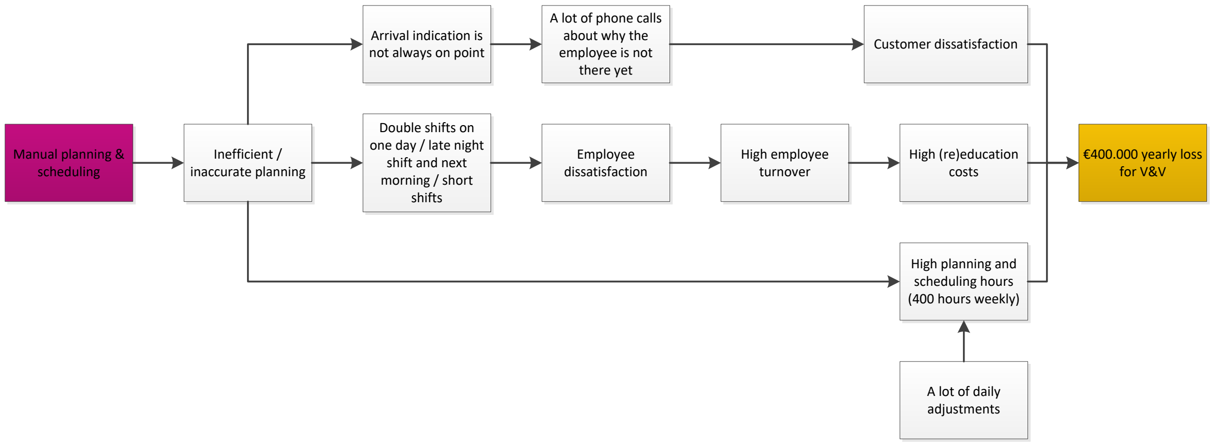

Figure 1: The problem cluster

To get a better understanding of the problem case, a broader explanation of the problems is given below.

1. *<u>V&V made a loss of €400.000 last year</u>*

   A lot of causes can be linked to this action problem. The most important ones for our research will be elaborated.

2. *<u>Customer dissatisfaction</u>*

   The customer satisfaction survey of 2019 shows that the customers are overall less positive about TWB, especially the client schedule aspects do worse than earlier years. TWB scores worse on 'does the care giver come on the agreed time?' and 'does the same care giver show up each time?'. These two points basically mean that employees are not able to stick to the made client schedule. Also the clients do think that they see more and more different employees each week. As indicated in the 2019 satisfaction survey they would prefer to see the same employees more often instead of a different one each time. Clients will start to call the service desk if the employee is late on the appointment, which causes more service costs for TWB.

3. *Employee dissatisfaction*

   Employees are getting less and less satisfied within TWB. A main cause of this is their current roster. Sometimes employees have to start working as early as 07:00 A.M. until 11:00 A.M. and then start again at 07:00 P.M. until 11:00 P.M.. So they have to work two short shifts on one day in order to meet up with the agreed hours on their contracts. They also sometimes have to work late at night and also the next morning. This can be stressful and inconvenient for employees. TWB thinks this is a main cause of why the employee turnover is increasing. More and more employees are leaving TWB. The result is that TWB has to find and educate new employees which brings costs with it.

   Inefficient scheduling process

   Currently all client schedules and employee rosters are made by hand. Each week there is a basic cyclic client schedule, which needs a lot of daily adjustments. Currently there are 11 FTE planners who work on a daily basis to make the client schedule for each cluster work. The manual planning and rostering is thought of as causing a lot of problems in the company. Especially the adjustments of the planning do take a significant amount of time each day. The increasing costs, employee and customer dissatisfaction cause a yearly loss of €400.000 for V&V.

1.2.2 Objective of the research

The adjustments to the client schedule takes by far the most time of the planners each day. TWB would like a client schedule which is generated fast after a disruption happens, with minimal changes to the old schedule. Hence:

The goal of this research is to determine a method to insert a new appointment into the schedule for the client appointments within seconds, with as few adjustments to the current schedule as possible.

1.2.3 Research questions

I. Analysis of the existing processes

The first step of the research is to understand how the current client schedule is made. We also have to know what the causes are of the disruptions in the client schedule and how often each of those disruptions occur. In order to know how the future client schedule should look like, it is very important to know which stakeholders need to be taken into account and what their wishes are regarding the client schedule. As a result, we formulate the following research question:

1. What problems are encountered with the current client scheduling approach?
    a. Who are the stakeholders and what do they want?
    b. How is the current client schedule made?
    c. What kind of disruptions occur and what is their frequency?
    d. What is the impact of those disruptions?
    e. (How) do the problems affect each other?

The planning process will be mapped by having Expert Interviews with several people in the company, including planners, managers and district nurses. The causes of disruptions in the client schedule and their frequencies will be monitored during a certain period due to the lack of data. The impact of the disruptions will be discussed with planners. The planners will make notes of how often and why they had to adjust the planning. The stakeholders and their wishes will be determined by Expert Interviews as well and by questionnaires. All of the above questions will be answered in chapter 2.

II. Solution approaches

Once the main problem is clear we will gather and possibly design various solution approaches, based on ideas gathered from the literature and from within the company. The different solution approaches can be found in chapter 3. The next research question is:

2. What are promising solution approaches for the main problem?

III. Assessment of the solutions

Again in chapter 3, a selection will be made on which solution will be tested in order to solve the problem. In this phase we will check how we can validate the different solutions. So the next research question is:

3. How can we validate the solutions?

IV. Best alternative and implementation plan

In chapter 4 we will check how good our solution is by running experiments. In order to do this we will make a scenario generator. The last research questions are:

4. What is the best alternative solution?
5. What is needed to implement this solution?

In this last phase we evaluate how well our solution performs in different situations. We will give a short list of steps that need to be taken in order to successfully implement the solution. An overview of the research framework is given in Figure 2.

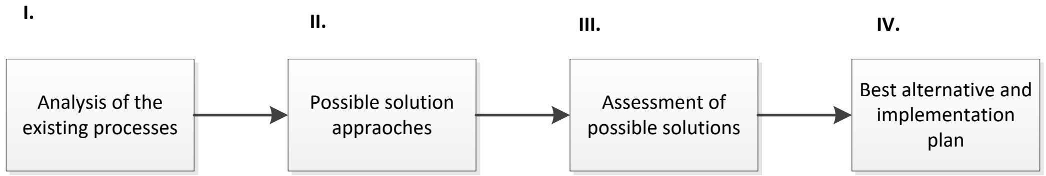

Figure 2: Framework of the research

2 Description of the existing situation

The amount of clients that can be helped by an employee is greatly affected by the efficiency of a route. Good tuning of routes based on time windows of clients will affect customer satisfaction. A well-designed client schedule results in efficient care giving and short travel distances. Effectively inserting the clients' appointment in the client schedule depends on the different stakeholders.

In section 2.1 we will state the stakeholders so we know who we have to take into account when we will insert the clients' appointment into the client schedule. Section 2.2 describes the existing situation regarding the planning process. We introduce the planning process, we will show what kind of disruptions occur, how often and how much impact it has on the client schedule. Finally, we conclude the chapter with a conclusion in section 2.3.

2.1 Overview of the stakeholders and the existing planning process

Figure 3 shows an overview of the stakeholders in the planning process at TWB. The stakeholders in the planning process are: (1) the clients, (2) the employees and (3) the board of TWB. Within the client group there are several different levels of care needing clients. For the employee group there are various employee levels, all with a different level of nursing they have to offer. Lastly, the board of TWB, which is bound to laws and rules set up by the government.

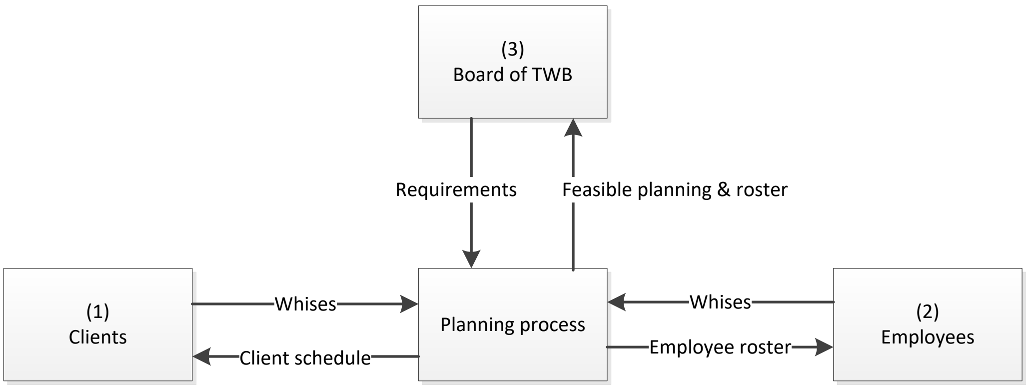

Figure 3: Stakeholder overview

We will give an overview of the wishes per stakeholder. This helps us to gather all the requirements the planning process has to fulfil in the end.

The clients

- The clients give their preferred time window in which they would like to get helped. For example they want their appointment between 9am and 10am.
- They would also prefer to have the same nurses each week, instead of always a different one.

The employees

- The duration of their shift must be between 3 and 8.5 hours.

The board of TWB

- All clients must be visited between 07:00 A.M. and 11:00 P.M.
- All clients need an employee with at least the required qualification level.
- An employee cannot work more than 10 hours on a day.
- After 5.5 hours of work an employee needs a 30 minute break.
- Employees must aim to visit a client with a maximum difference of +- 30 minutes outside their preferred time window.
- The client schedule must be fixed before the shift starts, no adjustments are allowed after it started. The only exception is when an employee calls in sick and the clients have to be split among the routes of other employees.

PROCESS STEPS

Generally a route is fulfilled completely by one employee. Routes are split up in either morning (O), Day (D) or Evening (A). The V&V department is split into 11 clusters:

- Bergen op Zoom Centrum/Zuid
- Bergen op Zoom Noord-Oost
- Bergen op Zoom / Halsteren
- Steenbergen
- Woensdrecht
- Rucphen
- Halderberge/Etten-Leur
- Roosendaal Centrum/Westrand
- Roosendaal Heilig Hart
- Kroeven -Tolberg
- Wouw

Each cluster consist of two to five teams, with each 12 to 18 employees. Each cluster has 1 FTE planner which is responsible for the client schedule and the employee roster.

Healthcare personnel is split up into different qualification levels; for this research we focus on 4 levels, namely:

- Level 2 ADL
- Level 2 Baxter
- Level C
- Level 3 IG

Clients can see via an app when the care giver is supposed to arrive (+- 30 minutes). In Figure 4 we see the current planning "tool" TWB uses. The planning tool contains a lot of client information, like appointment durations, locations and the needed care level. Information like client names and addresses have been hidden in the figure. In part one of Figure 4 the planners can see how the employee has to travel while traveling a certain route. The planners can, visually, try to improve the travel times. In part 2 we see all the client appointments that have not been scheduled on a route yet. Part 3 shows a single route with all clients on that route listed with their appointment durations. The planners now manually try to fit in a client appointment on a route. They do this by dragging the clients appointment to a certain position on a route and then compare how good this fits to the clients wishes and how much it affects the other planned appointments on that route.

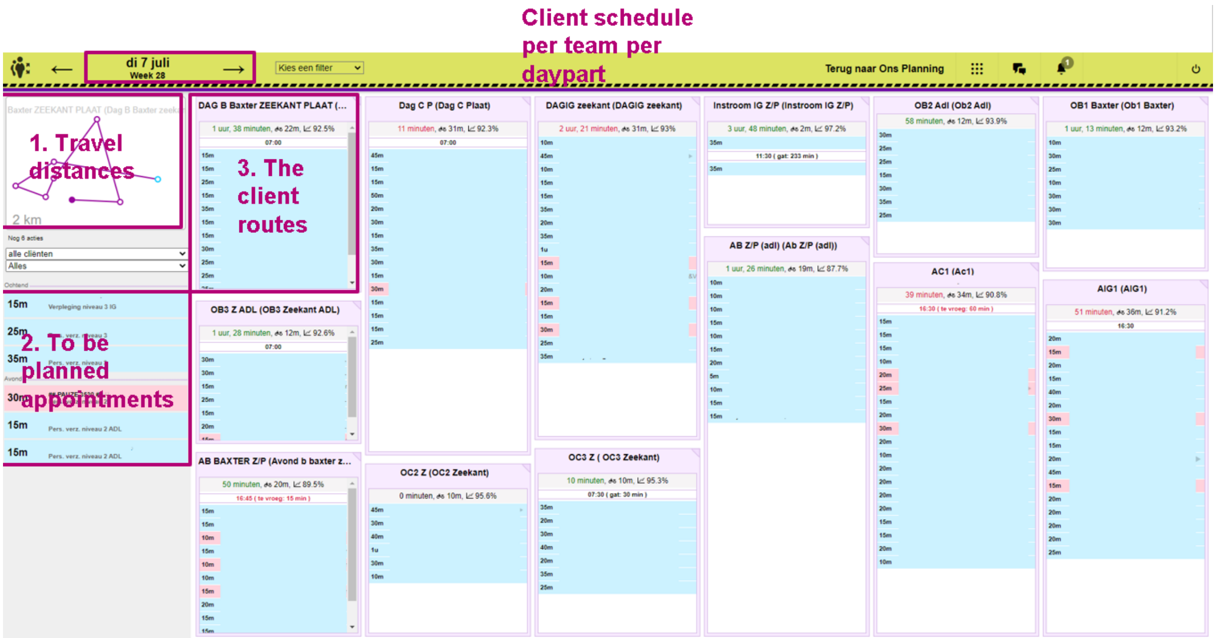

Figure 4:Current planning tool

2.2 Causes and effects of client schedule disruptions

There are several reasons of why the client schedule needs to be repaired, the main causes have been monitored within TWB in order to get a clear overview. During a period of 2 weeks data has been collected by 5 out of 11 planners. Data collection has been limited to 5 planners because it does take a lot of time to write down all the needed data. Each planner works a different amount of days, so all data is based on the average amounts per day. Table 1 gives an overview of how often each day a certain disruption occurs and how much time, on average, is needed to repair the client schedule after a certain disruption.

Table 1: Causes of disruptions

Cause of disruption	**Frequency per day**	**Minutes needed to repair the client schedule**	**Total minutes per day**
New client appointment	45	2 ⅔	100
Sick employee	6	13 ⅓	77
Removal of client appointment	18	4	72
Adjustment of client level	8	8	64
Adjustment of route because of ADL employee	9	6 ⅔	63
Adjustment of time or duration of client appointment	14	4 ⅓	62
Route is too short	7	6 ⅔	47
Employee route changes	1	4	4
Linking of trainees	1	1 ⅔	1
Total			487

Figure 5 shows that "a new client appointment" is by far the most often occurring cause of why the planners need to adjust the client schedule.

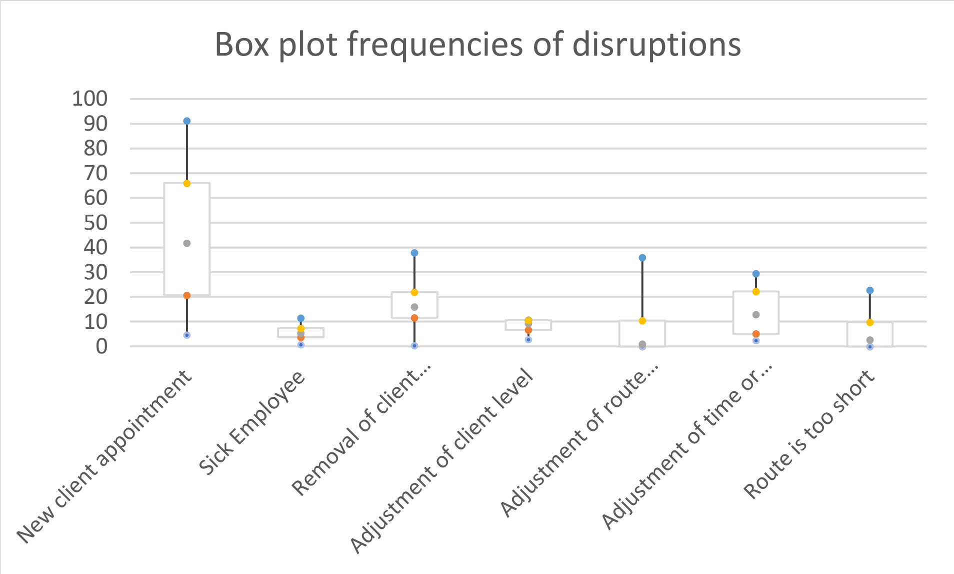

Figure 5 Box plot frequencies of disruptions

A description of the most important disruptions is given below.

New client appointment

Clients can call or send a message to make a new appointment. Also the district nurse can ask for a new appointment based on client visits. Client appointments can only be added the day after today or later.

Sick employee

An employee can call in sick. The planners got multiple options to choose from: get another employee to link to the route, split the route among the other employees. The last one does require a repair of the planning. This is the only adjustment that can be made on the same day.

Removal of client appointment

This means that a client appointment can be removed from the client master schedule. This may cause certain big gaps in the schedule. The current software program does collapse the schedule, so whenever an appointment is removed all other appointments after that appointment shift. This may cause certain appointments to fall out of their preferred time windows.

Adjustment of client level

This means that a client needs care on another nursing level. This can either be a higher or a lower level. For a higher level the client does need to be placed on a different route. When the care level goes to a lower required level the client might switch to a different route, but is also allowed to stay on the higher (old) route.

Adjustment of route because of ADL employee

Depending on the employees available for the routes it might be needed to adjust a route. ADL is the lowest care giving level. Normally routes contain both ADL and Baxter level client appointments. If a ADL employee is scheduled, the routes need to be split only in ADL tasks.

Route is too short

TWB sticks to a minimum of 3 hours for each route. If a route is shorter than 3 hours, the planners will check if they cannot divide the clients on this route over the other routes.

2.3 Conclusions

In this chapter, we have identified the existing planning process and the stakeholders. We now know who the different stakeholders are and what the current planning process looks like, in terms of what the planners do need to keep in mind while making the client schedule.

In addition, we have discussed the main causes of why the client schedule needs to be repaired. We have done this by asking the planners to write down the amount of times they had to adjust the client schedule because of a certain cause. They have also given a time indication of how long a single adjustment of the client planning takes. Multiplying the frequency and the duration has given us a list of causes which cause the most work for a planner each day.

Concluding this chapter we can say that the insertion of a new client appointment in the current client master schedule causes the most amount of work for a planner. Other causes like a sick employee or when a route is too short all result in client appointments that need to be (re)added to the client schedule once again. Therefore the main problem that needs to be tackled is a good and fast way to add a client appointment to the current client schedule. The next chapter, chapter 3, will look into different solution approaches on how this can be done best.

3 Alternative solution approaches

In this chapter, we review the literature in relation to home healthcare planning. We start by categorizing our problem in section 3.1. Section 3.2 presents what is written about home healthcare planning problems. Section 3.3 will discuss the data requirements for the alternative solution. In section 3.4 we will discuss the client schedule evaluation criteria, how do we evaluate how good a given solution is? Section 3.5 will discuss the different possible solution approaches. In section 3.6 we will present the chosen solution approach for our research. Section 3.7 will conclude the alternative solution approaches chapter.

3.1 The home healthcare planning problem

The planning problem we face at TWB can be classified as a home healthcare planning problem (HHCPP) according to Maya Duque, Castro, Sörensen, Goos (2015). Depending on the time horizon of the decision making process home care planning problems can either be categorized as tactical or operational. Chahed, Marcon, Sahin, Feillet, and Dallery (2009) state that there are two types of planning horizons, namely: short/very short term (operational problems) and long/medium term (tactical problems). The planning problem at TWB can be categorized as an operational planning problem, we therefore only focus on this decision level in the literature study.

3.2 Literature review

The home healthcare planning problems are relatively new, not much is written or researched on the topic. Therefore we deeply studied the papers written on this subject. Yet to make the study as broad as possible we have searched on the search terms in Table 2 in several databases (Scopus Utwente, Google Scolar, Web of Science).

Table 2: Search terms in databases

Robust home care planning	TSP with time windows
Robust home care scheduling	Home health care algorithms
Home care planning	Schedule Perturbation
Scheduling in batches	Offline client planning
Offline scheduling	Home care optimization
Online scheduling	Home care routing problems
Healthcare routing	Home healthcare planning

A total of 8 interesting papers about the HHCPP have been found. Below we categorize the used approaches based upon their algorithmic approach, the time horizon and the initial solution.

1. Mathematical Models and Algorithms for Home Health Care Services – Jorg Michael Steeg (2008): *Heuristic, short term, existing master schedule.*

The auteur of this paper states a problem where in an existing master schedule clients appointments have to be added while keeping the existing master schedule as much the same as possible. He does this by applying a two staged algorithm. Firstly he starts with a heuristic that inserts the currently best option for the new job. In the 2nd stage of the model he uses a tabu search meta-heuristic to improve the initial solution. He uses the tabu search because this is a widely used and successful meta-heuristic for vehicle routing problems with time windows.

2. Home care service planning. The case of Landelijke Thuiszorg - Chahed, Marcon, Sahin, Feillet, and Dallery (2009): *Heuristic, long term, new master schedule.*

They use an algorithm to create the initial master schedule. They build up the master schedule from scratch. They do not take an existing planning into account. They do use a 2 staged algorithm. First the schedule is optimized based on service level, the 2nd stage is optimized based on minimizing the travel distance while allowing a small decrease in service level. They made an extensive literature research about how other papers tried to solve mutual planning problems in the home health care.

3. Exploring new operational research opportunities within the Home Care context: the chemotherapy at home - Salma Chahed & Eric Marcon & Evren Sahin & Dominique Feillet & Yves Dallery (2009). *Exact model, short term, new master schedule.*

The auteurs use a simple exact model to fix routes for the treatment at home of cancer patients. This is done for a limit of 10 patients. They use a branch and bound algorithm enumerating the routes for the production unit.

4. Demand uncertainty in robust home care optimization - Paola Cappanera a , Maria Grazia Scutellàb , Federico Nervi b , Laura Galli b (2017): *Exact model, long term, new master schedule.*

The auteurs of this paper have designed another exact approach. They limit their computation time to 12 hours. For our project we need a new client schedule within a few seconds, in order for the planners to continue with their other tasks. This paper does have a list of constraints and several formulations of parameters, which might be useful for our problem.

5. A multi-objective modelling to human resource assignment and routing problem for home health care services - Laila En-nahli, Hamid Allaoui, Issam Nouaouri (2015): *Exact model, short term, new master schedule.*

This paper describes an exact model which solves the routing problem for home care while keeping in mind the time windows. This is done for a small group of patients. For larger models a heuristic is needed. This heuristic can still make use of the multi-objective function.

6. Hani El Sakkout, Thomas Richards, and Mark G. Wallace. Minimal Perturbation in Dynamic Scheduling. In 13th European Conference on Artificial Intelligence, Brighton, UK, pages 504–508. John Wiley and Sons, 1998: *Exact model, short term, existing master schedule.*

In this paper they try to repair an existing master schedule whenever external factors cause the current master schedule to become invalid.

7. Bertels, S., & Fahle, T. (2006). A hybrid setup for a hybrid scenario: combining heuristics for the home health care problem. Computers & Operations Research, 33(10), 2866–2890: *Exact & Heuristic, short term, new master schedule.*

This paper uses a hybrid setup of an exact model and a heuristic. First they run their exact algorithm for a maximum of 15 minutes and after that they use a heuristic to optimize the solution even further. They also state that it is hard to implement a lot of constraints into the more simple heuristics, these constraints increase the computation time significantly. They also give an overview of commonly used constraints for home healthcare problems.

8. Frifita, S., Masmoudi, M., & Euchi, J. (2017). General variable neighborhood search for home healthcare routing and scheduling problem with time windows and synchronized visits. Electronic Notes in Discrete Mathematics, 58, 63–70: *Heuristic, short term, new master schedule.*

This paper uses a general variable neighborhood search approach because the size of their problem is too big to solve with an exact model.

The performed literature study gives a good idea of the possibilities to solve our research problem. Furthermore we found 3 other papers that might be interesting for future research into client planning with stochasticity. We will list them shortly here, but we won't use them for our research: A Bayesian framework for describing and predicting the stochastic demand of home care patients (Argiento, R., Guglielmi, A., Lanzarone, E., & Nawajah, I. (2014)), A robust optimization for a home health care routing and scheduling problem with consideration of uncertain travel and service times (Shi, Y., Boudouh, T., & Grunder, O. (2019)) and Home Health Care Routing and Scheduling Problem Considering Temporal Dependencies and Perishability with Simultaneous Pickup and Delivery (Shahnejat-Bushehri, S., Tavakkoli-Moghaddam, R., Momen, S., Ghasemkhani, A., & Tavakkoli-Moghaddam, H. (2019)).

3.3 Data requirements

In order to know what a good possible position is for a new client appointment in the current client master schedule we do need to know some data. Therefore we need the current client schedule and the data of the new appointment.

The data of the new appointment should consist of at least:

- Client ID
- Client care level
- Duration
- Time window
- Urgency
- Zip code

The current client master schedule should exist of all the planned client appointments per route. Each client appointment should at least have the same data as the new client appointment.

3.4 Client schedule evaluation criteria

Based on several conversations within TWB we have decided that the objective function should be a weighted multi objective function. The objective function evaluates 3 key performance indicators (KPIs).

Travel costs

The travel costs are based both on the time travelled and the level of the nurse that is travelling. Higher level nurses cost more per hour and therefore their time spend on traveling is more expensive.

Overqualification costs

The overqualification cost are based on how many minutes a nurse spends on a client which is lower than their own nursing level.

Time window match

Each client is helped as good as possible, which means that the preferred time window is respected as much as possible. Each client can indicate a preferred time window. Based on the urgency level of a client an evaluation is made. There are 3 types of clients, all with a certain urgency. Urgency 1 is for ordinary clients, urgency 2 is for clients that need to go to daycare and urgency level 3 is for clients that need care for medical reasons, like injecting insulin.

Together these 3 indicators are combined in the weighted multi objective function:

*a_1 * Travel costs + a_2 * Overqualification costs + a_3 * Time window match.*

The values of a_1, a_2 and a_3 can be varied if needed. For now we assume, in consultation with the cluster managers, that the weights should be $a_1 = 0.3$, $a_2 =0.4$ and $a_3 =0.3$.

The client schedule which includes the new client appointment should look as much the same as possible. Therefore we will only make 1 adjustment to the current master schedule.

Based on a given client schedule we evaluate how good each possible position is for a client. We do this by calculating how many percentage points the objective function differs from the objective function without the new client appointment added.

We will also normalize each part of the objective function in order to make a more fair comparison. An increase of 1 in the travel distance might not have the same value as an increase of 1 in the time window difference. Therefore we will optimize the algorithm per part of the objective function and see the worst and the best values for each part. We will do this for each scenario.

Therefore our objective function changes into:

$$a_1 * (b1_{current} - b1_{minimum}) / (b1_{maximum} – b1_{minimum}) + a_2 * (b2_{current} - b2_{minimum}) / (b2_{maximum} – b2_{minimum}) + a_3 * (b3_{current} - b3_{minimum}) / (b3_{maximum} – b3_{minimum}).$$

Where $b1_{current}$ is the current value of the travel cost part of the objective function. $b1_{minimum}$ is the best value of the travel costs and $b1_{maximum}$ is the worst value. We do the same for b2 and b3, which are the overqualification costs and time window difference. By doing this analysis for each scenario we can scale the various parts of the objective function in a fair way.

3.5 Possible solution approaches

TWB wants to have a solution that is generated fast. There are two categories of solution approaches: exact and heuristic approaches. An exact approach does evaluate each solution within the solution space. A heuristic does only evaluate a certain selection of the solution space. By setting up bounds we are able to reduce the solution space significantly, therefore we are able to use an exact algorithm for our problem. The exact algorithm will result in the optimal solution.

3.6 Chosen solution approach

The idea of the exact algorithm is to insert a new appointment into the client master schedule within seconds, with as few adjustments to the current client master schedule as possible. We use the following weighted goal function:

$a_1 * (b1_{current} - b1_{minimum}) / (b1_{maximum} - b1_{minimum}) + a_2 * (b2_{current} - b2_{minimum}) / (b2_{maximum} - b2_{minimum}) + a_3 * (b3_{current} - b3_{minimum}) / (b3_{maximum} - b3_{minimum})$.

We have developed the following algorithm to solve the problem:

Given:

- Current client master schedule, which contains a list of routes, each of them has a required minimum care qualification level.
- A new client appointment.

The procedure will generate the best possible insertion position into the client master schedule.

Step 1: Determine performance of current client master schedule

Step 2. List all eligible routes, given the requested care qualification level

Step 3. List all possible insertion positions on the eligible routes within the preferred time window of the new client appointment. We include the first possible position before and after the preferred time window. Figure 6 shows the possible insertion positions.

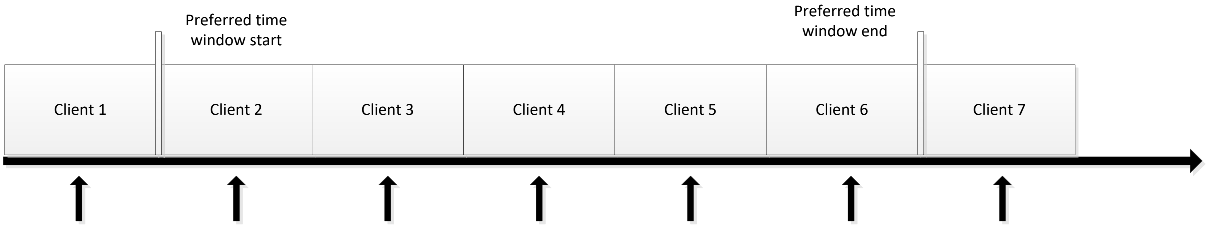

Figure 6: Possible insertion positions

Step 4. Enumerate the performance impact of all possible insertion positions to determine the best insertion position.

This approach could also be used, e.g. in a decision support system, to present the, say, five best insertion points to the planner.

3.7 Conclusion

The literature has shown that various approaches have been researched to solve different kind of home healthcare planning problems. There are two categories of solution approaches: exact and heuristic approaches.

An exact algorithm gives the optimal solution, this is done by checking every possible feasible solution within the solution space. As problems grow larger, more and more different solutions are possible. An exact algorithm quickly increases in computation time as the problem size grows. We are facing a Vehicle Routing Problem with Time Windows (VRPTW), which is known to be NP-hard, which means that this problem cannot be solved within a reasonable time by the computer for large instances. An optimal solution can be achieved, but this can sometimes take up to days, weeks or sometimes even months depending on the problem size.

A heuristic is an algorithm which does not necessarily result in the optimal solution, but it does result in a good solution within a reasonable time. A heuristic does not solve the model for every possible solution, but it takes a smaller sample of the solution space.

By reducing the solution space with the use of certain bounds we can make sure that the problem does not grow too large. This way we can still use an exact algorithm to solve our problem, which results in the optimal solution within reasonable time. We have therefore created an exact insertion algorithm which will be tested in chapter 4.

4 Experiment results

In this chapter we present the performance results of our exact algorithm based upon various starting scenarios. In this experiment we will use different starting scenarios. We do this because routes can differ a lot within TWB. We want our algorithm to perform well in different situations. In our experiment we will look into some interesting starting cases. We will compare the results of the experiments with various starting situations. In total we will run each starting situation 100 times and present the results. The starting scenario will consist of all routes in a certain team on a certain daypart. The scenarios have been chosen in consultation with TWB. In total we have chosen 5 starting scenarios:

- The classic urban TWB case (short distances, short and long appointments, average packed)
- Large distances
- Packed routes with few clients and long appointments
- Packed routes with a lot of clients and short appointments
- Multiple adjustments instead of just one

We think that those cases are interesting because they might be future cases. Travel distances might also increase when the algorithm will be used on rural area cases. Routes will also become more packed since more people will need home care. We also want to compare how the algorithm performs when more inserting positions will be available. Lastly we want to see if we can achieve a better solution when more than one adjustment to the current client schedule is possible.

4.1 Experiment set up

For each experiment we decided to make it possible to change parameters. In the experiments we will change either one or more of the following parameters:

- Total routes per care level
- Amount of clients per route
- Duration of client appointments
- Travel distance to next client

TWB can choose to change these parameters in case they want to evaluate a different scenario in the future. Each of the starting scenarios in the next 5 sections will be run 100 times. The results of the various variables in the objective function will be compared against the values of these variables before the insertion of the appointment of the new client.

For all scenarios tested we consider the parameters in Table 3, unless stated differently.

Table 3: Parameters of simulations

Amount of ADL routes	2
Amount of Baxter routes	2
Amount of C routes	2
Amount of IG routes	2
Amount of clients per route	10 to 15
Minimum client appointment duration in minutes	10 (uniform distribution)
Maximum client appointment duration in minutes	30 (uniform distrubtion)
Distance scale	1
Travel speed	20
Amount of simulation runs	100

4.2 Sub-optimization

Before we start the simulation runs we will first test the minimum and maximum values of each part of the objective function by optimizing the algorithm for each part of the objective function. This gives us, per scenario, an overview of how well a certain solution is. The values used for each scenario are listed below in Table 4. These values are determined by running 100 experiments by optimizing the algorithm over each of the parts of the objective function.

Table 4: parameters sub-optimization

Parameter	Classic urban TWB case	Large distances	Long appointment duration	Short appointment duration
b1minimum	1.000	1.000	0.960	0.983
b1maximum	1.101	1.020	1.084	1.033
b2minimum	1.000	1.000	1.000	1.000
b2maximum	1018	1.018	1.050	1.010
b3minimum	1.000	1.141	1.116	1.097
b3maximum	1.340	1.430	1.262	1.797

The parameters above will be used together with the weights given by the board of TWB, $a_1 = 0.3$, $a_2 = 0.4$ and $a_3 = 0.3$. The combination leads to the use of the following objective function with changing parameters of "b" for each scenario:

$$a_1 * (b1_{current} - b1_{minimum}) / (b1_{maximum} - b1_{minimum}) + a_2 * (b2_{current} - b2_{minimum}) / (b2_{maximum} - b2_{minimum}) + a_3 * (b3_{current} - b3_{minimum}) / (b3_{maximum} - b3_{minimum})$$

4.3 The classic urban TWB case

In Figure 7 we see the spread of 100 simulated runs. We can see that the model solves the insertion good if we look at the travel- and the quality cost difference. This means that the increase of the distance and the quality gap is affected minimal during the optimization. The time window difference on the other hand differs quite a lot. Some outliers even worsen the amount of time spent on a client outside its time window up to 1.75 times as much. Luckily 3 quarter of all simulations worsen this part of the objective function only up to 1.35 times. It is interesting to see that some solutions result in lower travel costs. This might be caused by the fact that when the new client appointment is placed on the last possible spot of a route that the distance to this location instead of the old location is shorter. The average run time of each simulation was 11.6 seconds.

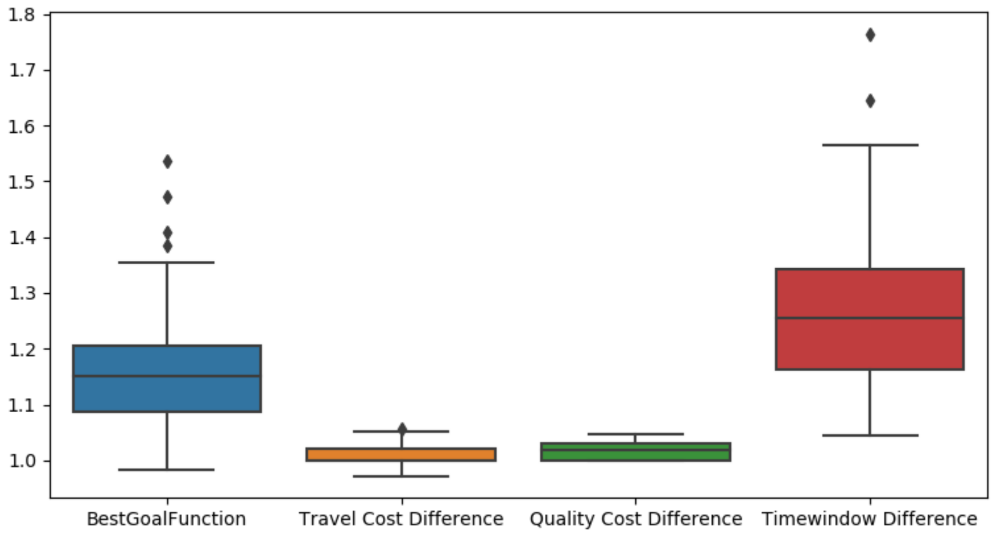

Figure 7: Objective function boxplots classic urban TWB case

4.4 Large distances

In this case the travel distance and the travel speed have been changed. The distance scale has been multiplied by 10 and the average travel speed is now 40 km/h. This way we get distances between 0 and 25km. In Figure 8 we see that as locations are more spread the time window differences increase slightly. Since a larger part of the available time is being used for traveling it becomes harder to plan every client in its desired time window. The distance difference has changed slightly compared to the classic TWB case, no more shorter distances are found. Furthermore the objective function values are more spread. This is a logic consequence of increasing distances. The running time of 1 simulation is 9.8 seconds, which is a decrease of 15% in computation time. Since fewer solutions will be interesting to save as temporary "best solution" in the algorithm, which saves computation time.

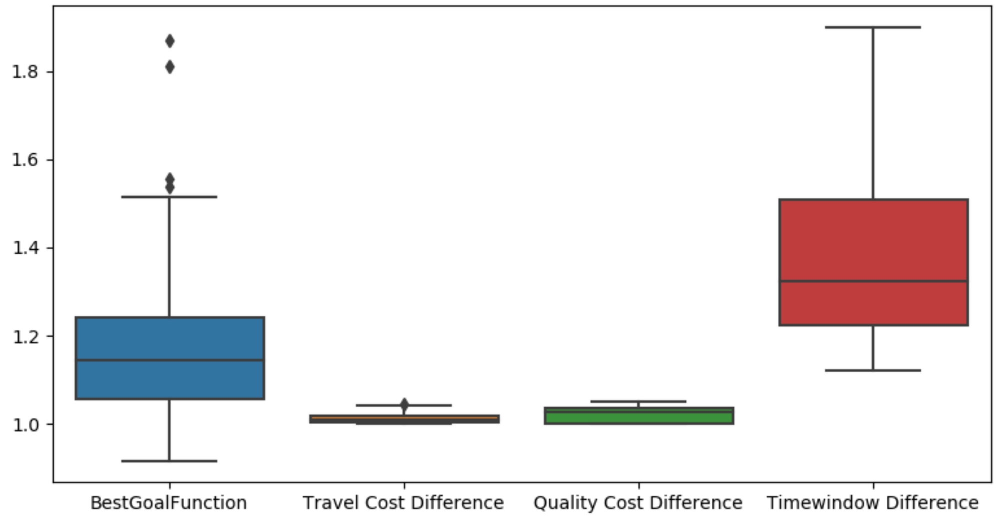

Figure 8: Objective function large distances

4.5 Long appointments

The appointment duration has been changed to a minimum of 30 minutes and a maximum of 60 minutes. Only 5 to 10 clients are listed per route now. We see that the performance of the algorithm, looking at the computation time, increases when less available spots need to be evaluated. The computation time decreases with 56% to only 5.1 seconds compared to the classic urban TWB case. In Figure 9 we can see that the 2nd and 3rd quartile of the time window differences have shifted upwards. This means that the average value of this part of the objective function performs worse when the durations of client appointments increase. We also see that quality cost increase. An increase in quality costs means that a client is served by a nurse of a higher nursing level than needed. This is a logic result as nurses are less flexible to serve clients within their time window due to the longer appointment durations. The travel cost results are more spread, when a client gets served by a higher nurse level then needed, the travel costs (increases per nurse level) also increase.

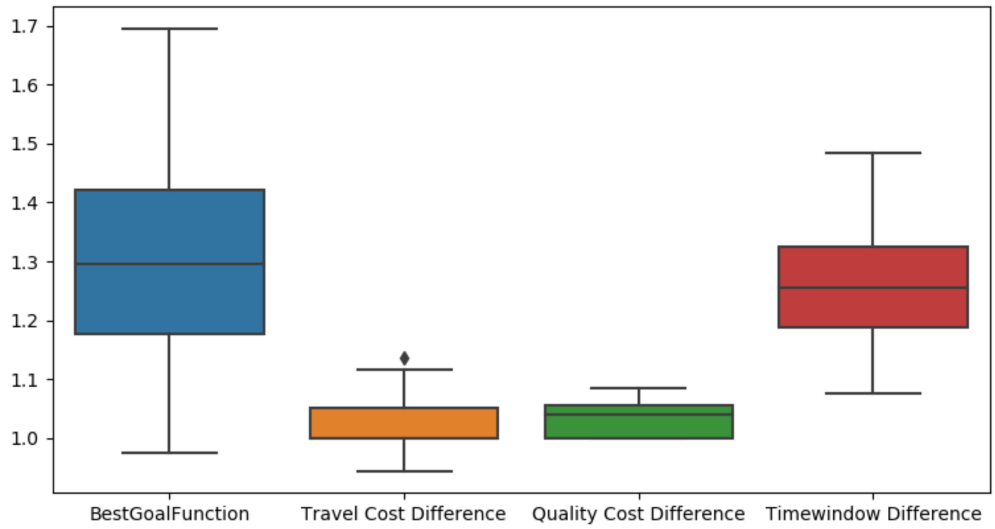

Figure 9: Objective function long appointments

4.6 Short appointments

In this scenario we decrease the appointment time and increase the amount of clients on each route. The amount of clients per route is increased again between 15 and 25 clients per route. The minimum duration has been decreased to 5 and the maximum duration of a client appointment to 20 minutes. We see in Figure 10 that the overall objective function performance has increased. All objective function variables perform better compared to the long appointment durations. The running time on the other hand has increased to 29 seconds per simulation run, which is an increase of 50% compared to the classic urban TWB case. Since the algorithm has more possible insertion spots when appointment durations get shorter and the amount of clients on a route increase. We also see that almost all clients get helped on their own nursing level.

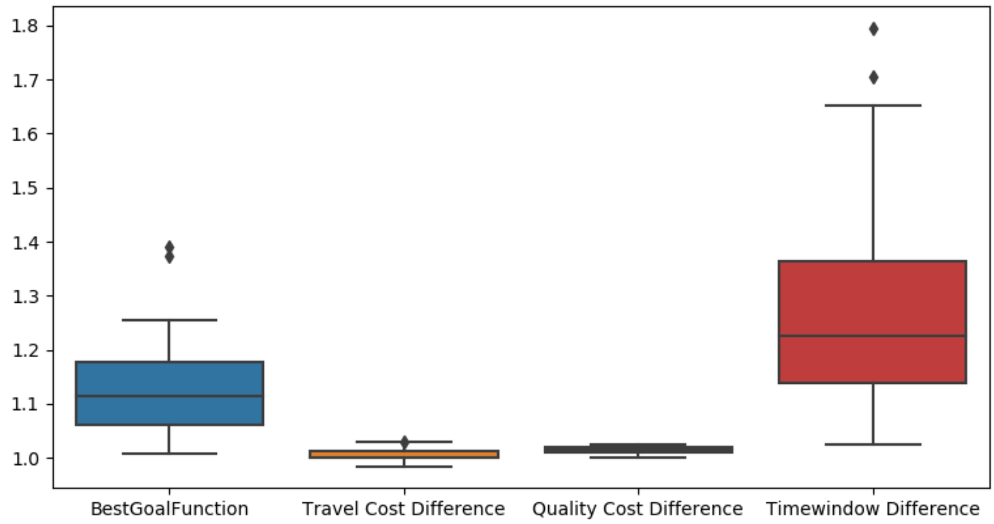

Figure 10: Objective function short appointments

4.7 Objective function results

This section gives a quick overview of the objective function results of all the simulated scenarios.

Table 5: Results of the 4 scenarios

Case	Average objective function value	Minimum objective function value	Maximum objective function value
Classic TWB	1.16	0.98	1.54
Large distances	1.17	0.92	1.87
Long appointments	1.30	0.97	1.69
Short appointments	1.12	1.01	1.39

4.8 Multiple adjustments possible

We have also tested a scenario where multiple adjustments can be made in the current client master schedule. We wanted to know if the exclusion of the only one adjustment constraint would result in a better client master schedule. After the insertion of the new client appointment we will randomly swap two client positions and evaluate of the client schedule improves or not. We have chosen for an amount of swaps which is roughly the same as the current time to insert a client appointment, which is about 160 seconds in which we can do 200 swaps. After running the algorithm 100 times for 200 swaps we can conclude that in ~20% of the cases a better solution is found, compared to when only one adjustment is allowed. Incase a better solution was found the average improvement of the client schedule was 4.5%.

4.9 Conclusion

Concluding the experiment chapter we conclude that the overall performance of the algorithm is good. Most of the experiments result in an acceptable objective function change. We observe that as the amount of possible insertion positions grows, the computation time of the code increases, which is a logical result, since this is an exact algorithm. On average the algorithm takes about 14 seconds to find the best position based on the given input parameters. We conclude that even when the starting situation changes, the algorithm still performs in almost the same way. This indicates that it is robust. The algorithm is less suitable for larger problems, as the computation time increases when the size of the problem grows. Another very promising result is that better solutions can be found when multiple adjustment to the client master schedule are allowed. In 20% of the cases a better solution can be found within 160 seconds with an average improvement of the objective function by 4.5%.

5 Recommendations for implementation

In this chapter, we give recommendations on how the proposed solution should be implemented.

The implementation of the new plan can be considered as a new project. A lot of steps need to be taken in order to make it work. For the implementation of this project we need resources (money, time and personnel). Since TWB would like to see the implementation of the project as soon as possible, we need to properly plan, organize and manage the project.

Since the implementing of the plan might overlap the current way of planning new appointments, disruption should be kept to a minimum. The new plan includes the integration of an exact algorithm in a different programming language (Python) than the current used program (Nedap ONS) for the client schedule.

To plan the proposed solution, we use the implementation steps of Joseph and Robert (1992). The steps include identifying the activities needed to carry out the project, determining the sequences of the activities, determining the resources required and the assignment of responsibilities of each activity. We will now apply these steps.

1. To effectively plan the implementation of the proposed solution we need to visualize the steps needed before we can move on to the next step.
   1. Analyze the communication possibilities
      We think that there are at least 3 possibilities that need to be researched. Currently we think that at least knowledge is needed on API's and web sockets.
      d. Work together with Nedap ONS. The goal of this option is to integrate the insertion method into the current Nedap ONS application. New client appointments should be inserted with 1 click.
      e. Build a shell around Nedap ONS. An interface is built over the current Nedap ONS application, it will give a suggestion where to place the client, but the planner has to drag the client to the insertion position himself within Nedap ONS.
      f. Build a new application. In this new application the client appointment is inserted with 1 click as well, but without any help from Nedap ONS. All information of Nedap ONS will be copied to this new application and a new client master schedule should be made in this application.

We will give a short list of the required client schedule information that needs to be exchanged between the applications:

- Client sequence per route
- Client ID
- Client care level
- Duration
- Time window
- Urgency
- Zip code

2. Decide which possibility is the best
3. Change coding in order to let different programs communicate

   Each piece of information that has to be exchanged between the applications needs some adjustments to be able to communicate.
4. Start pilots

   In this phase the solution will be tested with small teams.
5. Evaluate results

   After a while the results should be evaluated and adjustments should be made where needed.
6. Adjust coding based on results and possibly more restrictions

2. In this step we sequence the activities. The sequence is done based on activities. Some activities cannot start before another has finished. In our case we also have a visual circle. The first 3 steps will be done in a sequence, after that we will keep repeating steps 4 to 6. Figure 11 summarizes the sequence of the steps that need to be taken. This should improve the quality of the proposed solution.

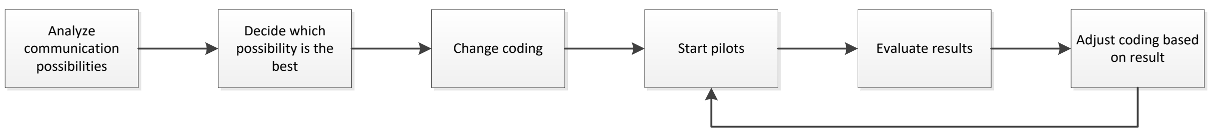

Figure 11: Implementation steps

3. In this step we manage the implementation. Once all activities are clear we have to plan the completion time of each step. In this step we have to take the availability of resources into account. Resources should be assigned to each activity in order to complete each step within the completion time.

   The most important resources of the implementation plan are money and human capacity. The implementation should start with the formation of a project team. This project team should assign responsibilities for each activity in the implementation plan. They should start by managing what, by whom and when each step should start and when it should be completed.

6 Conclusions and recommendations

This research has focused on identifying the inefficiencies related to the client scheduling process. In this chapter we discuss the overall conclusion and the recommendations of the research. We give an answer on how our main research question can best be solved:

“The goal of this research is to determine a method to insert a new appointment into the schedule for the client appointments within seconds, with as few adjustments to the current schedule as possible.”

We will also give an answer on all our sub questions in the next section.

6.1 Conclusions

What problems are encountered with the current client scheduling approach?

Currently all client schedules are made by hand. The most time consuming task is the insertion of new client appointments within the current client master schedule. This task takes on average 100 minutes from each planner each day, which results in a yearly cost of €178.750.

What are promising solution approaches for the main problem?

TWB needs a fast and good solution, the planners don’t have time to wait a few hours to find a good solution. Therefore we could use a exact algorithm, limited by boundaries, which results in the optimal solution. Another promising solution is a heuristic, which results in a good, but not optimal solution within reasonable time.

How can we validate the solutions?

The solutions have been validated by running experiments. Various scenarios have been tested in order to see how the algorithm performs. The evaluation consist out of a weighted objective function. This objective function takes the travel costs, the over qualification costs and how much time clients are helped outside of their preferred time window into consideration. The result of the algorithm is a preferred position on a certain route within the current client master schedule.

What is the best alternative solution?

The best solution to solve the problem is an exact algorithm which finds the optimal insertion position for the new client appointment within the current client master schedule. It evaluates each possible insertion position (see Figure 12) and gives the adjusted client master schedule with the new client appointment inserted optimally as output.

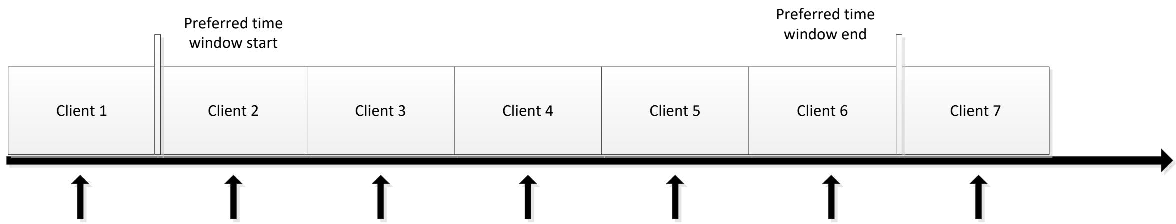

Figure 12: Possible insertion positions

What is needed to implement this solution?

The algorithm is currently written in the computer program "Python" and it needs to communicate with "Nedap ONS".

The first step for TWB is to think about the 3 implementation options:

a. *Work together with Nedap ONS.* The goal of this option is to integrate the insertion method into the current Nedap ONS application. New client appointments should be inserted with 1 click.
b. *Build a shell around Nedap ONS.* An interface is built over the current Nedap ONS application, it will give a suggestion where to place the client, but the planner has to drag the client to the insertion position himself within Nedap ONS.
c. *Build a new application.* In this new application the client appointment is inserted with 1 click as well, but without any help from Nedap ONS. All information of Nedap ONS will be copied to this new application and a new client master schedule should be made in this application.

Next the coding needs to be adjusted based upon the chosen implementation option. After that the pilots can start.

"The goal of this research is to determine a method to insert a new appointment into the schedule for the client appointments within seconds, with as few adjustments to the current schedule as possible."

The planners currently, on average, take about 160 seconds to find a suitable spot. Our algorithm finds the optimal solution in only 14 seconds and makes minimal adjustments to the current client schedule. This is a reduction of 90% of the most time consuming tasks of the planners. In total this can save up to 82 hours each week, which saves up to €159.900 per year.

We also wanted to add something to the literature on this topic. Therefore we have also created an instance generator, which can be used to create different kind of starting schedules for insertions of client appointments.

The scenario generator resulted in a confirmation that the algorithm still does result in the best insertion position, even when the starting scenario changes. This makes the algorithm usable for similar cases. As the amount of clients grow on a route the computation time also grows with it to 29 seconds.

6.2 Recommendations

Based on the results of our research, we recommend to implement the suggested algorithm in order to insert a client appointment in the existing client master schedule in an effective and fast way. Furthermore there are a lot of other interesting subjects / problems that became clear during our research. Some recommendations for further research:

- We believe that client scheduling on a higher level, cluster level, instead of team level could result in shorter travel distances and a better qualification match between the client and the nurse. Because employee capacity will be used in a more efficient way.
- In our research we focused on minimizing the “time cost” of a task needed to get every client on a route. Future research could also focus on minimizing the “frequency” of the occurrences of why the client schedule needed an adjustment. Research should be done on how to build a robust client schedule, so that the amount of changes to the client schedule can be reduced.
- During this researched we have focused on the most time consuming task of the planners. Research could be done on how to solve some of the other time consuming tasks as well.
- Experiments have shown us that in 20% of the cases a better solution can be found within 160 seconds when multiple adjustments are allowed. The average objective function improves by 4.5% when a better solution is found.

6.3 Discussion

The research resulted in a solution for TWB which reduces the time spent on the insertion of a new client appointment within the current client master schedule by 90%. Our algorithm also performs well when the parameters of the current client schedule change. The algorithm is less suitable for larger problems, as the computation time increases when the size of the problem grows. With the results of this research, TWB is able to find the optimal position for a new client appointment in the current client master schedule, within seconds, while making as few adjustments to the current planning as possible.

For this research we made some assumptions:

- We have only looked into the cluster of Bergen op Zoom due to being limited by a time constraint.
- There is already a client master schedule before a new client appointment needs to be inserted.
- Minimal changes must be made to the client master schedule.
- We assumed that there are always enough employees to fill all routes.
- We use random normal generated coordinates for the simulations.
- The travel speed is 20km/h for urban areas and 40km/h for rural areas.
- Employee breaks were left out of the scope.
- The minimal and maximal preferred working hours for an employee were left out of the scope.
- Only one new client appointment shows up at a time.

With the increasing amount of clients TWB needs to make adjustments to the current way of adjusting the client schedule, otherwise the planning & scheduling costs will only increase.

There are also some interesting things we have come across.

- Currently there is a standard travel time for every appointment, which is 2 minutes, no matter the distance that needs to be travelled by the nurse. We think that a calculation based on the travel distances should be used. A simple calculation of dividing the travel distance by the travel speed should result in a more accurate travel times.
- All information about how urgent a client needs its appointment on time is in the planners head or on a small side note. Whenever one of the planners stops working at TWB for whatever reason, this information will be lost. Therefore a knowledge system should be set up. All this information should be written down somewhere.
- The current pandemic (Covid-19) shows us that the amount of sick employees has doubled. Therefore it is, even more than ever, important that improvements will be made within a short term.

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Figure list