Planning of external logistics for Deventer Hospital

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Preface

This research completes my Master programme Industrial Engineering & Management at the University of Twente, specialization Production and Logistic Management. I really enjoyed to participate in this interesting study programme due to the high variety of courses. I want to use this section to thank some people for their support during this research.

First, my gratitude goes out to my supervisors from Deventer Hospital, Har Salden, Roy Gotink, and Marjo van den Elsen – Hutten. Thank you for the opportunity to conduct this Master thesis research at Deventer Hospital and all your support and helpfulness throughout this research. It was a pleasure to work with you. Moreover, I thank the operational managers of the laboratories and pharmacy for their input and experience during this research. It was very useful. I am also grateful to all other Deventer Hospital employees who contributed to this research, and to those who have given me an enjoyable internship during my research at Deventer Hospital.

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Third, I thank my girlfriend, Lisa, for her continuous support during my study as well as during the research at Deventer Hospital.

Finally, I thank my parents for their continuous support during my study career and the opportunities they offered. They made it possible for me to study and supported me throughout the years. Thank you very much!

Deventer, November 2015
Michel Barneveld

Management summary

This research aims to improve the planning of external logistics for Deventer Hospital.

Background
The laboratories and the pharmacy of Deventer Hospital are closely located to each other within the hospital and all of them organize their logistical services themselves. The core problem is that the current logistical services are not organized efficiently and there is need for service improvement. However, it is unclear how this can be realized and what performance can be expected. The research goal is:

To analyse the current planning of external logistics, and assess interventions to improve these at the laboratories and the pharmacy of Deventer Hospital.

Approach
We evaluate the current situation of Deventer Hospital and compare this with other interventions by means of a scenario analysis. We evaluate all scenarios with respect to total costs as well as the service towards clients, patients and employees of Deventer Hospital.

The proposed scenarios differ from the current situation on five aspects. First, beside the current point-to-point delivery option, we address a hub-and-spoke model for the collection of samples (see Section 4.1.2). In this model we use hub locations, which serve as transhipment points to the DH as well as to service points of DH. We vary the number of hubs as well as in the locations of the hubs. Second, we address to combine the transport for the laboratories. Third, we restrict the transport modes in the catchment area of Deventer Hospital to phlebotomists only, i.e., they are the only provider for the collection of samples for all the laboratories. Fourth, we vary the visit frequency of the pick-up locations for the microbiology and pathology, i.e., daily or interval. Fifth, in case hubs are used, we vary between phlebotomists and Dimence Group for the transportation between hubs and Deventer Hospital.

Results
The scenario analysis shows that there are various possibilities for successfully improving the efficiency of the logistical planning of Deventer Hospital. It turns out that the current situation of Deventer Hospital is one of the most expensive ones and yields the lowest service level towards their clients and patients.

The hub-and-spoke model outperforms the point-to-point delivery option on costs. We conclude that using the hub locations of Raalte and Rijssen will yield the highest savings if phlebotomists are performing the transport between hub locations and Deventer Hospital. However, in case Dimence Group performs the transport, larger savings can be achieved, and even more if we add Bathmen, Twello or both hubs to the model. The transport between hubs and DH should therefore be arranged by Dimence Group, since they yield the highest savings. In case Dimence Group can incorporate the addresses of the hub locations in their existing routes, even larger savings can be achieved and can reach an amount of €150 per week in case all hub locations are used.

Based on the service towards clients and patients of DH, the hospital should include the pick-up locations of the other laboratories on a daily basis. In case Deventer Hospital wants to maximize their profits, they should include the orders of the microbiology and pathology on an interval basis, i.e., once per week for the pathology and three times per week for the microbiology. This would result in additional savings of €180 up to €240 per week, depending on the other scenario decisions. However, a drawback of the interval basis is that the service towards the clients and patients remains moderately.

Finally, the model used for the scenario analysis has shown that using more iterations will result in better solutions for the scenarios. There is a significantly difference in the total hours used by phlebotomists for driving the routes between none, 10,000 and 50,000 improvement iterations. Every hour that could be reduced from the objective function means an additional saving of €43.75. The current manual planning of routes is by no means the optimal solution, which means that automating and optimizing the routes will yield higher savings for DH.

Recommendations
From the conclusions, based on service level, we recommend to use the hub-and-spoke delivery option with two hubs (Raalte and Rijssen) and include the pick-up locations of the other laboratories on a daily basis. The transport should be arranged by Dimence Group, due to the fact it outperforms phlebotomists based on costs. This scenario increases the service level towards the clients and patients of DH enormously, subsequently it reaches savings of approximately €380 per week. The additional savings between two hubs and four hubs is marginal and therefore we advise to use two hubs. The commissioning of the third and fourth hub would probably cost more than the additional savings.

Based on costs minimization, we recommend to use the hub-and-spoke delivery option with the same two hubs, but instead of including the pick-up locations on a daily basis, include them on an interval basis. The additional savings are €200 up to €235 per week.

Furthermore, for every scenario, we recommend to keep sending samples outside the catchment area to the hospital by means of the service of PostNL/Cycloon. It is abundantly clear that driving towards those locations will yield much higher costs than the postage costs of PostNL/Cycloon.

Management samenvatting

Dit onderzoek heeft als doel om de planning van externe logistiek voor Deventer Ziekenhuis (DZ) te verbeteren.

Achtergrond
De laboratoria en apotheek van het DZ liggen naast elkaar op de 3e verdieping van het DZ en regelen allemaal afzonderlijk hun eigen logistieke dienstverlening. Het hoofdprobleem is dat de huidige logistieke stromen niet efficiënt georganiseerd zijn, en dat er behoefte is om deze dienstverlening te verbeteren. Echter, is het onduidelijk hoe dit gerealiseerd kan worden en welke prestaties er verwacht kunnen worden. Het onderzoeksdoel is als volgt:

Het analyseren van de huidige planning van de externe logistiek, en het beoordelen van interventies om deze te verbeteren bij de laboratoria en apotheek van het Deventer Ziekenhuis.

Aanpak
We evalueren de huidige situatie van DZ en vergelijken deze met andere voorgestelde interventies door middel van een scenario analyse. We evalueren alle scenario's op basis van totale kosten alsmede de service richting de klanten, patiënten en medewerkers van het Deventer Ziekenhuis.

De voorgestelde scenario's verschillen van de huidige situatie op basis van vijf aspecten. Ten eerste, naast de huidige point-to-point leveringsoptie, passen we het hub-and-spoke model toe voor het collecteren van monsters. In dit model worden hub locaties gebruikt die fungeren als overdrachtslocaties voor het DZ alsmede voor de prikposten van DZ. We variëren in het aantal hub locaties alsmede de locaties ervan. Ten tweede combineren we het transport van de laboratoria. Ten derde beperken we de transportmogelijkheden in het verzorgingsgebied van DZ tot alleen trombosedienstmedewerkers, d.w.z., zij zijn de enige dienstverlener voor het collecteren van monsters voor alle laboratoria. Ten vierde variëren we in de bezoekfrequentie voor de 'pick-up'-locaties van de microbiologie en pathologie, d.w.z., dagelijks of op interval basis. Tenslotte, indien er gebruik gemaakt gaat worden van hub locaties, dient het vervoer tussen de hub locaties en DZ geregeld te worden.

Resultaten
De scenario analyse heeft aangetoond dat er verschillende mogelijkheden zijn voor het succesvol verbeteren van de efficiëntie voor de logistieke planning van het DZ. Het blijkt dat de huidige situatie van DZ één van de duurste scenario's is en de laagste service biedt naar haar klanten en patiënten.

Het hub-and-spoke model presteert beter dan de point-to-point leveringsoptie op basis van kosten. We concluderen dat het gebruik van de hub locaties Raalte en Rijssen de hoogste opbrengsten bieden in het geval trombosedienstmedewerkers het transport regelen tussen de hub locaties en DZ, en vice versa. Echter indien Dimence Groep het vervoer regelt zijn de opbrengsten hoger, en nog meer als we de hub locaties van Bathmen, Twello of beide toevoegen in het model. Het transport van de hubs naar DZ moet daardoor geregeld worden door Dimence Groep, omdat zij de hoogste opbrengsten genereren. In het geval Dimence Groep de locaties van de hubs in hun bestaande netwerk kunnen integreren, er nog hogere opbrengsten gerealiseerd kunnen worden. Deze kunnen oplopen tot een bedrag van €150 per week, afhankelijk van het aantal hub locaties.

Gebaseerd op service naar de klanten en patiënten van DZ, moeten we de 'pick-up'-locaties van de microbiologie en pathologie dagelijks bezoeken. In het geval DZ haar opbrengsten wil maximaliseren moet zij de 'pick-up'-locaties op interval basis bezoeken. Dat betekent één keer in de week voor de pathologie en driemaal per week voor de microbiologie. Dit levert het DZ een extra besparing van €180 tot €240 per week op, afhankelijk van de andere aspecten/keuzes. Echter, een groot nadeel voor het bezoeken op interval basis is dat de service richting de klanten en patiënten matig blijft. Dit aangezien de frequentie van bezoeken gelijk blijft en dus krijgen de patiënten ook niet eerder de uitslag van de testen.

Tenslotte laat het model voor de scenario analyse zien dat bij het gebruik van meer iteraties er betere resultaten gehaald worden voor de scenario's. Er is een significant verschil in het totaal aantal uren dat trombosedienstmedewerkers bezig zijn met routes rijden tussen geen, 10.000 en 50.000 verbeter iteraties. Elk uur dat er minder gereden wordt levert een bedrag op van €43,75. De huidige handmatige planning van routes voor de trombosedienstmedewerkers is geenszins de optimale oplossing, wat betekent dat bij het automatiseren en optimaliseren van de routes voor de trombosedienstmedewerker hogere opbrengsten gerealiseerd kunnen worden.

Aanbevelingen
Gebaseerd op service level, raden wij aan om het hub-and-spoke model te gebruiken met twee hub locaties (Raalte en Rijssen), alsmede het dagelijks bezoeken van de overige 'pick-up'-locaties. Het transport tussen DZ en de hub locaties moet worden geregeld door Dimence Groep, omdat er dan meer bespaart kan worden. Dit scenario verhoogt ook de service richting de klanten en patiënten van DZ enorm, en daarnaast levert het DZ een besparing op van €380 per week. De extra opbrengsten tussen het gebruik van twee en vier hub locaties is marginaal, en daarom adviseren wij twee hub locaties. Het inregelen van een derde en vierde hub zullen waarschijnlijk meer kosten dan de opbrengsten.

Op basis van kostenminimalisatie raden wij het hub-and-spoke model aan met twee hub locaties, en het ophalen van de monsters voor de microbiologie en pathologie op interval basis. Hierdoor bespaart het DZ bovenop de €380 per week nog eens €200 tot €235 per week.

Tenslotte, voor elke scenario, adviseren wij om monsters die buiten het verzorgingsgebied van DZ opgehaald moeten worden te laten bezorgen door PostNL/Cycloon. Het is overduidelijk dat de kosten voor PostNL/Cycloon vele malen minder zijn dan de kosten wanneer een trombose-dienstmedewerker naar deze locaties rijdt.

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1. Introduction

Health care is the largest expenditure of the Dutch government and it grows substantially every year. This increase is an international phenomenon and the expectation is that the increase in health care costs will remain for the coming years. Causes of this phenomenon is the more and better care, the higher expectations, the more support and the ageing of the population (in the Netherlands). Consequences for the entire population are the increase of taxes, as well as budget cuts in other government expenditures (Ministerie van Volksgezondheid, 2012).

Due to the abovementioned phenomenon, health care is also the most innovative sector in our society, e.g., seeking for new treatments for cancer, or applications (e.g., for mobile phones) to find the cheapest medications. Hence, hospitals are constantly seeking for opportunities to improve their treatments and processes. Innovation leads to health benefits, but also offers the possibility for efficiency gains. Without continuous innovation it will be hard to control the health care costs in the future (Nederlandse Vereniging van Ziekenhuizen, 2013). Delivering high-quality services with limited resources is one of the main challenges in healthcare systems today. Therefore, optimization problems in the healthcare sector have triggered many researchers, particular from the area of Operations Research (OR) (Grasas, et al., 2014).

This report describes a case study of improving the planning of logistics for external parties outside of Deventer Hospital (DH). This research study aims to aid DH in formulating interventions to the current logistical processes. These interventions will be done at three laboratories and the pharmacy of DH.

This chapter is organized as follows. In Section 1.1, the organisation and the departments involved in the project are described. Section 1.2 treats the problem description, followed by the research motivation in Section 1.3 and the research scope in Section 1.4. The research questions and approach are described in Section 1.5.

1.1. Deventer Hospital

DH is a medium sized Dutch teaching hospital in the Netherlands. In the summer of 2008, DH has been merged at one location, the Rielerenk in the Deventer area. Before, it was located at several locations in Deventer.

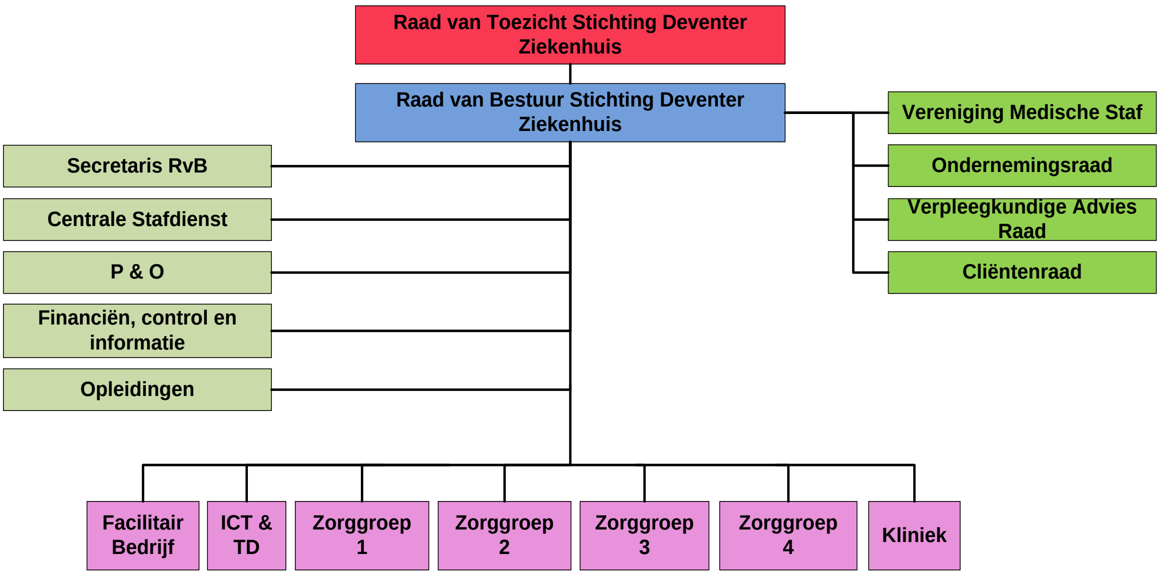

Figure 1.1: Organizational chart Deventer Hospital

The hospital provides the broad medical basic care for the residents of Salland and is also a proud member of the "*Samenwerkende Topklinische opleidingsZiekenhuizen (STZ)".* There are 28 hospital members connected to this association, which are not at an academical level, but due to their facility level and their educational effort they belong to the top of the general hospitals. The organizational chart of DH is given in Figure 1.1.[1]

Each health group ("Zorggroep") consists of several departments. For this case study only health group 4 is relevant and it consists of eight departments. Within this group of eight departments (see Figure 1.2) only four, green highlighted, are involved in this case study and are briefly explained. All other departments are out of the scope of this project.

Clinical Chemistry Laboratory
The clinical chemistry laboratory conducts investigations on blood, bone marrow, urine, stool, cerebrospinal fluid and other body fluids.

Laboratory of Microbiology
On the Laboratory of Microbiology, testing is done on patient material (e.g., urine, blood or stool) to investigate the causes of infections: all kinds of bacteria, viruses, parasites, yeasts and fungi.

Laboratory for Clinical Pathology
In the clinical pathology department testing is done in pieces of tissue or organs, which are removed from a patient.

Pharmacy
The department of clinical pharmacy provides pharmaceutical care to clinical patients of DH, to Dimence Group (DG), an institution providing healthcare for mentally ill patients, to Carinova, an institution providing care for elderly patients and to some pharmacies and dispensing general practitioners (GPs) in the area of Deventer.

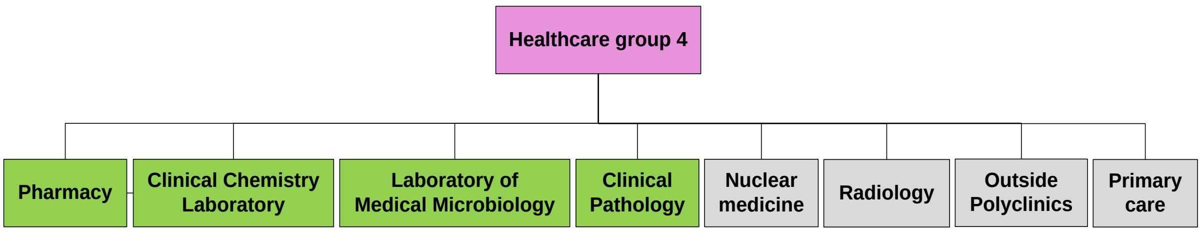

Figure 1.2: Organizational chart healthcare group 4

DH has about 2,200 employees which accounts for 1,650 Full-Time Employees (FTEs). Annually 115,000 people are coming to the hospital for a first consult at one of the polyclinics. The number of operation hours in 2013 was 18 thousand and the turnover of DH in 2013 was 177 million Euros.

1.2. Problem description

For the service of the clinical chemistry, blood or urine is collected from the patient and analysed in the laboratory situated in the hospital. For patients using this service and who are not hospitalised, it is not necessary to visit DH. The hospital has a network of about 30 service points in the surrounding areas where blood can be drawn or samples can be delivered. Furthermore, if patients are unable to visit any of the service points, the phlebotomists can visit patients at home for blood or sample collection. After collection, samples are transported to the laboratory of clinical chemistry in DH by the phlebotomists. Phlebotomists are specialised clinical support

[1] Annual Document DH, Social Report 2013

employees who collect blood from patients for examination in laboratories, the result of which, provide valuable information to diagnosing illness.

The anticoagulation service of the hospital (which is incorporated in the clinical chemistry department) uses the same network of service points as described above. This service is provided for outpatients using oral anticoagulant drugs for which blood is drawn and transported to the laboratory. Thereafter, prescription of the dosage of oral anticoagulant drug is given as well as the date of the next control measurement is given. Furthermore, the departments of microbiology and pathology benefits from the same service of clinical chemistry, i.e., the collection of samples to DH.

For samples other than blood, at the department of microbiology and clinical pathology, sample collection is done at GPs. The samples are sent to the laboratories, e.g., by means of a package of PostNL, which are (mostly) delivered the next day. An empty package with collection material is returned again by PostNL or is delivered by an employee within a week.

There are also new needs for logistical services:

- In the current setting there is a little need of service for GPs who want to draw blood in their own practice and work with organisations for only picking up material on a daily basis, i.e., phlebotomists does not have to visit the service point anymore, but only the transport of the samples have to be arranged. This service is interesting for patients in smaller villages where the service of the clinical chemistry of DH is less frequent (e.g., once or twice a week).

- Currently, the phlebotomists of the anticoagulation service only work in the morning. However, there are (many) requests from GPs for (non-)emergency cases in the afternoon. Currently, if there is an emergency case, an employee of the secretariat of the anticoagulation service or a phlebotomist at the polyclinic is visiting the patient (at home). If it is not an emergency case, the patients will not being treated that day. Therefore, there is a demand of phlebotomists in the afternoon to accommodate such (non-)emergency cases.

There are many existing logistical flows, but also needs to set up new logistical flows.

1.2.1. Core problem

Several departments are closely located to each other within the hospital and all of them organize their logistical services themselves. The core problem is that the current logistical services are not organized efficiently and there is need for service improvement; however, it is unclear how this can be realized and what performance can be expected.

1.2.2. Problem owner

The research is conducted at the hospital of Deventer. Within the hospital, several departments are involved in the project and can be seen as the "main problem owners", namely the laboratories and the pharmacy. More specifically, the care managers of the corresponding departments may be considered as the problem owners.

1.3. Research motivation and goal

Nowadays, the three laboratories and the pharmacy are located at the third floor of the hospital. Before, they were divided over several places in the surrounding area of Deventer. After a couple of years since the merger, the software package Intertour was purchased by the clinical chemistry laboratory. Intertour is an interactive planning system and it was intended for the anticoagulation service. Unfortunately, after some tests, Intertour has never been operational due to many bugs and restrictions. It just did not work the way they want it. Therefore, the planner and the employees of the anticoagulation service gave their preference to their previous way of working, the manual planning of routes. Purchasing Intertour was expensive, partly because of the 5-year service contract.

During the previous years till now, the network of service points and home visits at patients have increased significantly. Manually planning of routes takes several hours per day, many handling operations have to be performed and much paperwork is required. The manual scheduling should be digitized. However, before making another huge investment, some things have to be sorted out.

Besides the manually planning of the anticoagulation service, there are many more logistical flows that need to be planned. The three laboratories and the pharmacy are all having logistics for external parties outside DH, and are all organized by the departments themselves. Well considered interventions to improve the current logistical processes are essential for DH because it can result in a decrease in transportation costs and an increase of their customer satisfaction. Besides, when there is (extra) synergy between departments, an investment in a software package may be beneficial for more than one department.

We formulate the research goal as follows:

> *To analyse the current planning of external logistics, and assess interventions to improve these at the laboratories and the pharmacy of Deventer Hospital.*

1.4. Research scope

The background of this research is that DH wants to have a more efficient planning of the logistics for the external parties of DH. In order to decrease the complexity of the problem, we need to scope the problem. Only the three laboratories (clinical chemistry, pathology and microbiology) and the pharmacy belong to the scope of the project. Moreover, the project investigates the external logistics of the departments, i.e., no research will be done to the internal logistics.

1.5. Research questions

This section presents the research questions. In order to solve the research goal, we divided the research in five research questions. The chapter in which each research question is answered is mentioned before each question. The method of answering these questions is explained directly after each question.

Chapter 2: Current situation

1. *How are the logistical processes currently organized at the departments?*
   1.1. What are the clients and volumes?
   1.2. How is the transport process arranged and which transport modes are there?
   1.3. What are the logistical flows? What are the costs of these flows?
   1.4. What are the flaws, desires and threats?

Question 1.1 is answered through the use of databases. Question 1.2, 1.3 and 1.4 are answered by conducting interviews with the operational managers of the involved departments.

Chapter 3: Literature review

2. *What planning methods are available that might be relevant for the logistical services?*

Question 2 is answered by the means of a literature study. It will give a clear view about the scientific state-of-the-art of planning methods to the logistical problem in this research.

Chapter 4: Design

3. *How can the logistical planning be modelled?*

In this chapter, research question 3 will be answered. We will focus on building a model to obtain quantifiable results regarding time and costs of the logistical flows. The input parameters required for running the models are extracted where possible from available hospital data. If input data is not readily available, it is determined from measurements. We come up with different scenarios and options for DH to rearrange their logistical flows. For DH it is important to have quantifiable results that gives an indication of the possible costs/savings.

Chapter 5: Analysis of the results

4. *What is the expected performance of the proposed interventions?*

Question 4 is addressed in Chapter 5. We present the theoretical and computational results for the applied methods to see the impact of the interventions. Besides, an evaluation of the interventions will be given.

Chapter 6: Conclusions and recommendations

5. *What interventions should Deventer Hospital apply if it wants to minimize transportation costs and maximize customer satisfaction?*

We argue in Chapter 6 what costs and benefits are involved in solving this problem. We discuss the assumptions and conclude on the way the logistics services should be organised. Recommendations will be made in consultation with hospital employees.

2. Current situation

This chapter describes the current situation of DH. Section 2.1 treats the volume and clients of orders at the various departments, Section 2.2 the transport process and transportation modes, Section 2.3 the logistical flows and Section 2.4 the problem cluster.

2.1. Volume and clients

In this section the number of orders at the several departments is treated. An order can be described as the transport process of a sampling of body fluid, e.g., blood or urine. The order consists of various steps and is described in Section 2.2.1. The number of orders is registered into databases, such as LABOSYS/Trodis (for clinical chemistry), LABOSYS/Micros (for microbiology) and Limes/Palga (for clinical pathology). Since the data consists of sensitive information about patients, not every employee of the hospital has access to this system, nor trainees. However, due to the kindness of some colleagues, we were able to receive the correct data (without sensitive information of patients).

The quantity of orders provides a clear indication on the amount of workload at the laboratories. More important, the number of orders also provides information on the amount of flows to the laboratories, which will be treated in Section 2.3. Within the hospital, clients are divided into two client types: (i) internal clients, which are clients inside DH (e.g., medical specialists), and (ii) external clients, which are clients outside the hospital (e.g., GPs). In the next subsections the volume and clients of the laboratories and pharmacy will be treated.

Pathology

Palga, the database of clinical pathology, divides the orders in two categories; internal and external clients. The category internal clients consist of clinical patients, those who are hospitalised for a short or long period, and outpatients, those who are ambulant and are visiting the hospital for a consult. GPs are the only external clients for the clinical pathology, i.e., no orders arise from third parties. Table 2.1 shows the number of orders at the clinical pathology from 2010 to 2014 for both categories.

	2010	2011	2012	2013	2014
Internal	19,305	18,736	18,589	17,944	18,016
External	8,429	8,245	8,027	8,000	7,887
Total	**27,734**	**26,981**	**26,616**	**25,944**	**25,903**

Table 2.1: Number of orders at clinical pathology from 2010 to 2014

In 2014, 5,247 (32 internal orders and 5215 external orders) orders were from the cervical cancer screening programme. Unfortunately, this screening programme will be done elsewhere, due to legislation, approximately in the end of 2016 (RIVM, 2014). This means the external clients of pathology, particularly cytology, will have a decrease of approximately 65% in the amount of orders in the years after 2016. However, not every test in the laboratory is the same. Orders of the screening programme are 'easier' to test than others, i.e., the workload per order is different. Consequently, this does not mean that the workload of external clients will decrease by 65%. The fact remains that the workload of the cytology will have a decrease for the coming years.

Clinical Chemistry Laboratory

LABOSYS is the database used at the clinical chemistry laboratory. This database divides the orders in four categories: clinical, polyclinics, primary care, and other. Table 2.2 shows the number of orders for the various categories at the clinical chemistry from 2010 to 2014. In contrast with the database of clinical pathology, the database of clinical chemistry does distinguish between clinical patients and outpatients for the internal clients. This is because outpatients can also be treated outside the hospital. Primary care orders mostly come from GPs, while orders of the category other are derived from third parties.

	2010	2011	2012	2013	2014
Clinical	132,169	130,612	127,397	125,547	116,536
Polyclinics	81,534	84,688	87,625	85,081	89,696
Primary care	85,501	91,220	92,448	92,626	101,065
Other	22,762	28,029	30,776	31,000	25,075
Total	**321,966**	**334,549**	**338,246**	**334,254**	**332,372**

Table 2.2: Number of orders at the laboratory of clinical chemistry from 2010 to 2014

In order to know the amount of orders which correspond to the internal and external client groups, Table 2.3 is created. It provides us information about the origin of the orders in 2014. The orders of the various categories are split up into several groups: centralized, decentralized, and home. Patients who are visiting DH belong to the centralized group, internal clients. Patients who are visiting a service point of DH (decentralized) or who are visited at home by one of the phlebotomists, belongs to external clients.

	Centralized	Decentralized	Home	Total
Clinical	116,536	0	0	**116,536**
Polyclinics	66,853	21,054	1,789	**89,696**
Primary care	49,072	45,037	6,956	**101,065**
Other	13,561	11,059	455	**25,075**
Total	**246,022**	**77,150**	**9,200**	**332,372**

Table 2.3: Origin of orders from 2014

The division per category arises from the following. Clinical patients are treated in the hospital and are always in the centralized group. Patients who belong to the group polyclinics, primary care or other have received a referral of their GP or a medical specialist of DH for sample collection.

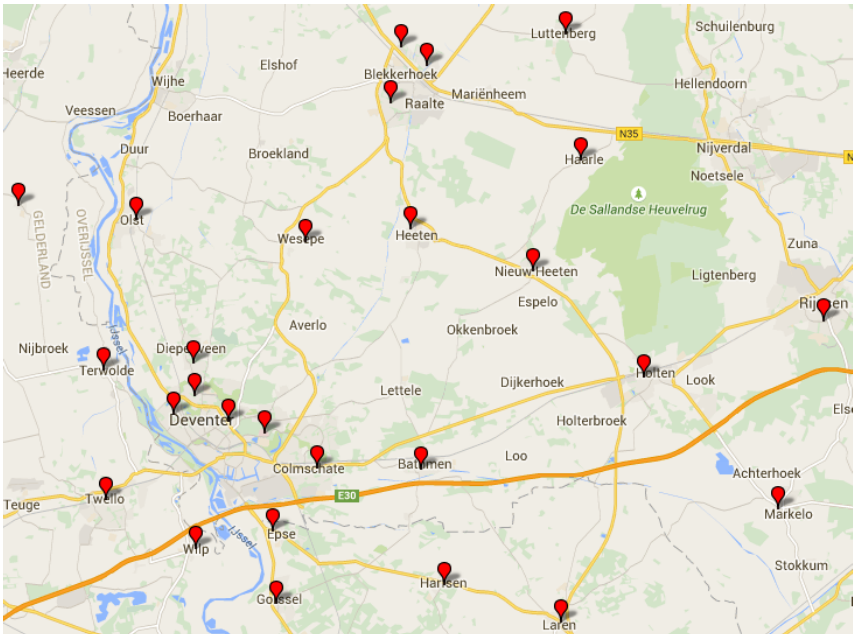

Figure 2.1: Overview service points of Deventer Hospital

Patients are then free to choose between visiting the hospital or one of the service points. As mentioned in the introduction, DH has a network of about 30 service points in the surrounding areas (see also Figure 2.1). The patients are allowed to use the service of any of these points.

Furthermore, if patients are unable to visit a service point, the phlebotomists can visit patients at home for blood or sample collection. Multiple groups per category are available.

Besides the LABOSYS database, the anticoagulation service of clinical chemistry laboratory uses the database Trodis. In Table 2.4 the orders of the anticoagulation service are displayed from 2010 to 2014. The origins of the orders of the anticoagulation service are always from external clients; decentralized or home visits.

	2010	2011	2012	2013	2014
Anticoagulation service	85,451	89,629	89,188	83,665	81,207

Table 2.4: Orders of the anticoagulation service from 2010 to 2014

Laboratory of microbiology

Micros, the database which is used by the laboratory of microbiology divides the orders in three different categories. Again, clinical and polyclinics belong to the internal clients. In contrast with the clinical chemistry, the microbiology only uses extramural for the external clients. Table 2.5 shows the number of orders at the laboratory of microbiology from 2010 to 2014.

	2010	2011	2012	2013	2014
Clinical	14,881	14,637	14,973	16,106	16,688
Polyclinics	16,029	15,197	14,618	12,937	12,463
Extramural	19,120	20,672	21,148	22,154	23,113
Total	**50,030**	**50,506**	**50,739**	**51,197**	**52,263**

Table 2.5: Number of orders at the laboratory of microbiology from 2010 to 2014

Pharmacy

The department of clinical pharmacy is different from the laboratories. Where the laboratories receive and process samples, the pharmacy does not. The pharmacy department provides pharmaceutical care to patients of the hospital and to third parties. Therefore the pharmacy department only deliver medicines to clients and does not receive materials, i.e., no return flow. Generating data about the number of orders is tough. However, this has no influence for the research, because the pharmacy has a structured planning for their flows, i.e., each day the pharmacy has the same addresses and routes, and it does not mind if the transporter has to deliver one order or ten orders at the same address (see also Section 2.3.4). Therefore the number of orders of the pharmacy is not included in this research.

Summary

The thesis investigates the planning of external logistics in DH, so we are interested in the number of external orders. The quantity of orders provides us a clear indication on the amount of flows to the laboratories. In Table 2.6 a summary is given about the orders of all departments in 2014. Due to various changes at the departments, e.g., other clients and modifications in the databases, we have chosen to only use the dataset over the entire year 2014, i.e., data before 2014 is not accurate enough anymore. Moreover, in meetings with the operational managers of all the departments, it can be concluded that there are only seasonal fluctuations in the number of orders during a year. These fluctuations are during holidays (e.g., in the summer and with Christmas). Additionally, there are also low fluctuations in the workforce in the departments per day and per week. Therefore we have chosen to only show the number of orders per year.

Number of orders	External	Internal	Total
Pathology	7,887	18,016	25,903
Clinical chemistry	86,347	246,025	332,372
Microbiology	23,113	29,151	52,264
Anticoagulation service	81,207	0	81,207
Pharmacy			
Total	**198,554**	**293,192**	**491,746**

Table 2.6: Number of orders of all departments in 2014

The databases have provided us information about the number of orders at the various departments. It is also possible to see the origin of the orders, (most of them) on address level. This will be used in Section 2.3, where the logistical flows of the various departments will be treated in more detail. But first, the transport process and transport modes of the laboratories and pharmacy will be treated in Section 2.2.

2.2. Transport process and transportation modes

In the first two sub-sections the order process of the laboratory and pharmacy will be treated. In the next sub-section the external transportation modes are described.

2.2.1. Process of blood/urine samples at the laboratories

The transport process of the laboratories consists of a requester and a provider of the service. The requester is the client, e.g., a specialist of DH, a GP, a health institution, or an external hospital. The provider of the service is one of the three laboratories. The patient, of whom the sample is, can be seen as the indirect client of the process. The whole process is shown in Figure 2.2.

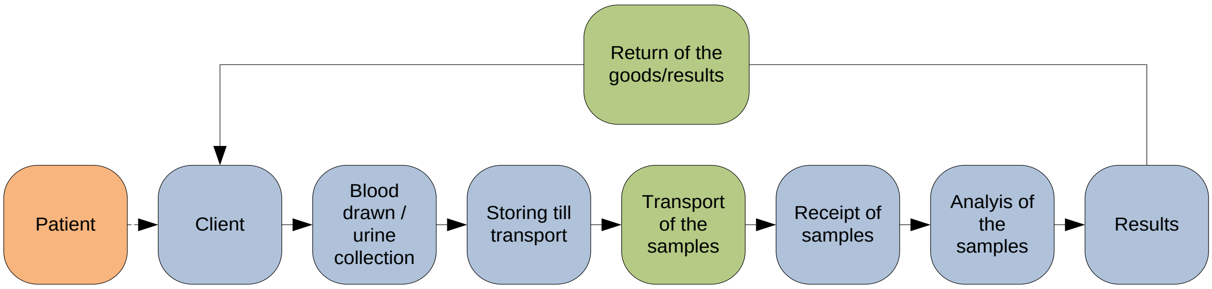

Figure 2.2: Order process at the laboratories

As mentioned in the previous section, there are two types of clients, internal and external. The steps taken in the process differ between the client types. For the internal clients, the process starts in the hospital where a request for blood sampling or urine collection is done for a patient. The patient then visits the policlinic of clinical chemistry in the hospital. At the policlinic blood is drawn or urine is collected and is stored at the policlinic. When enough samples are collected, the transportation of the samples is done by means of a small monorail between the policlinic and the receiving desk of clinical chemistry. At the laboratory the samples are analysed, material is cleaned and the goods are returned to the polyclinic. Next to it, the results of the analysis are sent to the internal client of DH. Those internal clients provide the patient of relevant information about the analysis.

A part of the process for external clients differs from the process of those of the internal clients. Again, the patient is the indirect client, but we are now dealing with external clients, e.g., GPs. Those external clients draw blood in their own practice, refer the patient to one of the service points of DH, or for a home visit. Samples are stored at the practice, or at one of the service points. Main difference between both processes is the transportation method. The samples which are drawn by GPs in their practices are transported by a courier of DG (see Section 2.2.3). The other samples, those of the service points and homes, are brought to the hospital by the phlebotomists of the anticoagulation service. When the phlebotomists arrive at the hospital, administrative proceedings per order have to be done, before it is brought to the receiving desk of clinical chemistry. There, the analysis per order are performed, before results are sent to the external clients. Phlebotomists who draw blood at service points have to be sure that enough sampling materials (e.g., tubes) are at the location of the service points for the next day (or week). GPs can order materials through a web application which are then transported from the hospital by one of the phlebotomists, through the pharmacy or the transportation service of DG.

2.2.2. Order process at the clinical pharmacy

The order process of the pharmacy is shown in Figure 2.3. An order at the pharmacy department is requested by the client, not the patient. Identical to the order process of the laboratories, the patient can be seen as the indirect client of the process. The client can be an internal client, a medical specialist, or an external client, someone of a third party. The client makes an order which is send to the clinical pharmacy department. When the order is received, the order is processed and medicines are prepared.

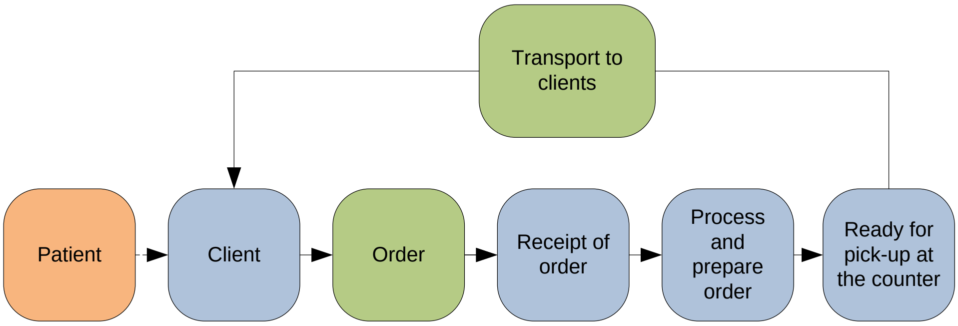

Figure 2.3: Order process of the clinical pharmacy department

At that moment the medicines are ready, they can be picked-up for transportation and delivery. The internal transport, within the hospital, is arranged by the pharmacy itself while the external transport is arranged by the third parties itself or by DH. In contrast with the laboratories, there is no return flow to the clinical pharmacy of DH.

2.2.3. External transport modes

Various transportation modes are available for the transport of orders. In this sub-section, the external transport modes will be explained.

PostNL

PostNL is a Dutch postal company, who delivers and retrieves postal items. The service of PostNL is used by the laboratories of microbiology and pathology. The external clients send their samples by means of a package (100-250 grams) to DH. PostNL is the transporter of the samples. An employee of PostNL retrieves the samples at the external clients of DH and takes them to the distribution centre. The next day, another employee of PostNL delivers the samples to DH. The whole process is (mostly) done within 24 hours. Besides, microbiology and pathology also return the shipping bag with zipper to the external clients by means of the transportation service of PostNL. The clinical chemistry laboratory uses disposable bags, consequently without return flow.

Courier JWB

JWB is a courier located in Deventer. They provide transportation service for regular trips (same moment every period) as well as for emergency trips. The laboratories (mainly clinical chemistry laboratory and microbiology) and the pharmacy of DH are using the service of JWB. Within the hospital, no employees are available for picking up samples or delivering consumer goods to external clients. Nor, the uses of other transportation modes are suitable and therefore JWB is asked.

Dimence Group

DG is an institution which provides healthcare for mentally ill patients in the region Almelo, Deventer and Zwolle. The patients of DG therefore need pharmaceutical care which is provided by the clinical pharmacy of DH. The clinical pharmacy receives orders from DG and prepares the type and dosage of the medicines. DG has it is own transportation service. Hence, several times a day, an employee of DG is visiting the hospital for picking up medicines for all patients situated in their route. The employee then distributes the medicines to the locations of DG. Besides the clinical pharmacy, the clinical chemistry and microbiology are also using the transportation service of DG. The clinical chemistry laboratory is having locations on the 'same route' as DG, where samples have to be picked up. Therefore, the clinical chemistry laboratory have outsourced the collecting of their orders to DG and are sharing the transportation costs. The other laboratories (microbiology and pathology) are benefiting from the agreements between DG and clinical chemistry laboratory, because they are 'lifting', i.e., they do not pay DG or clinical chemistry laboratory. Appendix A shows an overview of the current routes of DG.

Anticoagulation service of clinical chemistry

As stated in the problem description, the hospital has a network of 30 service points in the surrounding areas where blood can be drawn or samples can be delivered. Furthermore, if patients are unable to visit any of the service points, the phlebotomists can visit patients at home for blood or sample collection. Phlebotomists start their work day at one of the service points before they are visiting patients at home. The opening hours of the service points are given in Appendix B. After collection (both, service point and home), samples are transported to the laboratory of clinical chemistry in DH by the phlebotomists. Furthermore, the other departments benefit from the same service of clinical chemistry, i.e., the collection of samples to DH.

Employees of pathology

Analysts of the cytology department are visiting several GPs for the collection of orders for the cytology. This is (mostly) done at Monday mornings from 8:00 AM till approximately 10:00 AM. They have a fixed route, and are always visiting all nine GPs, no matter if there are samples present at the location or not. Besides the regular route, there are also analysts and pathologists who are collecting samples. During their trip from their home address to DH, or vice versa, they make a stop at a practice for the collection of samples. This is (mostly) done during business hours, since they arrive later at their workplace or are leaving their workplace somewhat earlier.

Employees of pharmacy

The clinical pharmacy provides pharmaceutical care to clinical patients of DH, to DG and to Carinova. In addition, they also provide the pharmaceutical care to some pharmacies and dispensing GPs in the area of Deventer. Those pharmaceutical care is delivered once per week by a pharmaceutical employee and a trip lasts approximately 2 hours.

Patients

Patients who are visiting a GP in the surrounding area of DH, and of whom a sample is collected, are having two opportunities. They can bring their sample to the hospital themselves or let the GP arrange the transportation (mostly sent with PostNL to DH). As advantage of self-delivering is that the sample is quicker at the hospital and therefore you will receive quicker an outcome of the tests. Disadvantage is of course, the time and costs for delivering the sample to the hospital. However, patients want the outcomes of the tests as quickly as possible and therefore patients are delivering samples very often.

2.3. Logistical flows

As mentioned in the introduction, the present DH has been merged in the summer of 2008. Before, it was located at several locations in Deventer. Nowadays, the laboratories and pharmacy are closely located to each other at the third floor of DH. Throughout the years, at the old and new location, the laboratories and pharmacy have acquired a large network of logistics.

In the previous sections we have treated the volume, the clients and the transportation modes. We treat the logistical flows of the laboratories and the pharmacy in the next four sub-sections. We are only interested in the external flows of the laboratories and pharmacy to external locations (e.g., GPs and third parties) and vice versa. Sub-Section 2.3.5 covers the costs involved in the logistical flows and Sub-Section 2.3.6 the time and spatial dimensions of the logistical flows. In Sub-Section 2.3.7, a summary is given about the logistical flows.

2.3.1. Clinical pathology

GPs are the only external clients of clinical pathology. We have used the database Palga, to find out the origin of the orders of clinical pathology. Next to it, interviews are done with the operational manager about the flows of clinical pathology.

In 2014, the clinical pathology received 7,887 orders from GPs. Various transport modes are used for transporting the samples.

1. PostNL
2. The anticoagulation service / Dimence Group
3. Analysts (and pathologists) of the cytology

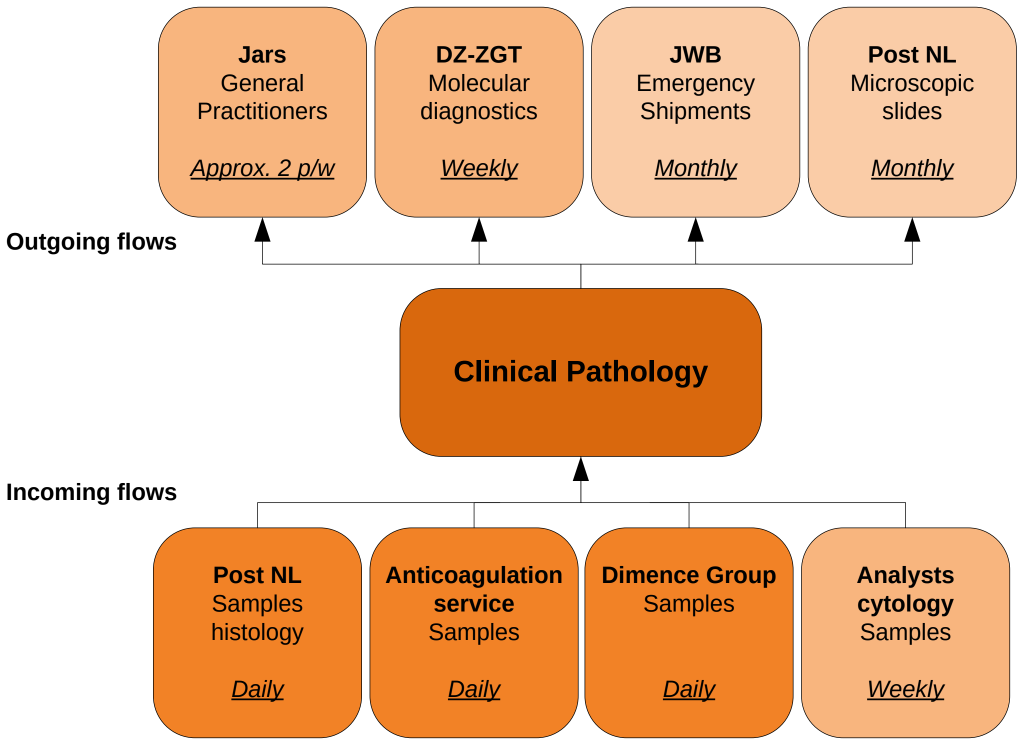

Figure 2.4: External flows clinical pathology

Besides the transportation of the samples, there are some other logistical flows. The clinical pathology uses the service of JWB for 'emergency' shipments, approximately once per month. Moreover, if second opinions are required, microscopic slides are send to other hospitals by means of a package of PostNL. A microscopic slide is a thin flat piece of glass, used to hold objects for examination under a microscope. Furthermore, once a day there is a flow between Deventer

Hospital and the hospital in Hengelo, ZGT, arranged by the laboratory of microbiology. The clinical pathology uses this transportation service as well for the purpose of molecular diagnostics of patient material, but only if the clinical pathology has materials for ZGT. Last, jars, for the transportation of tissues, are brought to GPs by employees of clinical pathology. It is done this way, because the transportation of jars by means of PostNL is very expensive (especially if goods do not meet the mail box format, which is the case). Furthermore, most of the employees of clinical pharmacy are living in the surrounding areas of DH and therefore they only have to make a small detour. In Figure 2.4 an overview is given about the incoming and outgoing flows at the clinical pathology.

2.3.2. Clinical chemistry laboratory

Polyclinics, primary care and the group others are all having external clients, both decentralized and home. Besides, we have the anticoagulation service which also belongs to the external clients. In Table 2.7, the orders of 2014 at the clinical chemistry department are given.

	Decentralized	Home	Total
Polyclinics	21,054	1,786	**22,840**
Primary care	45,037	6,956	**51,993**
Other	11,059	455	**11,514**
Anticoagulation service	41,632	39,575	**81,207**
Total	**118,782**	**48,772**	**167,554**

Table 2.7: External orders at clinical chemistry in 2014

Phlebotomists are visiting service points in the surrounding area of Deventer to draw blood and/or collect urine. Patients have received a referral of a medical specialist or a GP and are free to choose between visiting the hospital or one of the service points. In case the patient chooses to visit the hospital, it belongs to the internal clients group. In case the patient visits one of the service points, or blood/urine collection is done at home due to inability to visit any of these points, it belongs to the external clients group. Phlebotomists first visit one of the service points (see Appendix A: Opening hours service points, for the locations) before they are visiting patients at home. Since all service points are having approximately the same opening hours, phlebotomists are not able to visit more than one service point at a day. Besides, the phlebotomist collects the blood and urine of patients and take them to the hospital. All orders from Table 2.7 are brought in by the phlebotomists of the anticoagulation service of the clinical chemistry (except for the service points of Wilp and Raalte, see points 1 and 2 below). An interview is held with the operational managers of clinical chemistry and the anticoagulation service. From this we found that there are some more logistical flows.

1. The practice in Wilp collects blood and urine themselves. Daily, a courier of DG retrieves the samples and brings them to the hospital.

2. DG visits the hospital a few times a day. One of the trips of DG is driving to several locations in Zwolle. As soon as they return to Deventer, collection of blood and urine at the service points of DH in Raalte is done. The samples which are collected at these points, are returned to the hospital by DG. This ensures among others that the phlebotomists who have drawn blood at the service points do not have to visit the hospital for delivering the samples. This is also done to reduce peaks in the workload of the laboratory of clinical chemistry.

3. The clinical chemistry uses disposable bags for samples that are send to other hospitals in the Netherlands. They are sent to the hospital through the service of PostNL. Once the bags are at the laboratories of other hospitals, the disposable bags are thrown away. A disposable bag is cheaper than the return costs of shipment. This is in contrast with the other laboratories, since they are having a return flow of the bags.

4. Once a day there is a logistical flow between DH and ZGT Hengelo, arranged by the microbiology. The clinical chemistry uses this logistical flow for the transport of bone marrow examinations, approximately 2-3 times a week. However, the final destination is MST Enschede instead of ZGT Hengelo. The clinical chemistry pays for this additional route.

5. In case of 'emergency' shipments, mostly to other hospitals, e.g., University Medical Centre Groningen, JWB is asked to deliver the samples.

In Figure 2.5, an overview is given about the incoming and outgoing flows at the laboratory of clinical chemistry.

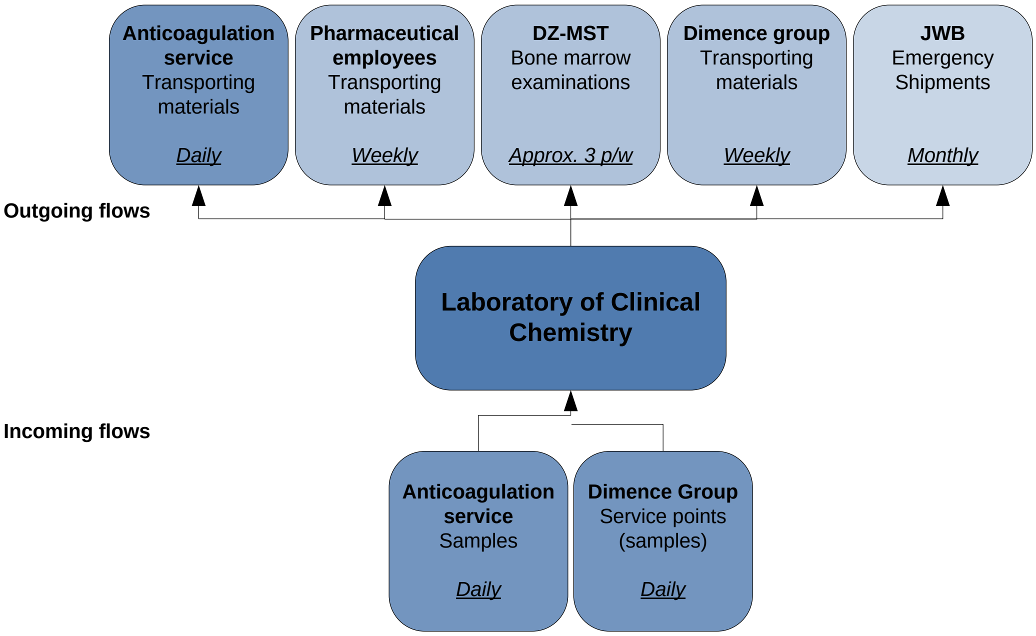

Figure 2.5: External flows clinical chemistry

2.3.3. Laboratory of microbiology

Extramural is the category which belongs to the external clients of microbiology and consists of GPs, third parties, realm costs and inspections. Realm costs, are investigations from the GGD, whereby the costs are for the realm. GGD ("Gemeentelijke Gezondheidsdienst") is an institution which is obligatory in every municipality to control several tasks in the field of public health. The group inspections are investigations for the purpose of an inspection, mostly life insurance scenarios. In 2014, the microbiology received 23,113 orders from all external clients. In Table 2.8 the extramural group is split into several groups. For each group, the transportation facility is different. Most of the samples of GPs are brought in by phlebotomists of the anticoagulation service. The other part is send by means of a package of PostNL, which also applies for the third parties, realm costs and inspections.

	Total
General Practitioners	18,009
Third parties	3,441
Extramural realm costs	1,655
Extramural inspections	8
Total	**23,113**

Table 2.8: Extramural orders of microbiology separated

In Figure 2.6 an overview is given of the incoming and outgoing flows at the laboratory of microbiology.

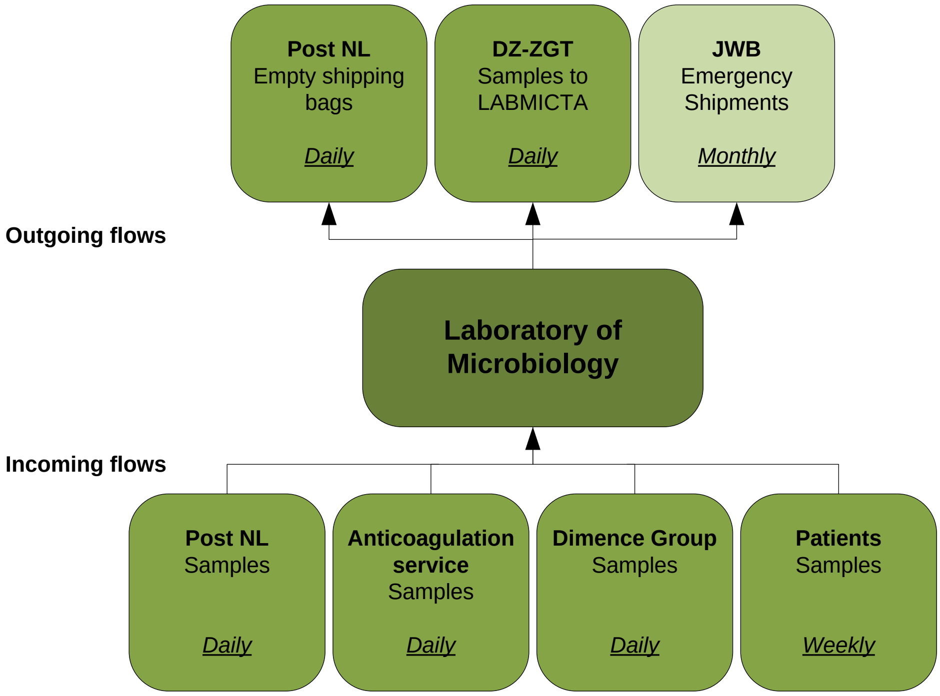

Figure 2.6: External flows laboratory of microbiology

2.3.4. Clinical pharmacy

DG, Carinova and some pharmacies and dispensing GPs in the area of Deventer are the external clients of the clinical pharmacy. The amount of orders as well as the origin of orders is of far less importance than for the laboratories, because the logistics at the clinical pharmacy are structured.

DG has access to their own transportation service. Therefore, three times a day (8:30, 12:00 and 16:00), an employee of DG is visiting the clinical pharmacy for picking up medicines. Each trip the employee is driving to different locations of DG. Besides, JWB is driving several trips for the clinical pharmacy listed below:

1. Regular trip to Carinova, 1-2 times a day (depending on the number of locations to visit)
2. Emergency trips to Carinova, ad hoc
3. Regular trip to Isala Klinieken, a hospital in Zwolle, once per week
4. Regular trip to University Medical Centre Groningen, once per week
5. Retrieving an order from the hospital in Nijmegen, once per week
6. Retrieving an order from the hospital in Hengelo, once per week

Besides the abovementioned list of trips, the clinical pharmacy delivers medicines to clinics in the villages Rijssen and Raalte. Medicines are first brought to DAS ("Dienst Apotheek Salland"), situated in the centre hall of DH. The courier JWB visits the "Dienst Apotheek Salland" for picking up the medicines and thereafter it is transported to the clinics in Rijssen and Raalte. Furthermore, pharmaceutical employees are delivering medicines to pharmacies and dispensing GPs (approximately twice per week). In Figure 2.7 an overview is given about the incoming and outgoing flows at the clinical pharmacy.

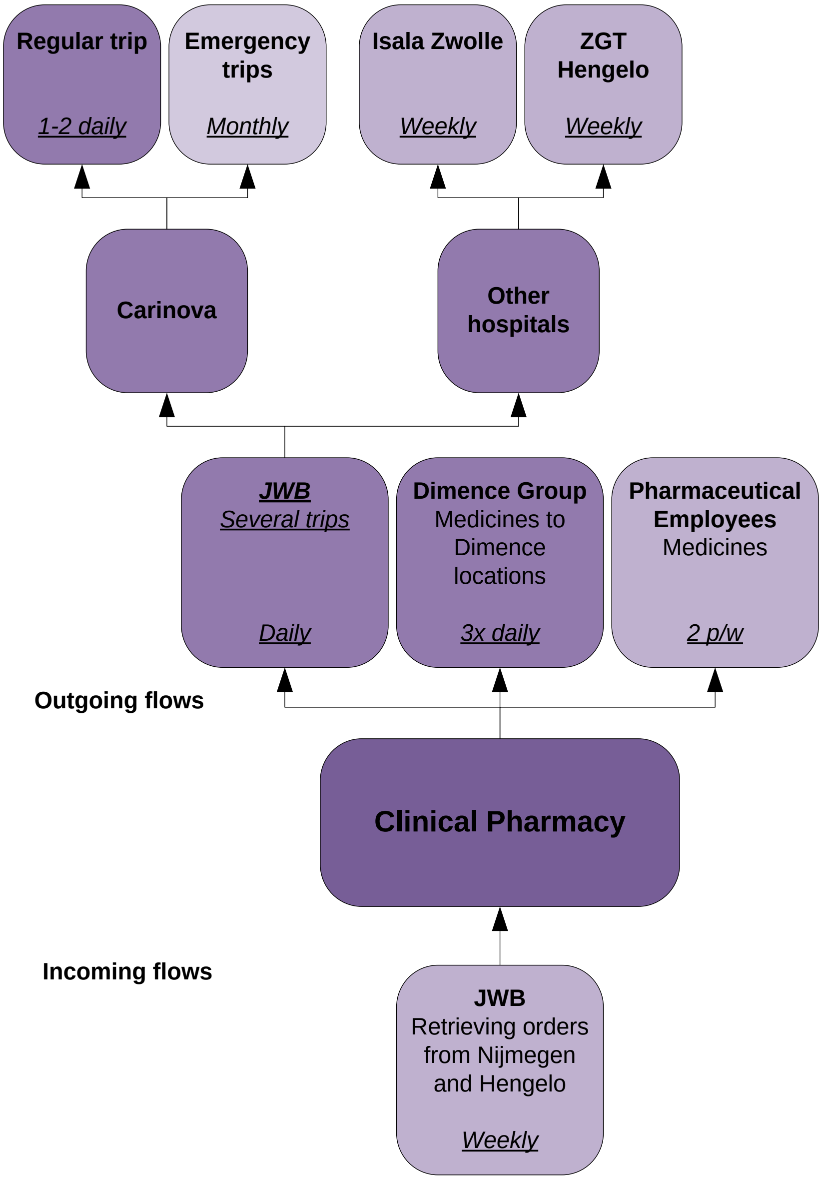

Figure 2.7: External flows clinical pharmacy

2.3.5. Transport orders

In the previous four sub-sections, insight was gained into the logistical flows of the laboratories and the pharmacy of DH. The flows are mainly dealing with sample collection for the laboratories and providing pharmaceutical care of the pharmacy towards different clients. Besides those flows, there are various other logistical flows that have been treated. Those other logistical flows will not belong to the scope of the model. This is due to the fact that those logistical flows are, e.g., not in the catchment area (thus too far away), are not frequent enough and/or we have to deal with 'emergency' shipments.

Below we have listed the several logistical flows that are left out for the evaluation of the scenarios.

- All 'emergency' shipments of the departments (mostly to other hospitals)
- The weekly molecular diagnostics of the pathology to ZGT Hengelo
- The monthly microscopic slides of pathology to other hospitals
- Bone marrow examinations of clinical chemistry to MST Enschede
- Samples of microbiology to LABMICTA (ZGT Hengelo)

- ➢ Regular trips of the pharmacy to UMC Groningen
- ➢ Retrieving orders for the pharmacy of the hospitals in Nijmegen and Hengelo

In Section 2.1, the volume and clients of the several departments have been discussed. The information used is retrieved from several databases, and is used to create an Excel-overview of the orders of all departments. The Excel-overview contains among others the number of orders, the applicant, the department of the order, the transportation type and the address. The Excel-overview contains all the orders of all laboratories in the period from 1-1-2014 till 31-12-2014. In Table 2.9, a (random) part of the overview is given.

Department	Applicant	Transport type	City	Zip code	Address	# Orders
Microbiology	Smits	PostNL / patient	Waalre	5582HH	Gestelsestraat 16	2
Clinical chem.	Prikpost Gorssel	Service point	Gorssel	7213CR	Hoofdstraat 45	3283
Anti. service	Prikpost Gorssel	Service point	Gorssel	7213CR	Hoofdstraat 45	1378
Pathology	Schroth	PostNL	Epse	7214AT	Het Wilgert 1	6
Pathology	Schroth	Anticoagulation service employee	Epse	7214AT	Het Wilgert 1	104
Clinical chem.	Prikpost Laren	Service point	Laren	7245AG	Verwoldseweg 1	1901
Anti. service	Prikpost Twello	Service point	Twello	7391BT	Raccordement 8	4021
Microbiology	A.L. Scholte	Anticoagulation service employee	Twello	7391BT	Raccordement 8	994

Table 2.9: Excel-overview of the orders of all departments from 1-1-2014 till 31-12-2014

The Excel-overview consists of almost 500 rows. Unfortunately, not for every row all data is available. For example, single applicants are sometimes registered under a shared name instead of under their own name, and therefore for those orders, no addresses are available. From the known addresses a map is created, see Figure 2.8.

Figure 2.8: all addresses in a map

The map above shows us all the locations were orders arise or were pharmaceutical care has to be delivered. As shown, many addresses are in the catchment area of Deventer hospital. However we can also see that there are a few locations far away from the hospital, e.g., in Groningen, Amsterdam and Eindhoven. In order to find out the amount of orders per location we have created another map. This is called a ‘thematic map’ and is shown in Figure 2.9. The map is created, based on the four digits of the zip codes in the Netherlands.

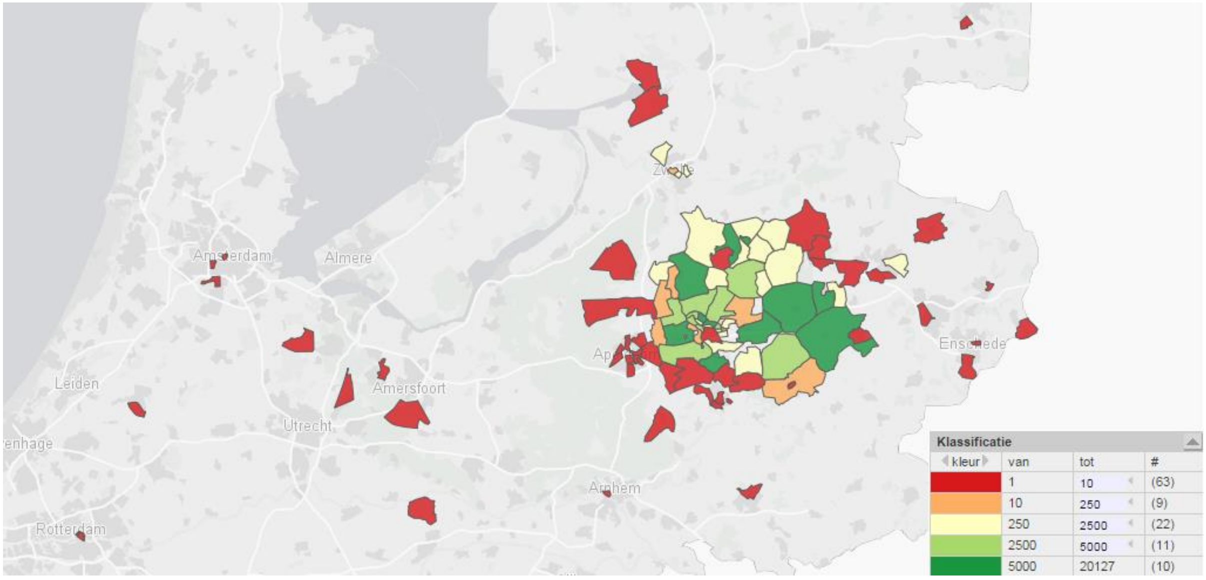

Figure 2.9: Heat map of the orders of the laboratories per 4 digit zip code (2014)

From the legend in the figure above, we see that the orders which are far from the hospital are coloured red. This means that at those locations, the numbers of orders over 2014, lies between 1 and 10, which is extremely low. Comparing those addresses with the Excel-overview, we see that orders from those locations are all send to the hospital with PostNL. Sending those orders with PostNL to the hospital remains much cheaper than driving to the locations and back. This is due to the fact that the frequency is extremely low (once per year till once every 5 weeks) and there are no other locations were samples have to be collected or pharmaceutical care has to be delivered nearby. No calculations are required to presume this. Therefore we have chosen to only incorporate the orders in the catchment area of DH, and the cities Zwolle and Almelo. This is graphically shown in Figure 2.10. We focus on this part of the samples. The rest, in total 314 orders, will still be send by PostNL. This is a relatively small part, since there were 198,554 orders in 2014, i.e., 99,84% of the orders from the laboratories are incorporated in the model. The 314 orders which are not taken into account can be divided as follows:

- 13 samples from the pathology
  - 3 orders are registered under a common name (“single applicants”)
  - 10 orders are not in the catchment area of DH

- 2 samples from the clinical chemistry
  - 2 orders are inserted incorrectly

- 299 samples from the microbiology
  - 129 orders from GCA Wageningen
  - 26 orders from LABMICTA Hengelo,
  - 21 orders are inserted incorrectly or are registered under a common name
  - 123 orders are not in the catchment area of DH

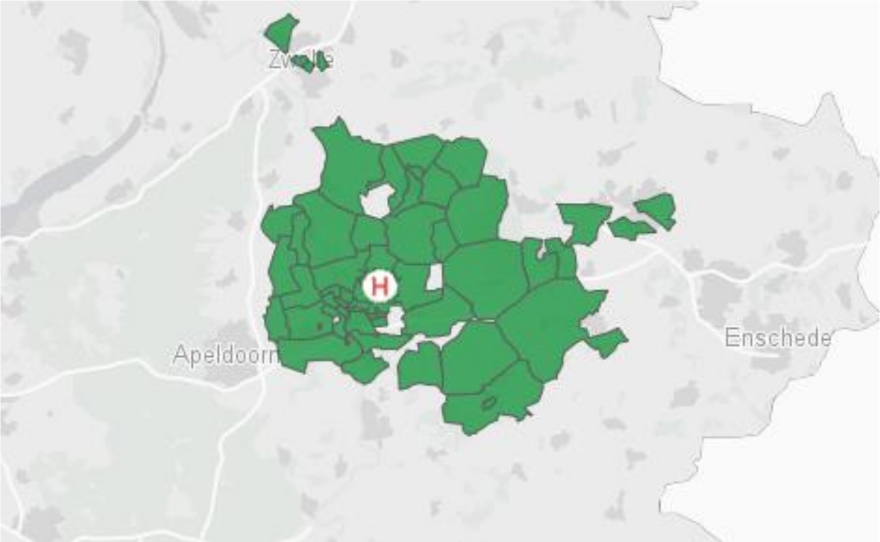

Figure 2.10: Catchment area DH, including the cities

Besides the orders which are not in the catchment area, we should also consider orders that are free of charge for the hospital. In the current situation, patients who are visiting a GP, are having the choice of either bringing the sample to the hospital themselves or leaving it at the general medical practice. The first option is frequently used by patients, and is beneficial for the hospital, since there are no costs and resources for DH involved in the logistical process. As a side mark, the service provided by DH is not efficient. There is no constant tracking of the order between the time of removal and the time the order is received by the hospital. In this research we want to increase the service towards the clients of DH and therefore we exclude the logistical flow of sample delivery carried out by patients from the model.

Other logistical flows that are 'free' for DH are those of the pharmaceutical care provided by the pharmacy towards DG and Carinova. These flows are 'free' for DH, since the transportation costs are charged to DG and Carinova. However, these flows are by no means 'free', since DG and Carinova have to pay the transportation costs. DG and Carinova are two large clients of DH and therefore it could be interesting to minimize the costs for them. The service of the logistical flows provided by DH towards DG and Carinova are well organised, and there are not clear issues that could improve the service, i.e., it is well organised already. Since this research is more focused on service improvement, rather than on cost minimization, we have excluded the flows of the pharmacy from the model.

The conditions described in this sub-section will hold for all scenarios which are described in Chapter 4.

2.3.6. Costs involved in the logistical flows

The costs of the logistical flows must be made clear, due to two reasons. First, they are required to compute the current situation of DH. Second, they are required for building the model (Chapter 4) and for the evaluation of the flows (chapter 5). The costs of the logistical flows are given in Table 2.10, and the reasoning of how this costs are achieved are described thereafter.

Logistical flow	Cost price
Hourly wage anticoagulation service employee	€ 28.25
Travel allowance per km of the anticoagulation service (own car)	€ 0.30
Transportation costs per km anticoagulation service (DH car)	€ 0.619 / €0.283
Transportation costs per km Dimence Group (same route)	[redacted]
Transportation costs per km Dimence Group (extra route)	[redacted]
Transportation costs of Cycloon to client (price per unit)	[redacted]
Transportation costs of Cycloon from client (price per unit)	[redacted]
Travel allowance per km of the pathology (own car)	€ 0.30
Hourly wage analyst of cytology	€ 30.52
Hourly wage pharmaceutical employee	€ 28.21
Transportation costs patients	€ 0.00

Table 2.10: cost prices for logistical flows

Employees of the anticoagulation service are visiting service points and patients at home for the collection of blood and urine. Those employees are paid, on average, a gross hourly wage of €28.25 and are travelling between clients by using their own car, or one of DH. The employees can declare a car allowance when using their own car and are paid €0.30 per kilometre (€0.19 untaxed and €0.11 taxed). The price per kilometre for the cars of DH is more complex. Those cars are leased and the leasing costs per month per car are €476.49 (for the 2 Volkswagen Polo's) and €229.50 (for the 5 Suzuki Alto's). Besides the leasing costs there are only fuel costs because all other costs, e.g., insurance and tax, are incorporated in the leasing costs. After some calculations with the operational manager of the anticoagulation service, the fuel costs per car (in total 7) are approximately €100 per month. The Volkswagen Polo drives 100 km with (on average) 6.5 litres of fuel, while the Suzuki Alto drives 100 km with (on average) 5.2 litres. The fuel consumption is based on real data and not on numbers published by car manufacturers. The average price of gasoline (at the moment) is €1.65 per litre. Hence, the kilometre price for the VW Polo is €0.62 per kilometre and for the Suzuki Alto it is €0.28 per kilometre. Moreover, the employees of the anticoagulation service, who are using their own car, are receiving two coupons for the car wash (€7.50 apiece) per year.

DG delivers pharmaceutical drugs, provided by the pharmacy of DH, to their locations. The pharmacy would charge Dimence Group for the delivering of pharmaceutical care. Therefore Dimence Group has chosen to deliver the pharmaceutical care themselves. In addition, DG is also driving for the collection of samples for the laboratories to several locations. The clinical chemistry made agreements about the transportation costs with DG for the collection of samples and entails the following. Transportation costs are shared if both parties are using the same routes/destinations. They have agreed a fixed price per kilometre, i.e., [redacted] per kilometre (and includes fuel and wages). Besides, for every extra kilometre that DG has to drive, the fixed price is doubled, i.e., [redacted] per kilometre. Those transportation costs of DG are charged to the clinical chemistry and currently those costs are [redacted] per month for 2015. The invoices are tacitly extended every year with only a small change due to indexing, an adjustment to prices prescribed by CBS (Centraal Bureau voor de Statistiek). As advantage of the agreements, the microbiology and pathology benefits from the same service for the order collection of their samples, since they are not paying the clinical chemistry and/or DG for the collection of their samples.

Another frequent used logistical flow is the one of PostNL. This service is used till 1 April 2015, and from that moment DH changed to Cycloon (another postal company). They provide sustainable transport and more important is the fact that they provide cheaper rates for the delivering of postal items compared to PostNL. Cycloon only delivers in their own catchment area, and outside their catchment area is still done by PostNL. For us, the price per unit is important, since the microbiology and pathology are using the service of postal companies very frequent. The logistical manager of DH has made special agreements with Cycloon about the rates. However, the rates per unit are not fixed, but they depend on the quantity of units, i.e., the more units means less unit price, and vice versa. In a meeting with the logistical manager we received estimations for the unit prices. The price per unit is fixed at [redacted] inside the catchment area (Cycloon), and [redacted] outside the catchment area (by Cycloon via PostNL). Those prices are for the delivery of postal items to, e.g., GPs and third parties. Besides, the GPs and third parties also have to send postal items to DH. This is done by sending the postal items to the freepost number of DH and the costs for DH are [redacted] per unit.

On Mondays, analysts of the cytology are collecting orders at nine different locations of GPs. They collect orders with their own car and afterwards they declare a price per kilometre of €0.30 (€0.19 untaxed and €0.11 taxed) by the operational manager. Besides the car allowance, the analysts are not available for their daily work. A trip along the GPs has approximately a duration of about 2 hours and an hourly wage of an analyst of the cytology is €30.52. Besides the regular weekly trip, there is also one pathologist who collects samples at Lochem every week and one analyst who collects samples at Gorssel every week. Those two people are living close to the GPs and are not charging any costs. However, sometimes they are leaving the hospital somewhat earlier, but this may be negligible.

Twice a week, pharmaceutical employees are delivering pharmaceutical care to some pharmacies and dispensing GPs in the area of Deventer. A trip along the GPs has approximately a duration of about 2 hours and those employees are charged an hourly wage of €28.21. They are using the cars of the clinical chemistry and are using them for free, i.e., no costs.

The cheapest logistical flow is the delivery of orders to DH by patients, because there are no employees and modes of DH involved in the logistical flow towards DH. Patients have visited a GP and may decide to bring the sample(s) to the hospital themselves. If they are not capable of delivering the orders to the hospital, other transportation modes are used by the GPs, e.g., Cycloon.

Finally, we also have JWB, which drives every day a regular route to the locations of Carinova. An employee of JWB picks up the pharmaceutical care at the pharmacy of DH. The pharmacy is involved in the logistical flow but the costs of delivering are charged to Carinova, i.e., the pharmacy does not make any transportation costs for the delivering of medicines to Carinova locations. Besides, JWB provides also the regular trips of the pharmacy to the hospitals of Zwolle and Groningen, and the emergency trips for all departments.

2.3.7. Time and spatial dimensions

In this subsection the time and spatial dimensions of the logistical flows will be treated. From the previous sections, where the logistical flows of the several departments are described, we have seen several transportation modes. For each transportation facility we will describe in short the time dimension.

- PostNL delivers every day a bag with samples, mostly at the end of the morning.
- The planning of the anticoagulation service of clinical chemistry varies every day. On average, 17 employees of the anticoagulation service are visiting the service points of DH and patients at home. They start between 7:30 and 8:00 and end their workday between 11:30 and 12:30, according to the routes.
- Analysts of the cytology are visiting 9 addresses in Deventer. They only visit the addresses at Monday and it takes two hours.
- DG is driving to some addresses for DH, for picking up samples for the laboratories and delivering medications for the pharmacy. In total there are three routes that are driven every day. Route C is from 9:30 till 17:00, route D from 7:30 till 17:00, and route F from 7:30 till 13:30. DG has incorporated their own addresses for picking up and delivering materials, i.e., not all the time of the routes is used for the collection/delivering of DH.

- Patients, who visited a GP, are bringing samples to DH. They can deliver their sample during a working day period (8:00 – 17:00).
- JWB is driving once or twice a day to Carinova for the delivering of medications of the pharmacy. Moreover, JWB drives to the hospital of Zwolle and UMC Groningen once per week.

Per laboratory there is a time restriction for the maximum duration of sample collection, i.e., the time between the moment the sample is taken and the sample arrives at the laboratory. For the clinical chemistry this time is set at six hours. For the laboratory of microbiology the maximum time is two days, and last for the clinical pharmacy the restriction is seven days.

Besides the time dimensions of the transport of orders, we also have to take into account the spatial dimensions. In Figure 2.9, a thematic map is given of the orders of all laboratories per 4 digit zip code. As shown in the figure, the gross of the orders arise from Deventer city and the surrounding areas of Deventer. Besides there are a couple of zip codes that are far away from the hospital, but the amount of orders is relatively negligible from the total amount of orders. Moreover, the orders of the clinical pharmacy are not included in the figure below. But the addresses are comparable to those of the laboratories.

2.3.8. Summary

In Figure 2.11, a histogram is shown about the number of orders per department per transportation facility. All transportation modes are operating on a daily basis, except for the analysts of cytology, because they only collect orders on Mondays. It can be concluded that several departments are sharing their service, e.g., the anticoagulation service, which is a part of the clinical chemistry, is used by pathology and microbiology. Moreover, it can be concluded that most orders are collected by the anticoagulation service. At least, there are approximately 20,000 orders (from clinical chemistry, including the anticoagulation service) that are classified to the group 'unknown'. In an interview with an employee of clinical chemistry, who manages the database, it is said that approximately 60% of those orders are not assigned to a service point. Normally an order is assigned to one of the service point. However, due to unknown reasons, orders are assigned to the group 'service point unknown', since those orders are drawn at a service point, but it is not clear which service point it was. The other part that is classified into the group 'unknown' are drawn and collected in DH, but are also not assigned to the correct group.

In Table 2.11 the outgoing flows of all departments are given. An X indicates whether a department uses that specific transportation facility, and in addition, the frequency of the transportation modes are given.

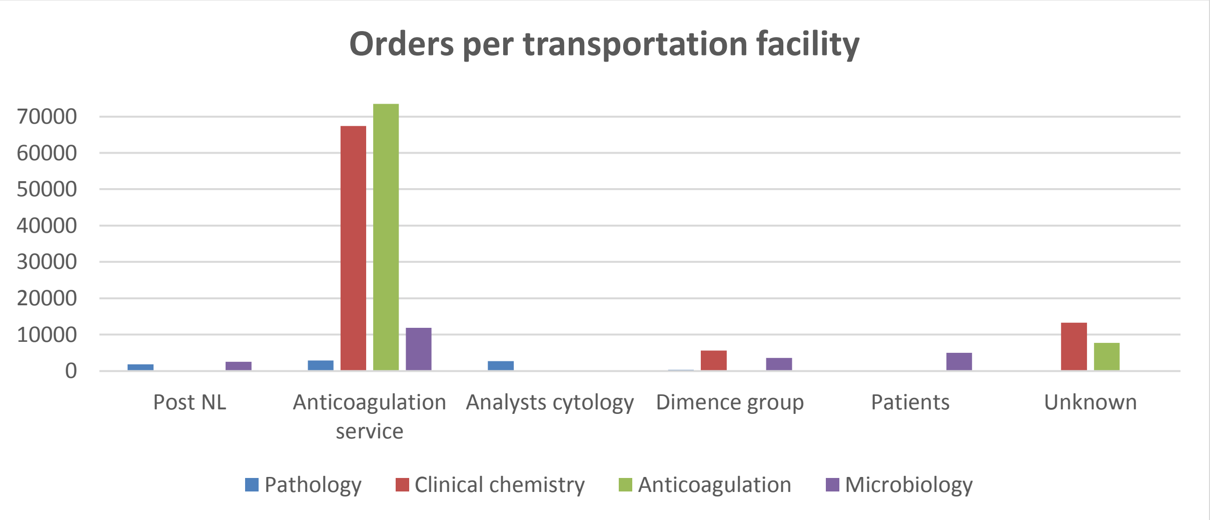

Figure 2.11: Incoming orders per transportation facility

	Pathology		Clinical chemistry		Microbiology		Pharmacy	
JWB (regular trip)							X	Daily & weekly
JWB (emergency trip)	X	Monthly	X	Monthly	X	Monthly	X	Monthly
PostNL	X	Monthly			X	Daily		
DZ – ZGT (Hengelo)	X	Weekly			X	Daily		
DZ – MST (Enschede)			X	3 p/w				
			X	Weekly			X	Daily
Employees pathology	X	2 p/w						
Pharmaceutical Employees			X	Weekly			X	2 p/w
Anticoagulation service			X	Daily				

Table 2.11: Outgoing flows of all departments

2.4. Problem cluster

In the previous sections the logistical processes are described, i.e., the logistical flows, transport processes and transportation modes. In this section the flaws, desires and threats will be discussed with respect to the current situation for the laboratories and pharmacy of DH. Therefore, interviews were conducted with the operational managers of the several departments. Below, we listed, in an arbitrary order, the flaws, desires and threats. At the end of this paragraph a problem cluster for this research is given.

Flaws

There are several flaws in the current situation:

- Different external transportation modes are visiting the same locations for different laboratories, resulting in high costs.
- There is some communication between departments about their logistics which has led that departments are using the same transportation facility. However, no 'helicopter view' has ever been applied to combine logistics of several departments.
- Employees of the anticoagulation service have to perform many handling operations when they return at their office in DH. A lot of paperwork is involved.
- Analysts of the pathology are visiting GPs. Mostly at Monday's, one of the analysts is visiting 9 GPs and it takes about 2 hours for the whole trip.
- For the cytology, which is a department of pathology, jars are brought to all external clients. This is done by all employees of pathology and there are approximately 90 trips per year.

Desires

There are several desires addressed by the operational managers:

- The planning of the anticoagulation service is done manually. Daily, an employee of the secretariat of the anticoagulation service is spending four hours on the planning of the anticoagulation service for the next day. Since it requires several hours every day, it will be of great importance if this could be automated in the future.
- New requests of clients, e.g., GPs, should be accepted and easy to implement in the current logistical planning.
- In the current setting, for the clinical chemistry department, there is some service for GPs who want to draw blood in their own practice and work with organisations for only picking up material on a daily basis. This service is interesting for clients in smaller villages where the service of the clinical chemistry of DH is less frequent (e.g., once or twice a week).
- At the moment, phlebotomists of the anticoagulation service only work in the morning. However, there are requests from GPs for (non-)emergency cases in the afternoon.

Currently, if there is an emergency case, an employee of the secretariat of the anticoagulation service or a phlebotomist at the polyclinic is visiting the patient (at home). If it is not an emergency case, the patients will not being treated that day. Therefore there is a demand of phlebotomists in the afternoon to accommodate such (non-)emergency cases.

- The pharmacy department has intentions in the future for the service of delivering medication to patients at home.
- Temperature controlled transport would improve the test results at the laboratories, especially urine samples.
- GPs are ordering material goods by telephone for the pathology, while the clients of clinical chemistry are using a web application. Digitizing the ordering of material goods would improve customer satisfaction for the clients of pathology.

Threats

There are several threats addressed by the operational managers:

- Increasing transportation costs of PostNL. Each year, PostNL increases their transportation prices.
- The clients are important for DH, since they contribute for a large source of income. Therefore, customer satisfaction is also important for the hospital. The laboratories and pharmacy have to meet the requirements and demands of their clients. Else, there is a chance that clients will switch between hospitals.

Now the flaws, desires and threats have been treated, a problem cluster is created, see Figure 2.12. This problem cluster covers all abovementioned bullets. The core problem of this research is mainly based on this problem cluster and is stated as: '*the current logistical services are not organized efficiently and there is need for service improvement; however, it is unclear how this can be realized and what performance can be expected'.*

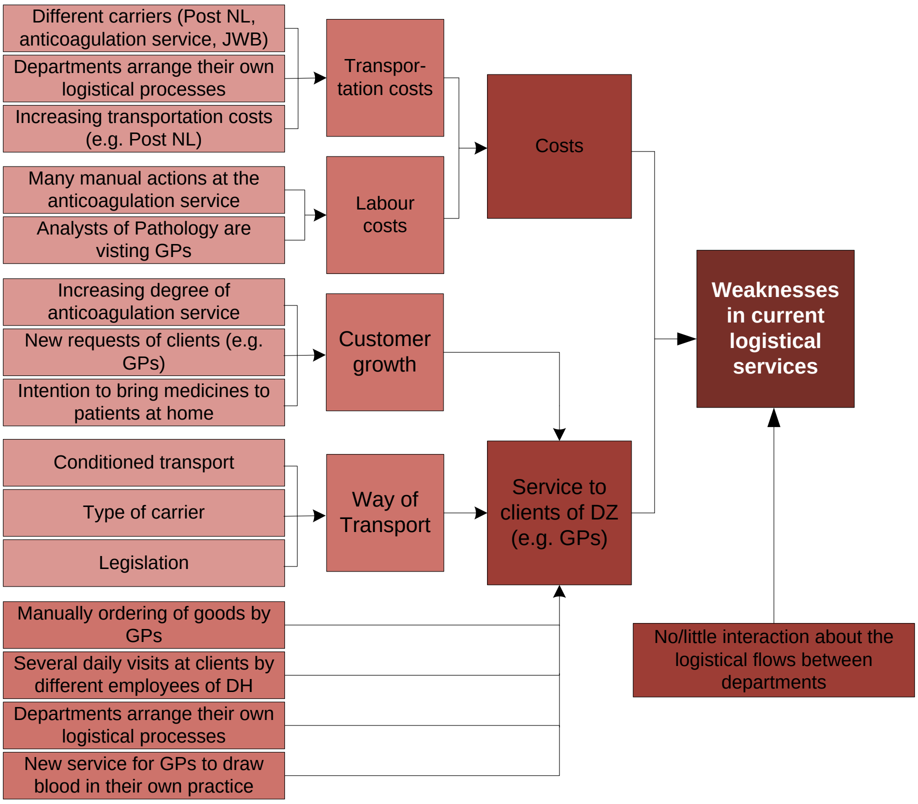

Figure 2.12: Problem cluster

3. Literature study

In this chapter, an answer will be given to research question 2: *"What planning methods are available that might be relevant for the logistical services?"* The planning of logistics for DH lies between two separate problems. First, orders have to be assigned to a transport mode, which is called "the assignment problem". Thereafter, the problem arises of how the optimal collection of orders should be arranged from DH to a number of geographically scattered customers. This is called the "Traveling Salesman Problem" (TSP), more specifically the "Vehicle Routing Problem" (VRP). Section 3.1 starts with the assignment problem, continuing with the Vehicle Routing Problem in Section 3.2. Section 3.3 presents a short conclusion about the literature in this chapter.

For this report it is not essential to make near optimal routes, but more on the problem of choosing which transportation modes to use and on how to arrange the logistics. Therefore, the goal of this literature chapter is to give insight into the assignment problem as well as in the VRP. Within the VRP we show several exact algorithms and heuristics for optimizing problems, and we focus on the methods of those algorithms and heuristics to give an idea behind the VRP literature.

3.1. Assignment problem

The generalised assignment problem (GAP) is a common topic in the fields related to linear and network flow theory (Liang-Hsuan Chen, 2007). The GAP is a well-known, NP-complete combinatorial optimisation problem (Chu, 1997). A problem is NP-complete if it is NP, and any problem within NP is polynomially reducible to this problem. The abbreviation NP refers to "nondeterministic polynomial time". GAP solves the problem of assigning n jobs to n agents, such that minimum costs or maximum profit is obtained. Thereby, each job is assigned to exactly one agent and vice versa. In the literature, various algorithms have been developed to find solutions for the GAP efficiently, e.g., linear programming (Balinski, 1986), the Hungarian algorithm (Kuhn, 2005), and the genetic algorithm (Chu, 1997).

For the case of DH, we have to assign orders (from the laboratories) to different transportation modes. The characteristic of the general assignment problem is to assign each order to a different transportation facility and vice versa. Assigning one transportation facility to one order is unrealistic for the case in DH, since several transportation modes can collect and carry multiple orders at a time, e.g., phlebotomists. The 'capacity' of those transportation modes are 'infinite' for the case of DH, i.e., the amount of orders will never exceed the space capacity of a car at an arbitrarily day (also because we have to deal with time restrictions (Chapter 4)). It is unrealistic that one agent can collect and deliver all orders of the laboratories and pharmacy at an arbitrarily day. This time issue will be treated in Section 3.2, where we will present the Vehicle Routing Problem (VRP).

Due to the abovementioned reasons, the GAP cannot be applied for DH. Still we have to assign orders to a type of a transport, and therefore the problem of DH is related to an assignment problem. The assignment problem Deventer Hospital faces can be best described as the multi-commodity flow problem or a network/transport problem. The multi-commodity flow problem is a network flow problem with multi commodities (flows) between different source and sink nodes. The network/transport problem is a problem where things have to be shipped from point A to point B, where B can be seen as the transport mode. In the remainder of this section, several articles which are somewhat related to any of the abovementioned problems will be treated.

In (Lingaitiene, 2008), a mathematical model for selecting transport modes for multimodal freight transportation is described. The model chooses the optimal route, while taking into account time, costs and safety of transportation. The paper is written as a result of the question how to carry goods quickly, safely and at low cost to any place in the world. They incorporated all means of transport, i.e., road, railroad and water transport. For each transportation facility they calculated the costs. The mathematical model can be used for calculating any route, when applying the data on particular vehicle fleets.

For the general assignment problem, only the cost or profit is considered in the problem formulation. The paper of (Liang-Hsuan Chen, 2007) reformulates an assignment problem by considering multiple inputs and outputs for each possible assignment, e.g., demand levels and capabilities can be considered as inputs, while service quality and employee satisfaction may be considered as outputs. For practical applications, this paper extends the classical assignment problem by considering various inputs and outputs for each assignment. For the case of DH, cost and time are the only variables that are playing a role in assigning orders.

3.2. Vehicle Routing Problem

A large number of real-world planning problems are called combinatorial optimization problems and are sharing the following properties: they are optimization problems, are easy to state, and have a finite but usually very large number of feasible solutions. Examples are vehicle routing, crew scheduling, and production planning. All of these problems are NP-hard, i.e., it is very unlikely that the problem can be solved in polynomial time. The optimization problem in this report is the Vehicle Routing Problem (VRP).

The VRP can be described as the problem of designing optimal (delivery or) collection routes from one (or several) depots to a number of geographically scattered cities or customers, subject to side constraints (Laporte, 1992). It is assumed that all vehicle routes must start and finish at the depot. Moreover, the objective function for the VRP can be minimizing the number of vehicles, travel distance or travel time.

The VRP is a generalization of the Travelling Salesman Problem (TSP) that has many practical applications (Christofides, 1981). The difference between routing problems lies in the restrictions. A TSP solves the problem for one tour, with one start and one end location, whereas a VRP can serve multiple routes, i.e., the availability of multiple vehicles. Using multiple vehicles reduces the capacity and time constraint. In Figure 3.1, the difference between TSP and VRP is also shown graphically. The TSP consist of one individual route, whereas the VRP consists of two (red and blue) routes.

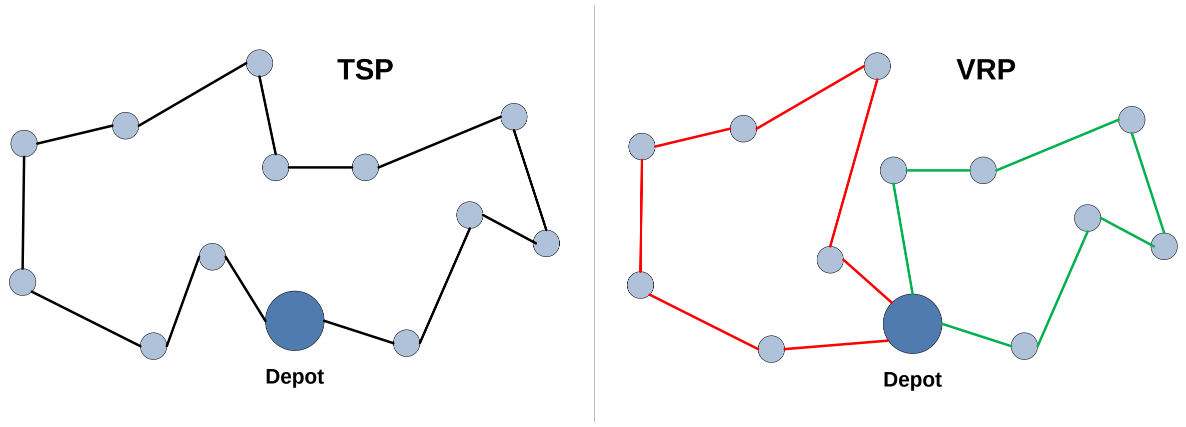

Figure 3.1: TSP and VRP

VRPs and TSPs can be solved with exact solution approaches. When it is an easy problem, it can be solved in “polynomial time” and all possible solutions will be calculated. But mostly the problem is NP-hard, and thus cannot be solved in computational time. Since most of the real-life problems cannot be solved in polynomial time, (meta)-heuristics were conceived. These are practical methodologies that do not guarantee to be optimal, but are giving a reasonable good solution to the problem. Mostly those (meta)-heuristics yield results close to optimum. Figure 3.2 gives an overview of exact algorithms and heuristics that can be applied to the VRP. Those algorithms will be treated in Section 3.2.1 and Section 3.2.2.

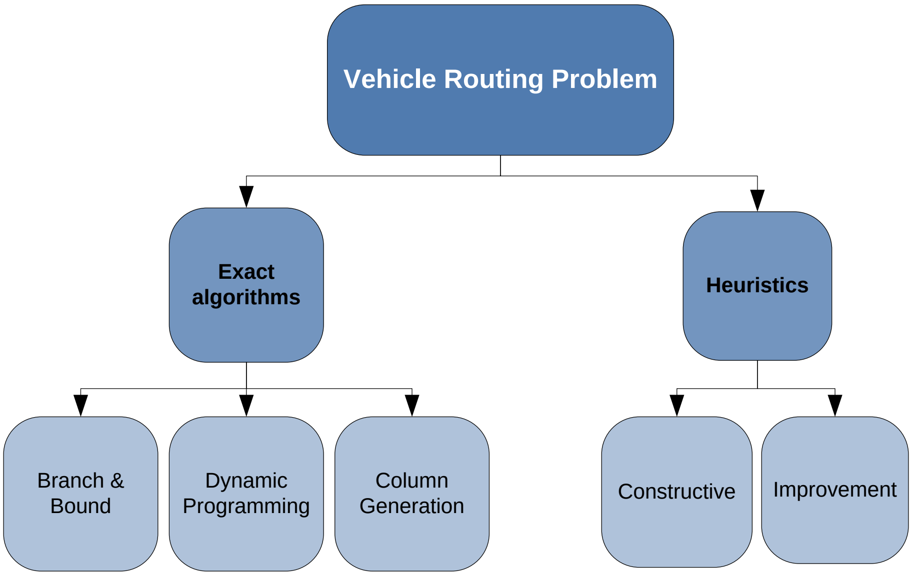

Figure 3.2: Vehicle Routing Problem algorithms

Since the VRP plays a central role in the fields of distribution and logistics, there is a wide variety of VRPs and a broad literature on this class of problems (Laporte, 1992). The vehicle routing problem is also called the "vehicle scheduling problem", the "vehicle dispatching problem" or simply the "delivery problem", and appears frequently in practical situations not directly related to physical delivery of goods. Think about, the collection from mail-boxes, the pickup of children with school buses, house-call tours by a doctor, etc. (Christofides, 1981).

A VRP can have several side conditions and the most common constraints are:

1. *Capacity constraint*: non-negative weight and/or the sum of weights may not exceed the vehicle capacity.
2. *Total time constraint*: the length of any route may not exceed a prescribed length.
3. *Time window constraint*: clients or addresses have to be visited within a certain time interval.
4. *Precedence relations*: clients have to follow up each other, e.g., client X must be visited before visiting client Y.

3.2.1. Exact algorithms

There are various exact algorithms to solve VRPs and the most common ones are: Branch-and-bound (B&B), dynamic programming, and column generation. B&B is a general method for finding optimal solutions to combinatorial optimization problems. The B&B algorithm searches the entire space of candidate solutions, though the B&B algorithm can exclude large parts of the space solution by using previous estimates. This avoids the algorithms to search for "useless" solutions and thus decreases the computational time. However, for large instances the B&B-algorithm takes a lot of time.

Typically a B&B algorithm can be seen as a tree search, see Figure 3.3. At any node of the tree, the algorithm must make a decision. Mostly each variable is valued by a 0 or 1, and the algorithm must decide whether or not to select 0 or 1. At the end of the B&B tree, the optimal solution for the problem is found. In Figure 3.3, an example is given of a branch and bound tree with three variables. As can be seen from the figure, there are eight (2^3) possibly outcomes.

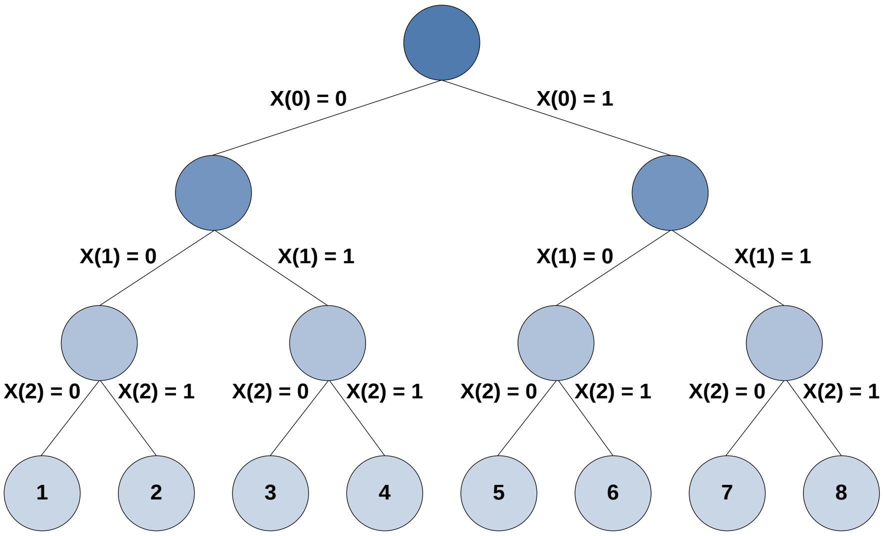

Figure 3.3: Branch and Bound tree

Dynamic Programming (DP) is an optimization approach to solve a complex problem by breaking the complex problem into a sequence of simpler problems, i.e., those who are easier to solve. DP is not applicable for the problem of DH, because DP will lead to long computational times before getting an optimal solution. Since the problem of DH consists of many customers and multiple vehicles.

Column generation is a technique that is often used for solving larger linear programs (LPs) (see e.g., (Barnhart, 1998), and (Vanderbeck & Wolsey, 1996). The overarching idea is that LPs are too large to consider all the variables explicitly. Therefore, a linear problem is split into different "columns" which can be solved separately, so called sub problems. Those sub-problems belong to the original problem, also called master problem. The master problem generates dual prices, which can be used in the objective function of the sub-problems. Those sub-problems try to find variables with negative reduced cost, assuming it's a minimization problem. If this is the case those sub-problems are added to the master problem, and is re-solved. This process is repeated until there are no more variables with negative reduced cost. After that we conclude that the master problem is optimal.

3.2.2. Heuristics

The difference between heuristics and meta-heuristics can be explained as follows. Heuristics are problem dependent techniques, whereas meta-heuristics are problem independent techniques. Heuristics are usually adapted to the problem at hand and try to take full advantage of the particularities of the problem. The problem of heuristics is that they are often too greedy. This ensures that the heuristic usually gets stuck in a local optimum and thus fails to reach a (near) optimal solution. Meta-heuristics, on the other hand, do not take advantage of any problem dependent particularities. In fact, meta-heuristics even accept deteriorating solutions, which allows the meta-heuristic to explore more thoroughly into the solution space of the problem, i.e., to avoid a local optimum. This will normally result in better solutions than for (greedy) heuristics.

Besides heuristics and meta-heuristics there also exists hyper-heuristics. The key idea behind hyper-heuristics is to devise new algorithms for solving problems by combining known (meta)-heuristics. In literature, hyper-heuristics might be thought as "*heuristics to choose heuristics*".

There are many suggestions on how to find good or near optimal solutions for VRP (meta)-heuristics. They can be split into two different types: constructive and improvement heuristics (see also Figure 3.2). The difference between both heuristics is that constructive heuristics are extending an empty solution until a complete solution, whereas improvement heuristics are taking a complete solution and tries to improve it. There are a lot of (meta)-heuristics in literature, but only the most relevant and important ones will be treated in the remainder of this section.

Constructive heuristics

In 1964, Clarke & Wright published an algorithm for the solution of the classical vehicle routing problem and is based on a so-called savings concept. It is the most well-known construction heuristic to solve VRPs. Since it is a heuristic, it does not provide an optimal solution to the problem with certainty. However, often this method does yield a relatively good solution, i.e., little deviation from the optimum. The basic idea behind the cost savings algorithm is to combine routes, i.e., merge routes into fewer routes. The savings concept is illustrated in the figure below. In the left figure, there are two separate routes, starting from the depot. One route travels to 'client A' and the other to 'client B'. Afterwards both are returned to the depot. An alternative to visit both clients is shown in the right figure. The route starts at the depot, visits 'client B', then 'client A' and then returns to the depot. Because transportation costs are given, the savings that results from driving the route shown on the right, instead of the left, can be calculated. The savings of combining client A and B are calculated as follows: the transportation costs of B to depot and depot to A are added and subtracted by the transportation costs of B to A. In formula, $S_{AB} = C_{BD} + C_{DA} - C_{BA}$. This heuristic is also known as the cheapest insertion algorithm.

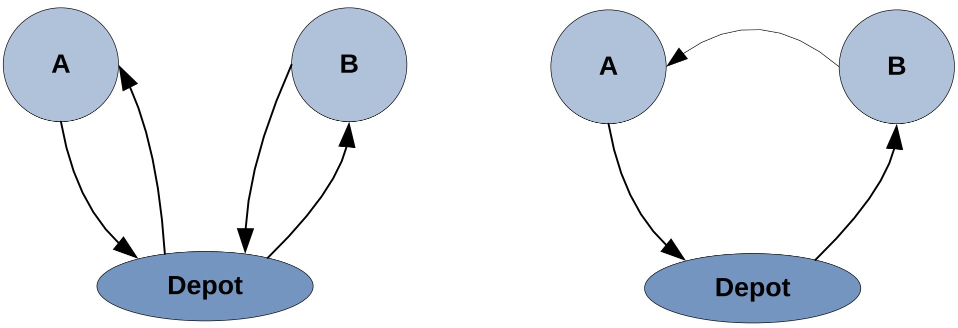

Figure 3.4: Savings algorithm

In 1981, Fisher & Jaikumar, proposed a cluster-first, route-second algorithm. The first step of their algorithm is to assign seed points for each route, evaluate insertion costs for each customer and assigning customer to routes. This first step is solved by the generalized assignment problem (see section 3.1). The second step of their algorithm is to sequence the customers within routes (or clusters) by solving the TSP per cluster.

Another well-known construction heuristic is the sweep algorithm. It seems that the origin of the sweep algorithm can be traced back to the work of Wren and Holiday. However, the method is commonly attributed to Gillett and Miller who gave the algorithm its name. The algorithm uses the polar coordinates and the idea behind the sweep algorithm is to draw a ray from the depot and adds customers to the route as encountered as long as the capacity is not exceeded. If not all customers are assigned to a vehicle, a new vehicle is used (i.e., a new route starts). When all customers are assigned, each route (or cluster) is optimized separately by solving the TSP. In Figure 3.5, the sweep algorithm is shown graphically. On the left side, customers are added to the route according to the ray, which starts at the top and moves clockwise. The capacity of one route, in the example, can contain five customers. On the right side, for each route (or cluster) a TSP is solved, i.e., the shortest path for all customers together.

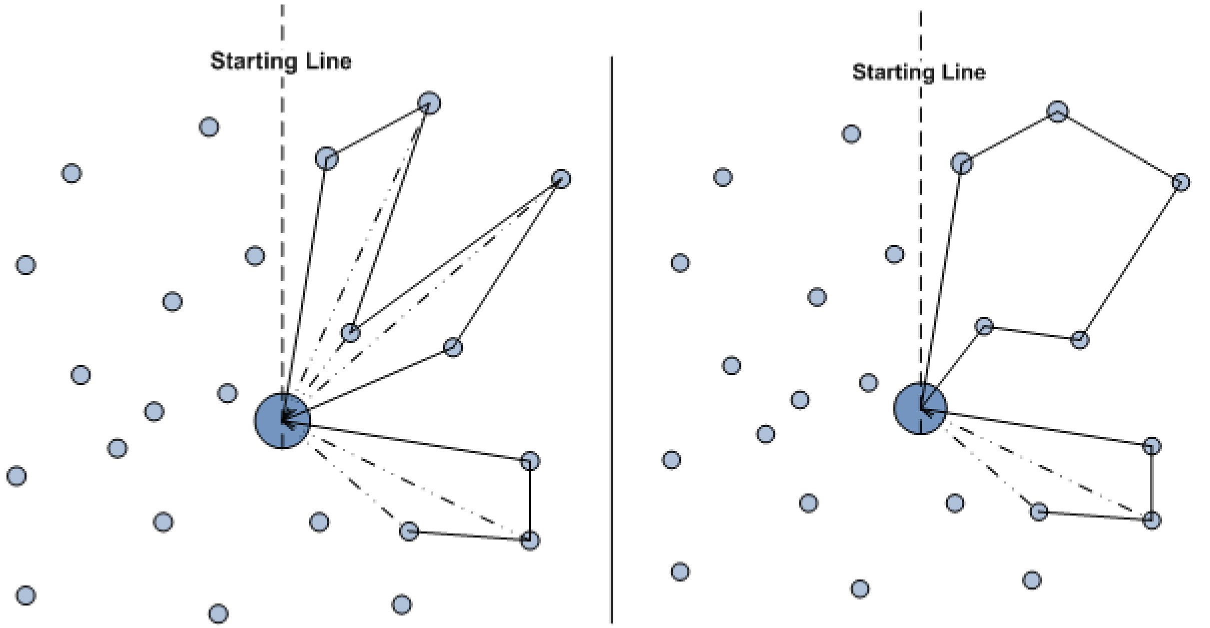

Figure 3.5: Sweep algorithm

Improvement heuristics
Besides constructive heuristics, there are also improvement heuristics. Within those improvement heuristics, our focus is on the meta-heuristics. In the beginning of this section the difference between both is explained. In fact, meta-heuristics even accept deteriorating solutions, which allows the meta-heuristic to explore more thoroughly in the solution space of the problem. This will normally result in better solutions than those achieved by greedy heuristics. In the next paragraphs the most common and relevant meta-heuristics will be treated.

Simulated annealing is a well-known meta-heuristic. It is an improvement heuristic, since it first generates a random solution. This solution can be generated in many ways and the key point is that it is random (i.e., it does not need to be the best guess of the optimal solution). For the first iteration the random solution is the base solution of the algorithm. The algorithm calculates the solution of the base (e.g., cost or time), it generates a new (neighbour) solution and it calculates the new (neighbour) solution. When the new solution has a better solution than the old solution, the new solution will became the base for the next iteration. When the new solution is not better than the old solution, the algorithm will calculate the 'acceptance probability' and compares this to a random number. In case of a minimum solution, the new solution will be accepted if the outcome of the acceptance probability is higher than the random number. A parameter called 'temperature', is decreased at the end of each iteration by multiplying it with a constant factor 'alpha'. The algorithm stops when the 'temperature' parameter becomes lower than the minimum temperature. The strength of the simulated annealing algorithm is that it avoids getting caught at a local optimum (solutions that are better than their neighbours, but are not equal to the best solution).

Another meta-heuristic is the Tabu Search algorithm introduced by (Glover, 1986). The approach undertakes to transcend local optimality by a strategy of forbidding certain moves (Glover, 1986). The purpose of forbidding certain moves, i.e., 'tabu' moves, is to prevent cycling. The Tabu Search heuristic starts with an initial solution, mostly generated by another heuristic. Thereafter Tabu Search generates a neighbourhood of slightly different ones. Those neighbourhood solution can be generated, among others with different exchange heuristics as 2-opt and Or-opt (Potvin & Rousseau, 1995). The best solution in the neighbourhood is determined and becomes the new current solution. Non-improving moves are allowed to avoid getting trapped in a local optimum (as with simulated annealing). This is done in the hope of finding better solutions afterwards and not getting stuck in a local optimum. Most important characteristic of the algorithm is the 'Tabu list', that is created to prevent cycling, i.e., the lists records the recent history of the search and prevents going back to previous solutions. If for an iteration no feasible solution exists, i.e., all solutions are 'tabu', the algorithm stops. Gendreau, et al. (1999) describe a dynamic problem for the vehicle routing of customer requests with soft time windows. They adapted a tabu search heuristic for it, which was initially designed for the static problem of the Vehicle Routing Problem with time windows. The article of (Cordeau & Laporte, 2005) reviews ten of the most important tabu search heuristics for the Vehicle Routing Problem. The computational results are compared for the ten implementations and it could be concluded that the best known solutions are obtained by the technique of (Rochat & Taillard, 1995).

The last well-known meta-heuristic we treat are Genetic Algorithms. Those algorithms are using random search in an efficient way to solve optimization problems. They exploit historical information to direct the search into the region of better performance within the search space. The algorithm repeatedly modifies a population of individual solutions. At every step, individual solutions of the population are selected and are called 'parents'. Those 'parents' are used to produce 'children' for the next iteration. These steps are repeated 'n' times, and over successive generations, the population reaches towards the optimal solution. There are various rules to select individuals and to create 'children'. In Baker & Ayechew (2003), the Genetic Algorithm is compared to tabu search and simulated annealing algorithms for solving the basic VRP. They show that their approach, where they incorporate neighbourhood search into the GA, can be competitive with other modern heuristic techniques in terms of solution time and quality. Ombuki, et al. (2006) present a genetic algorithm for solving the VRP with time windows as a multi-objective problem (number of vehicles and total costs). Also in this paper, the Genetic Algorithm can compete with other heuristic techniques. Grasas, et al. (2014) present a project to improve the logistics of blood sample collection at two laboratories in Spain. Using a genetic algorithm, they were be able to reduce the number of routes at the laboratories, while satisfying two constraints: (i) two-hour time windows between collection and delivery, and (ii) the vehicle capacity.

Besides the three abovementioned meta-heuristics, there are also other known meta-heuristics as the evolutionary algorithms (Prins, 2004), neural networks, adaptive memory procedures, variable neighbourhood search, threshold acceptance methods, ant colony optimization, greedy randomized adaptive search procedure and scatter search.

3.2.3. Hub-and-spoke

In the previous sections, we focused on the VRP with only one depot and several pick-up locations. However, in the literature there are various articles which are treating the hub-and-spoke distribution network. This network might be relevant for the case of DH. Hub-and-spoke networks are utilized by many distribution systems, especially in the airline industry and package delivery industry (Bryan & O'Kelly, 1999). The system can be described to imagine the system like a wheel, in which all traffic moves along spokes that are connected to the hub at the centre. The hubs serve as transhipment points to the depot in case of picking-up, or otherwise to 'retailers' in case of delivery. Translating the hub-and-spoke network to the case of DH, several service points of the anticoagulation service could function as a hub (a collection or transfer point). All the other service points, as well as the pick-up locations of the microbiology and pathology, are the 'spokes' and are connected to the hubs.

The idea of the hub-and-spoke system is the opposite of point-to-point delivery (also called direct shipments). In the literature there are several variants were they combine, thus mix, both delivery systems, e.g., in the article of (Liu, Li, & Chan, 2003). The results of their computational experiments shows that the mixed system can save around 10% total traveling distance on average, compared with either of the two pure systems.

3.3. Conclusion

This chapter answered research question 2: *"What planning methods are available that might be relevant for the logistical services?"* We conclude that the solution for DH is not directly available, i.e., that the literature does not know the problem of DH.

The vehicle routing problem, as well as its variants (e.g., with time windows and or pickups and deliveries) are treated extensively in the literature. There are also many (meta-)heuristics for finding good and fast solutions for the vehicle routing problem, but for the case of DH, it is not necessary to use complicated routing algorithms. A simple algorithm (e.g., the 2-opt exchange heuristic) is sufficient to plan routes according to different scenarios.

The hub-and-spoke model is also an interesting option for DH, where transport flows can be combined at the hub locations instead of the current point-to-point delivery.

4. Modelling the transport problem

In this chapter, an answer will be given to research question 3: *"How can the logistical planning be modelled?"* We come up with different scenarios for DH in Section 4.1, describing the model in Section 4.2 and the assumptions of the model in Section 4.3. Section 4.4 treats the algorithm used in the model, Section 4.5 verifies and validates the model and Section 4.6 draws conclusions.

4.1. Scenarios for DH

In this first section of the modelling chapter we come up with different scenarios for the logistical planning of DH. In Chapter 2, the current logistical flows of DH are treated extensively. Besides the sample collection of the laboratories and the providing of pharmaceutical care of the pharmacy towards different clients, various other logistical flows have been treated. As described in Section 2.3.5., those logistical flows (and orders) will not be part of the model and thus do not belong to the scope of the model. In the first sub-section we treat point-to-point delivery and in the next sub-section the hub-and-spoke delivery. In the last sub-section we come up with the different scenarios for the model. This model is used to perform the scenario analysis.

4.1.1. Point-to-point delivery

In the current situation of DH, there are approximately between 25 and 30 phlebotomists working at an arbitrary day for the collection of samples. They visit a service point, are doing home visits, or doing both of them. Besides their own sample collection (for the clinical chemistry), they also pick up a part of the samples which belong to the other laboratories. This is mainly done at the locations of the service points, i.e., locations the phlebotomists already need to visit. Sometimes, a small detour is done to collect some samples at another address for one of the laboratories.

With point-to-point delivery, we incorporate all the orders of the microbiology and pathology in the existing network of the anticoagulation service for the collection of samples. The orders which will be included are the ones laying in the catchment area as described in Section 2.3.5. The phlebotomists will start their route in one of the service points, before starting with home visits and pick-up locations (at GPs or third parties) for the other laboratories. Incorporating the pick-up locations of the other laboratories can be beneficial, since phlebotomists only have to make a small detour instead of using other transportation modes for picking up those orders. If the last location is visited, the phlebotomist will return to DH.

Moreover, with point-to-point delivery, other transportation modes, as analysts of the cytology, Dimence Group, and PostNL, will not be used anymore for the collection of samples. The only transportation facility that would be used in the catchment area of DH with point-to-point delivery are phlebotomists.

4.1.2. Hub-and-spoke delivery

The hub-and-spoke delivery describes the scenario of creating a spoke-hub distribution network, as described in the literature chapter (Section 3.2.3). This network requires the need of transhipment points, also called hubs. For the network of DH, service points of the clinical chemistry can function as hubs.

The idea of the hub-and-spoke delivery option is for the major part identical to the point-to-point delivery option. Phlebotomist will again start their route in one of the service points, before starting with visiting other addresses. However, the phlebotomists will now have the opportunity of visiting one of the hubs or directly travelling to the hospital. This last opportunity is desirable for locations which are closely located to the hospital.

The hub-and-spoke model requires to determine the locations of the hubs. As said before, the service points of the clinical chemistry will function as a hub for the model. Currently, DH has two different, so called, 'outside clinics' that are suitable to operate as hubs, since they are open every workday. In Figure 4.1, an example is given of how the 'outside clinic' of Raalte Vrieswijk can look like. The phlebotomists of the service points of Luttenberg, Haarle, Nieuw-Heeten, Heeten, Wesepe and Zwolle are delivering their samples to Raalte instead of to DH. As a result of the collection at Raalte, we only need one transportation flow from Raalte to DH. Furthermore, the network of DH probably requires more than one hub, and therefore three other locations are also suggested to function as a hub location: Rijssen (also an 'outside clinic'), Twello (wholesale customer) and Bathmen (situated in the south-east of the catchment area of DH).

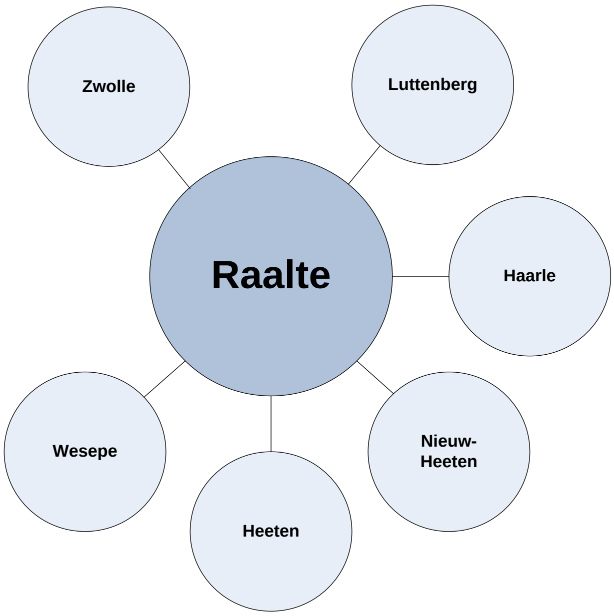

Figure 4.1: Raalte Vrieswijk as hub

The idea of the hub-and-spoke distribution network is enlarged with the locations of the microbiology and pathology that are shown in the map of Figure 4.2. The proposed hubs (Bathmen, Raalte, Rijssen and Twello) are underlined. Besides the locations of the service points, the locations of the microbiology and the pathology are also shown in Figure 4.2. The locations of the home visits are not shown in the figure, given the high number of addresses.

Figure 4.2: map for all the locations of the laboratories

For the hub-and-spoke delivery option, transport has to be arranged from the hubs towards DH, and vice versa. The end destination for this delivery option is one of the hub locations. This is in contrast with the point-to-point delivery option where DH is the end destination of all the phlebotomists. However, as given in the next section, a decision in the scenario analysis is who is going to perform the transport between the hub locations and DH. There are two (suitable) options for this: phlebotomists or Dimence Group. As said before, currently phlebotomists are bringing the samples to DH and therefore it may be an option to use those phlebotomists who are sampling at the (proposed) hubs for bringing the samples towards DH. However, the second option may be to use the transportation service of Dimence Group. Currently, they are combining transport and therefore Dimence Group may be an interesting option for the transport between DH and hub locations.

4.1.3. Scenario options

In this sub-section we come up with different scenarios for the scenario analysis. As decisions, in addition to the delivery option (point-to-point or hub-and-spoke) and the set of hub locations in case the hub-and-spoke model is used, we use three other decisions for the scenarios. First, with or without the pick-up locations of the other laboratories. Second, in case the pick-up locations are included, a daily pick-up or an interval pick-up (see section 4.2.3). Third, in case the hub-and-spoke model is used, who should arrange the transport from the hub locations to DH; the phlebotomists or Dimence Group. The abovementioned decisions will results in the following 5 choices for the scenarios in the scenario analysis:

1. Point-to-point delivery or the hub-and-spoke model
2. Which set of hub locations (if the hub-and-spoke model is used)
3. With or without the pick-up locations of the microbiology and pathology
4. Daily pick-up or interval pick-up (if the samples are picked-up)
5. Phlebotomists or Dimence Group for the transport between hubs and DH (if the hub-and-spoke model is used)

Beside the five abovementioned decisions, there are a couple of decisions which are not included in the scenario analysis but are decided before. In addition, we include the decisions which are taken in the routing algorithm.

6. Transportation modes for the collection of samples
7. The opening hours of the service points
8. The number of phlebotomists at a service point
9. Routing decisions

In Chapter 2, we addressed all transportation modes which are currently used in the logistical processes of DH. Since DH wants to improve their service and be more efficient, e.g., on costs, we restricted the transportation modes in the scenario analysis to phlebotomists only. This is done due to the fact the service level is improved when using phlebotomists instead of using the transportation modes of PostNL, Dimence Group or from patients of DH. In addition, analysts (of the cytology) are more expensive than phlebotomists, and thus less efficient.

In the current situation of DH, the opening hours of the service points are the same for every week (see Appendix A). In addition, the number of phlebotomists at a specific service point are also fixed (see Appendix B). Retain the opening hours as well as the number of phlebotomists at a specific service point is desirable for the problem owners. We therefore exclude those decisions in the scenario analysis.

Last, but not least, within the routing algorithm, explained in Section 4.4, several decisions are taken. The routing of a phlebotomist starts at a service point, before visiting patients at home or visiting pick-up locations for the other laboratories. Those home visit or pick-up addresses are assigned to the phlebotomist who is closest to the addresses. This means that an address in Raalte is assigned to one of the phlebotomists who is sampling at a service point in Raalte, instead of a phlebotomist in Deventer. In case there multiple phlebotomists equally close, the address is assigned to the first available phlebotomist. These decisions are taken this way because the assignment of addresses is the same as the manual planner of the anticoagulation service does. Furthermore, using these decisions will also provide a good initial solution for the 2-opt exchange heuristic.

Above we have mentioned nine decisions. The first five decisions are not fixed before the scenario analysis, and will be taken into account in the scenario analysis. Decisions six to nine are fixed before the scenario analysis, i.e., they are not decisions anymore in the scenario analysis.

The set of decisions will provide us with 39 scenarios, which are shown in Appendix C as well as in Table 4.1. The columns are representing the decisions that will be taken in the scenario analysis. First, the delivery option (including the set of hub locations). Second, with or without the pick-up locations of the other laboratories. Third, the frequency of visiting those additional locations, and fourth, the transportation mode between hub locations and DH if the hub-and-spoke model is used. The current situation of DH can be modelled as the point-to-point delivery option, and not picking-up any samples for the laboratories. The other decisions are not relevant since we do not use the hub-and-spoke model in the current situation, and we are not picking-up samples. The current situation will thus be scenario one (see Table 4.1). The goal of the model for the scenario analysis is stated as follows:

"Minimize the total costs for all phlebotomists to deliver materials and collect samples at all locations of the laboratories"

The time for a phlebotomist is computed as the sample time/pick-up time plus the time a phlebotomist travels between two separate locations. The goal function is to minimize the total costs for all the phlebotomists at an arbitrary week, and therefore we have to multiply the total time of the phlebotomists with the hourly wage of a phlebotomist.

Scenario	Delivery option	LMMI/PA	Frequency	Transport hub-DH
1	DH (point-to-point)	Without	-	-
2	DH (point-to-point)	With	Daily	-
3	DH (point-to-point)	With	Interval	-
4	DH, Raalte, Rijssen, Twello, Bathmen	Without	-	Phlebotomists
5	DH, Raalte, Rijssen, Twello	Without	-	Phlebotomists
6	DH, Raalte, Rijssen, Bathmen	Without	-	Phlebotomists
7	DH, Raalte, Rijssen	Without	-	Phlebotomists
8	DH, Raalte	Without	-	Phlebotomists
9	DH, Rijssen	Without	-	Phlebotomists
10	DH, Raalte, Rijssen, Twello, Bathmen	With	Daily	Phlebotomists
11	DH, Raalte, Rijssen, Twello	With	Daily	Phlebotomists
12	DH, Raalte, Rijssen, Bathmen	With	Daily	Phlebotomists
13	DH, Raalte, Rijssen	With	Daily	Phlebotomists
14	DH, Raalte	With	Daily	Phlebotomists
15	DH, Rijssen	With	Daily	Phlebotomists
16	DH, Raalte, Rijssen, Twello, Bathmen	With	Interval	Phlebotomists
17	DH, Raalte, Rijssen, Twello	With	Interval	Phlebotomists
18	DH, Raalte, Rijssen, Bathmen	With	Interval	Phlebotomists
19	DH, Raalte, Rijssen	With	Interval	Phlebotomists
20	DH, Raalte	With	Interval	Phlebotomists

21	DH, Rijssen	With	Interval	Phlebotomists
22	DH, Raalte, Rijssen, Twello, Bathmen	Without	-	Dimence group
23	DH, Raalte, Rijssen, Twello	Without	-	Dimence group
24	DH, Raalte, Rijssen, Bathmen	Without	-	Dimence group
25	DH, Raalte, Rijssen	Without	-	Dimence group
26	DH, Raalte	Without	-	Dimence group
27	DH, Rijssen	Without	-	Dimence group
28	DH, Raalte, Rijssen, Twello, Bathmen	With	Daily	Dimence group
29	DH, Raalte, Rijssen, Twello	With	Daily	Dimence group
30	DH, Raalte, Rijssen, Bathmen	With	Daily	Dimence group
31	DH, Raalte, Rijssen	With	Daily	Dimence group
32	DH, Raalte	With	Daily	Dimence group
33	DH, Rijssen	With	Daily	Dimence group
34	DH, Raalte, Rijssen, Twello, Bathmen	With	Interval	Dimence group
35	DH, Raalte, Rijssen, Twello	With	Interval	Dimence group
36	DH, Raalte, Rijssen, Bathmen	With	Interval	Dimence group
37	DH, Raalte, Rijssen	With	Interval	Dimence group
38	DH, Raalte	With	Interval	Dimence group
39	DH, Rijssen	With	Interval	Dimence group

Table 4.1: scenarios for scenario analysis

4.2. Model description

In chapter 3 we have discussed the literature about the assignment problem and the vehicle routing problem. We also concluded that the main goal of the report is not specifically to create optimal routes, but more on the problem of choosing which transportation modes to use for which samples. Moreover, increasing the service for clients of DH is more important than cost minimization. This subsection is structured as follows. Section 4.2.1. gives an introduction of the model, Section 4.2.2 treats the datasets that will be used for the model. In Section 4.2.3 and Section 4.2.4, we present the constraints and parameters that are used in the model.

4.2.1. Introduction

In this subsection we introduce some important aspects for the model. First, the model will be programmed in a program called Embarcadero Delphi XE7. This is an integrated development environment (IDE) for several applications, e.g., desktop and mobile. Second, in the previous chapters, we have used data from the year 2014. However, for the modelling we have chosen to only use two (non-consecutive) weeks. This is done to shorten the computation time drastically. Since the number of orders are stable over time, except for the drops in the summer months, we have chosen to model week 6 and 41 of 2014. These two weeks are representative for the other weeks of 2014.

4.2.2. Datasets

We sketch two datasets which will be used for the model:

1. Time windows

Time windows are really important for the collection of samples. Currently, the anticoagulation service uses a scheme with opening hours for the service points. During the opening hours of the service points, phlebotomists are taking blood or collecting urine from patients. Those samples can only be picked up after all patients are treated. Therefore time windows (with buffers) are required.

2. Travel distances and time

The model requires data about the travel distances and times between the locations. In Section 2.3.5., we already provided an Excel-overview of all the samples. This overview contains, among others, the addresses, which are used to compute the travel distances and times between the locations, as described in the next two paragraphs 'Distance Matrix' and 'detour factor'.

Distance Matrix

For the model, we need a matrix of travel distances between each of the locations. To obtain this matrix, several steps are taken. The locations that will be used in the model, as well as their addresses, are obtained from the Excel-overview. The addresses were copied to a tool at the website of GPS Visualizer's[2] to convert multiple addresses into GPS coordinates. Those GPS coordinates are then used in an Excel document[3] to translate GPS coordinates into RD-coordinates (Rijks-driehoekscoördinaten). The national triangulation system (Rijksdriehoek-stelsel) is the national coordination system of the Netherlands. The coordinates in the system are having x-coordinates (from the west to east) and y-coordinates (from the south to north), and with those coordinates it is easy to compute distances. Once the x- and y-coordinates of all the locations were obtained, a distance matrix was generated in Excel using some macros. The first macro was built to copy the locations and the associated coordinates from the left side of the matrix to the top of the matrix. The other macro was built to compute the Euclidean distances between the locations on the basis of the theorem of Pythagoras.

Detour factor

For the distance matrix above, the Euclidean distance is computed between each of the locations. However, phlebotomists cannot drive in a straight line from a location to another, or vice versa. Therefore we have to adjust the Euclidean distance into a network distance (a street distance). This can be achieved by adding a detour factor. In the paper of Nordbeck (1964), the relationship between shortest network distance and the Euclidean distance is addressed. He finds detour factors of around 1.2 – 1.25. In another paper from Rietveld et al. (1999), this detour factor in commuting is about 1.40, and for shorter trips it is slightly higher (1.50). He presents three reasons for this. First, the network is not so fine meshed. Second, due to psychical boundaries such as rivers and railroads. Third, the network consists of roads with different speeds (a detour may save travel time). In our case, we are having some boundaries, such as the river "De IJssel" and railroads. We also have done some random checks with our own data and conclude that adjusting our matrix with 1.25 for large distances (greater than 15 kilometres) and 1.4 for short distances (smaller than 15 kilometres) results in good estimates for the real travel times. We used 15 kilometres since this is the mean of all distances.

4.2.3. Constraints

We model several constraints in this research:

1. Maximum duration of a route

The maximum duration of a route may not be more than 4.25 hours. This means that when phlebotomists start their workday at 8:00 o'clock, no more addresses (home visits as well as pick-up locations) may be planned after 12:15 o'clock. This is done because the bulk of the samples must be at the hospital before 13:00 o'clock the same day. However, there are some locations which are having opening hours longer than 4.25 hours. At those locations, the above mentioned constraint is not applicable, since they are not visiting patients at home or picking-up samples for other laboratories. In this case the 'route' may be longer than 4.25 hours.

[2] http://www.gpsvisualizer.com/geocoder/ (accessed at 24 Augustus 2015)

[3] home.solcon.nl/pvanmanen/Download/rd2wgs.xls (accessed at 24 Augustus 2015)

2. Maximum duration of sample collection

The laboratories are applying a maximum duration for the collection of samples. Samples of the clinical chemistry have to be at the laboratory within six hours after the sample is taken, for the microbiology within two days, and for the pathology within a week.

3. Number of visits per week

Usually, in the current situation, service points are visited once every day, however there are also service points which are not visited every day, i.e., not open every day of the week. The visit frequency of service points (Appendix A) may not change.

4. Number of phlebotomists per service point

Each service point of the clinical chemistry is provided with at least one phlebotomists during the opening hours of the specific service point. However, there are also service points which need more capacity for sampling, i.e., more than one phlebotomists. The number of phlebotomists per service point are given in Appendix B.

5. Number of addresses per phlebotomist

The number of addresses per phlebotomist is restricted to 30 addresses, i.e., that a phlebotomist never visits more than 30 addresses in one trip on an arbitrary day. This is fixed by the route planner of the anticoagulation service.

6. Car capacity

The capacity of DH and DG cars are infinite for this research, since the samples are very small, also with the packaging material around it. This means that those cars can collect all the samples at an arbitrary day (for all the laboratories). The other way around, i.e., delivering of material towards GPs and/or third parties is also not a problem for the capacity.

4.2.4. Parameters

There are various parameters that are used in the model:

1. Pick-up time

In the model we use a fixed pick-up time for the collection of samples. Employees have to park the car, enter a building (e.g., a GP or service point), collect the samples and return to their car. The pick-up time for the collection is set at 5 minutes, no matter the type and number of samples.

2. Sample time

The time an phlebotomists is available for sampling patients at a service point is fixed according to the opening hours of the service points (Appendix A). In addition, the sample time for a home visit is fixed at 5 minutes, and is based on the experience of phlebotomists working in the field.

3. Distance matrix

All cost parameters are linked to distances and time travelled (Section 4.2.1).

4.3. Assumptions of the model

In the section we sketch several assumptions made in this research:

1. Start location of phlebotomists

In the model, we assume that phlebotomists are having their start location at one of the service point, and not at DH. The management of the anticoagulation service intends to have their phlebotomists closely located to the service points were they draw blood, currently and in the future.

2. Locations to visit
The locations obtained from the data of 2014 are used in the model. We assume that the locations obtained from the data are representative for the coming years.

4.4. Routing algorithm

In this section we provide two flowcharts for the routing. The first flowchart displays the nearest service point algorithm that is used for creating routes and is shown in Figure 4.3. The second flowchart displays the 2-opt exchange heuristic used for improving the routes and is shown in Figure 4.4.

The procedure of the nearest service point flowchart starts with sorting the addresses on type of applicant. This means that service points become on top of the list followed by the pick-up/sample addresses of respectively the home visits, the microbiology and pathology. This is done because routes start with a service point, and not with a home visit or pick-up location. The next step of the flow chart is to pick the next address of the list. If the address is a service point it can be assigned to an 'empty' route (or phlebotomist), i.e., a phlebotomist who is not assigned to a service point yet. If the address is a home visit or a pick-up location, the address is assigned to an 'existing' phlebotomist. From all the 'existing' phlebotomists, the distance between the service point of the corresponding phlebotomist and the current address is calculated. If there is only one phlebotomist with the shortest distance, the address is assigned to that specific phlebotomist. If there are more phlebotomists with the shortest distance, then the earliest available phlebotomist is chosen. The routes are ready when all locations are assigned to one of the phlebotomists. These decisions are taken this way because the assignment of addresses corresponds to the way the manual planner of the anticoagulation service assigns addresses to phlebotomists. Furthermore, this procedure also holds a good initial solution for the 2-opt exchange heuristic.

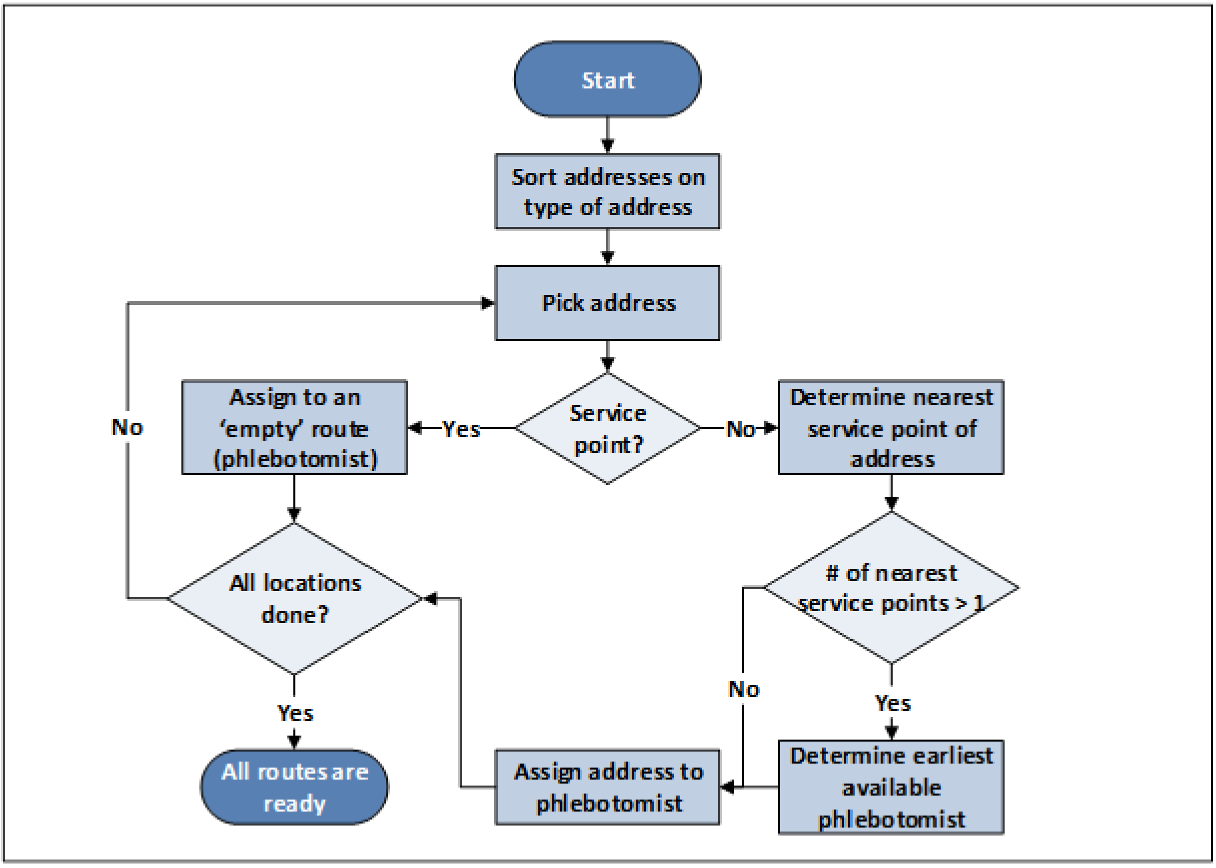

Figure 4.3: Flowchart of the algorithm

The next flowchart (Figure 4.4) displays the procedure for the 2-opt exchange heuristic that is used for the DH case. First, we determine the number of iterations that have to be performed for the heuristic. The more iterations that will be performed, the better the end solution will be. In each iteration two random locations are selected. The first location is a pick-up/sample location of the specific week. The next random location is restricted to the same day of the first random location. This means that if the first location is collected at Monday, the second location must be a random location at Monday. Next, the locations are swapped visually. Once the locations are swapped, the (new) distances are calculated, i.e., the distance towards both new locations as well as the distances from both new locations to their next location. If the total new distance is shorter than the old total distance, the locations are swapped. If this is not the case, nothing happens. Finally, if the last iteration is performed the heuristic is done.

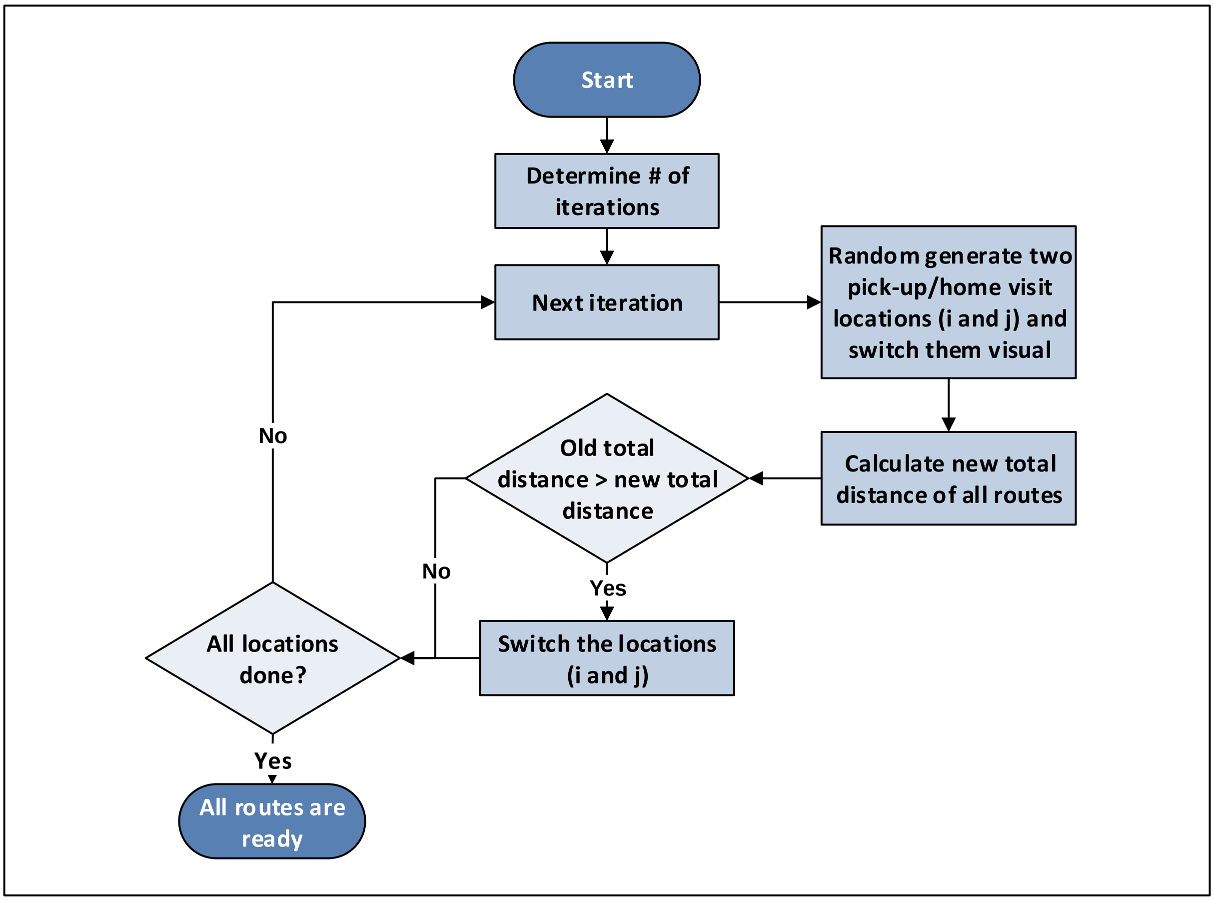

Figure 4.4: 2-opt heuristic

4.5. Verification and Validation

This section describes the verification and validation process of our model. The verification process is concerned about the computer program if it works as it intends to do (Law, 2007). We used several techniques for verifying the model as proposed in the book of Law (2007). Initially, we built the model, which is progressively made more detailed. Each expansion of the model is verified by means of visual checks of the model and parameters, and debugged when necessary.

The validation process determines whether the data obtained from the simulation model (closely) resembles the output data that would be expected from the actual system. Since we address 38 other scenarios besides the current situation we can only validate the current situation. However, not every data from the current situation was available, e.g., the duration of each route and the kilometres driven. To validate the correctness of the model, we let two hospital employees carefully survey the results of the model. They deem the model acceptable to simulate the other scenarios. Therefore, we conclude that the results are realistic.

4.6. Conclusion

This chapter has given an answer to research question 3: *"How can the logistical planning be modelled?"* In the first section we described the two delivery options that are suitable for the logistical network of DH: point-to-point and hub-and-spoke. In addition we came up with a list of decisions that are also relevant for the logistical network, and discussed about those decisions which ones to include and which ones to exclude from the scenario analysis. We came up with 39 interesting scenarios for the scenario analysis which will be evaluated in the next chapter.

In section 2 of this chapter we described the model, and presented the assumptions made in the model in section 3 of this chapter. Section four described the procedures of the nearest service point algorithm and the 2-opt exchange heuristic. Both procedures are presented in a flowchart and represent the steps taken to create routes for the phlebotomists.

5. Evaluation of the scenario analysis

In this chapter we evaluate the different scenarios. The first section of this chapter describes the costs that are involved with the current transportation modes. These costs are required to compare the different scenarios with each other. Section 5.2 describes the results of the proposed alternative scenarios.

5.1. Costs transportation modes

In this section, we describe the costs involved with the transportation modes described in Chapter 2. To compare the 39 scenarios (as introduced in the previous chapter) with each other we have to include the same orders. In some of the scenarios we do not take the orders (pick-up locations) of the microbiology and pathology into account. To compare those scenarios with the scenarios were the orders of the microbiology and pathology are taken into account, we have to add the costs of PostNL to the scenario without the pick-up locations. This also holds for analysts of the cytology and patients. In addition, we have to include the costs of the transport between hub locations and DH to the scenarios who are using the hub-and-spoke delivery option. This is not required for the scenarios that are using the point-to-point delivery option, since the end destination is already the hospital.

Analysts of the cytology

Analysts of the cytology are collecting samples for the cytology every Monday for approximately 2 hours and their labour costs are €30.52 per hour. In addition, they declare a car allowance of 30 kilometres at a rate of €0,30 per kilometre. This means that in total the cost per week are €70,04.

PostNL / Cycloon

Yearly, approximately 3,000 samples of the microbiology are send to DH and 1,863 samples of the pathology, which results in a total of 4,863 samples. As mentioned in Section 2.3.6., there are different prices per unit. The price per unit is fixed at [redacted] inside the catchment area (Cycloon), and [redacted] outside the catchment area (PostNL). For the return from e.g., GPs to DH, the price per unit is [redacted] (freepost number). This means, in case all samples are delivered and send back by Cycloon in the catchment area of DH, that we have 4,863 samples against a price of [redacted]). However, not every postal item is delivered by Cycloon, since Cycloon only operates in the catchment area of DH. The price per unit outside the catchment area is [redacted], which equals an additional amount of [redacted] per unit compared to the price per unit inside the catchment area. From the Excel overview (Section 2.3.5.), we see that yearly, 1,942 samples are delivered by PostNL instead of Cycloon. This means the total yearly costs can be computed as follows:

[redacted]

On average the costs per week are [redacted] divided by 52 weeks). Moreover, we wanted the exact costs for the model and therefore we received the amount of orders send by PostNL and Cycloon for the microbiology and pathology for week 6 and 41 (modelling weeks), and are given in Table 5.1. In addition we have computed the costs corresponding for this two weeks on the same way as described above. We conclude that the costs for microbiology and pathology for week 6 and 41 nearly equals the average costs per week of [redacted]. Moreover, the costs for patients equals zero (see next paragraph).

	PostNL/Cycloon	Costs	Patients	Costs
Week 6 - Microbiology	58	[redacted]	88	€ 0
Week 6 - Pathology	36	[redacted]	0	€ 0
Week 41 - Microbiology	66	[redacted]	99	€ 0
Week 41 - Pathology	24	[redacted]	0	€ 0

Table 5.1: Costs involved by PostNL and Cycloon.

Patients
Another logistical flow that is used quite often is those of the patients itself. A sample is taken at the practice of a GP, and afterwards the patient is asked to bring the sample to the hospital themselves. This logistical flow is only used by microbiology, and occurs around 4,500 times a year, i.e., about 15 to 20 per workday. There are no costs involved in this logistical flow for DH, since the transport is arranged by the patients themselves. For the scenario analysis, we have to include these costs towards the scenarios who are not picking-up samples for the microbiology and pathology. However, the costs are null.

Transportation from hubs
For the hub-and-spoke delivery/collection option we have to deal with the fact that samples are collected at the hubs and that materials have to be distributed from DH towards the hubs. In the previous chapter, four possible hubs have been addressed as locations for the delivery/collection option. Since the model does not cope with the transportation from DH to hubs and vice versa, we have to calculate them separately. In Table 5.2 the prices per week (containing 5 workdays) for each hub for both transportation options are given.

	Single trip (mins)	# KM (single trip)	Price phlebotomists	Price DG
DH - Raalte	20	19,9	€ 141,25	[redacted]
DH - Rijssen	25	31,5	€ 164,79	[redacted]
DH - Bathmen	15	8,6	€ 117,71	[redacted]
DH - Twello	15	8,7	€ 117,71	[redacted]

Table 5.2: prices for the transportation from hubs to DH and vice versa

The price for phlebotomists are based on time, while the price of Dimence Group is based on the number of kilometres driven. For the phlebotomists we include an additional amount of 20 minutes for picking-up the samples at the hubs, and for Dimence Group we use a KM-price of [redacted] The hourly wage of a phlebotomist is €28.25, and a single trip is one trip from a hub location to DH or vice versa. The next two equations clarify this.

1. $Price\ phlebotomist = (single\ trip\ (mins) * 2 + 20) * 5\ (\#\ of\ workdays) * hourly\ wage$
2. $Price\ dimence\ group = (\#\ of\ KM\ single\ trip * 2) * 5\ (\#\ of\ workdays) * KM\ price$

5.2. Scenario analysis
Section 5.2.1. treats the results of the different scenarios. In the remainder of this section the results will be analysed, and answers will be given to the following questions. What would be the best delivery option? Shall we incorporate the samples of the other laboratories in the routes? If so, what should the frequency be of picking-up the samples? Which transportation modes should we use from the hubs to DH and vice versa if we use hub locations?

5.2.1. Results of the different scenarios
In this section we come up with the results of the proposed scenarios. In the previous chapter we addressed 39 scenarios, and modelled them with input data based on week 6 and week 41. The results per week are shown in Appendix D. However, instead of 39 scenarios, we see 21 scenarios. This is due to the fact the transportation mode from the hubs to DH and vice versa is not calculated within the model, but afterwards. We therefore can reduce the number of scenarios in Appendix D from 39 towards 21 scenarios.

Appendix D shows us the decisions taken in the scenario. In addition, we see the initial solution, the average solution after 10,000 improvement iterations and the reduction compared to the initial solution. The initial solution is calculated after the nearest service point algorithm as described in Chapter 4. Moreover, for each scenario we have performed 10 repetitions, for 10,000 improvement iterations. The averages of those 10 repetitions are given in the table. Finally, the table shows the costs reduction between the initial solution and the averages after 10,000 improvement iterations. To compare the scenario, we have to include additional costs (as mentioned in Section 5.1) to the corresponding scenarios. This are, e.g., PostNL and transportation costs between hub locations and DH. The results of the total costs per scenario for both weeks are given in Table 5.3. In addition, the difference between the first scenario (current situation of DH) and the other scenarios are given.

Scenario	Total costs per week	Difference between scenario 1	Total costs per week	Difference between scenario 1
	Week 6		Week 41	
1	€ 15.060,97		€ 14.724,35	
2	€ 15.272,25	€ -211,29	€ 14.891,54	€ -167,18
3	€ 15.009,98	€ 50,98	€ 14.707,00	€ 17,35
4	€ 14.625,14	€ 435,83	€ 14.280,13	€ 444,22
5	€ 14.575,12	€ 485,85	€ 14.252,13	€ 472,22
6	€ 14.581,47	€ 479,50	€ 14.265,43	€ 458,93
7	€ 14.548,88	€ 512,09	€ 14.241,62	€ 482,73
8	€ 14.763,56	€ 297,41	€ 14.429,42	€ 294,93
9	€ 14.800,42	€ 260,55	€ 14.471,56	€ 252,80
10	€ 14.831,48	€ 229,49	€ 14.487,53	€ 236,82
11	€ 14.765,03	€ 295,93	€ 14.429,82	€ 294,53
12	€ 14.799,23	€ 261,74	€ 14.455,62	€ 268,73
13	€ 14.759,05	€ 301,92	€ 14.421,21	€ 303,15
14	€ 14.965,99	€ 94,98	€ 14.611,04	€ 113,31
15	€ 14.977,79	€ 83,17	€ 14.654,31	€ 70,04
16	€ 14.588,84	€ 472,13	€ 14.293,13	€ 431,23
17	€ 14.536,13	€ 524,83	€ 14.254,92	€ 469,44
18	€ 14.575,06	€ 485,91	€ 14.261,21	€ 463,14
19	€ 14.523,07	€ 537,89	€ 14.218,25	€ 506,10
20	€ 14.742,01	€ 318,96	€ 14.430,55	€ 293,80
21	€ 14.774,06	€ 286,91	€ 14.471,55	€ 252,80
22	€ 14.385,96	€ 675,01	€ 14.040,95	€ 683,40
23	€ 14.415,81	€ 645,16	€ 14.092,82	€ 631,53
24	€ 14.421,72	€ 639,25	€ 14.105,68	€ 618,68
25	€ 14.469,00	€ 591,97	€ 14.161,74	€ 562,61
26	€ 14.709,87	€ 351,10	€ 14.375,73	€ 348,62
27	€ 14.774,23	€ 286,74	€ 14.445,37	€ 278,99
28	€ 14.592,30	€ 468,67	€ 14.248,36	€ 476,00
29	€ 14.605,72	€ 455,24	€ 14.270,51	€ 453,84
30	€ 14.639,48	€ 421,49	€ 14.295,87	€ 428,48
31	€ 14.679,17	€ 381,80	€ 14.341,32	€ 383,03
32	€ 14.912,30	€ 148,67	€ 14.557,35	€ 167,00
33	€ 14.951,60	€ 109,37	€ 14.628,12	€ 96,23
34	€ 14.349,66	€ 711,31	€ 14.053,95	€ 670,40
35	€ 14.376,82	€ 684,14	€ 14.095,61	€ 628,75
36	€ 14.415,31	€ 645,66	€ 14.101,46	€ 622,89
37	€ 14.443,19	€ 617,78	€ 14.138,37	€ 585,98
38	€ 14.688,32	€ 372,65	€ 14.376,86	€ 347,49
39	€ 14.747,87	€ 313,10	€ 14.445,36	€ 278,99

Table 5.3: Total costs per scenario (both weeks)

5.2.2. Delivery option

The point-to-point delivery and hub-and-spoke delivery are two options for the collection of samples towards the hospital. For the hub-and-spoke delivery option various hubs are suggested, and different scenarios with a different set of hub locations are modelled.

	No pick-up (P)	No pick-up (DG)	Daily pick-up (P)	Daily pick-up (DG)	Interval pick-up (P)	Interval pick-up (DG)
DH, Raalte, Rijssen, Twello, Bathmen	€ 435,83	€ 675,01	€ 229,49	€ 468,67	€ 472,13	€ 711,31
DH, Raalte, Rijssen, Twello	€ 485,85	€ 645,16	€ 295,93	€ 455,24	€ 524,83	€ 684,14
DH, Raalte, Rijssen, Bathmen	€ 479,50	€ 639,25	€ 261,74	€ 421,49	€ 485,91	€ 645,66
DH, Raalte, Rijssen	€ 512,09	€ 591,97	€ 301,92	€ 381,80	€ 537,89	€ 617,78
DH, Raalte	€ 297,41	€ 351,10	€ 94,98	€ 148,67	€ 318,96	€ 372,65
DH, Rijssen	€ 260,55	€ 286,74	€ 83,17	€ 109,37	€ 286,91	€ 313,10
DH (Point-to-Point)			€ -211,29	€ -211,29	€ 50,98	€ 50,98

Table 5.4: Difference between scenarios and current situation (Week 6)

	No pick-up (P)	No pick-up (DG)	Daily pick-up (P)	Daily pick-up (DG)	Interval pick-up (P)	Interval pick-up (DG)
DH, Raalte, Rijssen, Twello, Bathmen	€ 444,22	€ 683,40	€ 236,82	€ 476,00	€ 431,23	€ 670,40
DH, Raalte, Rijssen, Twello	€ 472,22	€ 631,53	€ 294,53	€ 453,84	€ 469,44	€ 628,75
DH, Raalte, Rijssen, Bathmen	€ 458,93	€ 618,68	€ 268,73	€ 428,48	€ 463,14	€ 622,89
DH, Raalte, Rijssen	€ 482,73	€ 562,61	€ 303,15	€ 383,03	€ 506,10	€ 585,98
DH, Raalte	€ 294,93	€ 348,62	€ 113,31	€ 167,00	€ 293,80	€ 347,49
DH, Rijssen	€ 252,80	€ 278,99	€ 70,04	€ 96,23	€ 252,80	€ 278,99
DH (Point-to-Point)			€ -167,18	€ -167,18	€ 17,35	€ 17,35

Table 5.5: Difference between scenarios and current situation (Week 41)

Table 5.4 and Table 5.5 show the differences in total costs between the current situation (scenario 1) and the other scenarios for respectively week 6 and 41. The positive numbers are showing a saving, while the negative numbers are showing extra costs. These costs are the same costs as presented in Table 5.3., however in a different setting. In Table 5.4 and Table 5.5, the delivery option is shown in the first column, where the last row represents the point-to-point delivery option. The other column headings represent if samples are collected for the other laboratories, and their frequency (daily or interval). Moreover, the transportation facility from the hubs towards DH and vice versa is given in the columns, where the letter 'P' stands for phlebotomists and DG for Dimence Group.

The current situation uses point-to-point as delivery option, does not pick-up samples for other laboratories and the transportation facility does not apply to this scenario since DH is the only collection point. The current situation is also compared with itself and therefore in the last row, column two and three are left blank. All the other scenarios are compared with the current situation and the differences are shown in the tables.

We draw the following conclusions. First, the point-to-point delivery option has significantly lower savings than any other delivery option with hubs. Second, we conclude that using two or three hubs rather than one hub results in higher savings, i.e., comparing Raalte or Rijssen with any other scenario with two or three hubs. Third, if we compare the scenario with two hubs (Raalte and Rijssen) with the scenarios with more than two hubs we conclude that if DG travels between the hub locations and DH, the savings can be larger if we add more hub locations, and in case phlebotomists are travelling between the hubs and DH, we have to use two hubs, Raalte and Rijssen. Fourth, as stated by point three, DH will have more savings if DG travels between the hubs and DH if we include more than two hubs. The highest savings can be achieved if we use four hubs. However, the difference in savings between adding the fourth hub compared to using two hubs is relatively small, approximately between €80 - 120 euro per week (depending on the pick-up frequency). In contrast with the difference between no hubs and two hubs, were the difference approximately lies between €550 - €600 per week.

5.2.3. With or without other laboratories

Table 5.4 and Table 5.5 provides us with relevant information about whether we should include the pick-up locations of the other laboratories or not. We therefore have to compare the columns without pick-up locations with the columns where we include the pick-up locations, both on a daily basis as well as on interval basis. Based on the costs we should include the pick-up locations of the other laboratories in case of interval pick-up, because this yields higher savings. Picking-up the samples on a daily basis yields lower savings compared to excluding pick-up locations.

Besides costs, we can also argue on service. A daily pick-up of samples for the other laboratories generates much more services towards the clients of DH and their patients compared to an interval pick-up or even worse no pick-up. When phlebotomists are picking-up the samples on a daily basis, patients do not have to visit the hospital anymore, and the majority of the patients will receive a rash of the lab tests earlier than in the current situation.

	No pick-up	Interval pick-up	No pick-up	Interval pick-up
	WEEK 6		WEEK 41	
DH, Raalte, Rijssen, Twello, Bathmen	€ 206,34	€ 242,64	€ 207,41	€ 194,41
DH, Raalte, Rijssen, Twello	€ 189,92	€ 228,90	€ 177,69	€ 174,91
DH, Raalte, Rijssen, Bathmen	€ 217,76	€ 224,17	€ 190,19	€ 194,41
DH, Raalte, Rijssen	€ 210,17	€ 235,98	€ 179,58	€ 202,95
DH, Raalte	€ 202,43	€ 223,98	€ 181,62	€ 180,49
DH, Rijssen	€ 177,38	€ 203,74	€ 182,76	€ 182,76
DH (Point-to-Point)	€ 211,29	€ 262,27	€ 167,18	€ 184,53

Table 5.6: Additional savings compared to daily pick-up

In Table 5.6 the additional savings are shown if there are no pick-up locations or the pick-up locations are visited on an interval basis, compared to a daily basis. The additional savings are not influenced by the transportation modes from the hubs towards DH and vice versa, because the costs are subtracted from each other. As shown in the table, additional savings of about €167.18 to €262.27 per week can be obtained, depending on the delivery option, if the pick-up locations are excluded or the pick-up locations are only visited on an interval basis. The other way around, to obtain an better service towards the clients and patients, it will cost DH between €167.18 and €262.27 per week, depending on the delivery option. Furthermore, we conclude that the interval pick-up option outperforms the no pick-up option for most of the scenarios.

5.2.4. Way of transport to hub locations

In case the delivery option contains hubs, transportation has to be arranged from the hubs to DH and vice versa. In the previous chapter (Section 4.1.2.), we have addressed the two possibilities for this transport: phlebotomists and Dimence Group. For each possibility, we have calculated the total costs for each scenario by incorporating the corresponding costs of those transportation modes (see Section 5.1). The results of those scenarios are already shown in Table 5.3.

To compare both transportation modes, we have subtracted the cost of phlebotomists from the cost of Dimence Group, and is given in Table 5.7. As shown in the table, using Dimence Group to arrange the transport from hubs towards DH will yield higher savings compared to let phlebotomists drive to DH and hubs. We also conclude that using more hubs results in higher savings.

	Phlebotomist	Dimence Group	Difference
DH, Raalte, Rijssen, Twello, Bathmen	€ 541,46	€ 302,28	€ 239,18
DH, Raalte, Rijssen, Twello	€ 423,75	€ 264,44	€ 159,31
DH, Raalte, Rijssen, Bathmen	€ 423,75	€ 264,00	€ 159,75
DH, Raalte, Rijssen	€ 306,04	€ 226,16	€ 79,88
DH, Raalte	€ 141,25	€ 87,56	€ 53,69
DH, Rijssen	€ 164,79	€ 138,60	€ 26,19

Table 5.7: Difference between phlebotomists and Dimence Group

In the worst case, Dimence Group does not drive in the direction of one of the hubs and DH has to pay [redacted] per kilometre. In case the route is used partly by DG, e.g., the half of the route, DH has to pay [redacted] per kilometre. The best case scenario is if DG already drives towards the hubs, i.e., DH pays [redacted] per kilometre to DG. The cheaper the price per kilometre for DH, the higher the savings that will be realized. The additional savings can reach to an amount of €151.14 (see Table 5.8).

	[redacted]	[redacted]	[redacted]
DH, Raalte, Rijssen, Twello, Bathmen	[redacted]	[redacted]	[redacted]
DH, Raalte, Rijssen, Twello	[redacted]	[redacted]	[redacted]
DH, Raalte, Rijssen, Bathmen	[redacted]	[redacted]	[redacted]
DH, Raalte, Rijssen	[redacted]	[redacted]	[redacted]
DH, Raalte	[redacted]	[redacted]	[redacted]
DH, Rijssen	[redacted]	[redacted]	[redacted]

Table 5.8: Difference between prices per kilometre

5.2.5. Number of iterations

In this section we describe the influence of the number of iterations performed. Obviously, the more iterations the model performs, the higher the savings that will be achieved. Table 5.9 shows us the total number of hours (for one simulation week) of enlarging the number of iterations for a couple of scenarios. Due to the long computation time of the model, we have chosen to only run the model again, with more iterations, for the most promising scenarios (with two hub locations) and the current situation (scenario 1).

Scenario	Initial	10,000	50,000
1	487.6	481.4	474.5
7	468.8	462.5	456.1
13	488.4	481.1	472.5
19	481.0	474.5	466.7

Table 5.9: 50,000 and 10,000 iterations (week 6)

The additional savings, e.g., for scenario 1, can be achieved can be computed the savings as follows:

$$Additional\ savings = \big((difference\ in\ hours) * hourly\ wage\ phlebotomist\big) + \\ (difference\ in\ hours) * 50 * price\ per\ kilometre)$$

In the calculation, a factor 50 is used for the translation of hours towards kilometres. This factor is also used in the distance matrix, Section 4.2.2. The additional savings that can be achieved when going from 10,000 to 50,000 iterations can reach to an amount of €275 up to €375 per week.

5.3. Conclusion

Chapter 5 has analysed the results of the scenarios proposed from Chapter 4. These scenarios are modelled based on different decisions: delivery option (including the set of hubs), in- or excluding pick-up locations of other laboratories, the frequency of visiting the pick-up locations, and, if we use hubs, the transportation facility from the hubs towards DH and vice versa. These scenarios were also tested between two separate weeks, in order to see whether there are differences between them. From the results we conclude that the differences between both weeks are negligible, and therefore we assume that all other weeks can be expected to have similar results.

The results have shown that the current situation of DH can be improved regarding costs. In addition, the service towards clients, patients and employees can also be improved considerably.

Based on service level, DH should include the pick-up locations of the other laboratories on a daily basis into their routes. This is due to the small difference in costs between including the pick-up locations on a daily basis and the other options. In order to maximize their savings, they should include the orders on an interval basis. However, this will slightly improve the service of DH towards their clients and patients, since there are no changes in the arrivals of samples at the hospital, i.e., the samples of patients does not arrive earlier at the laboratory, but only the transportation option is changed (phlebotomists instead of PostNL or patients).

The hub-and-spoke option outperforms the point-to-point delivery option. Therefore a decision has to be made which transportation facility to use for the transport of DH to hubs and vice versa. We conclude that the use of Dimence Group yields higher savings than using phlebotomists. If Dimence Group can incorporate the addresses in their existing routes, i.e., sharing the route, even larger savings can be achieved up to €150 per week.

6. Conclusions, recommendations and implementation

This chapter presents the conclusions of our research in Section 6.1, followed by recommendations in Section 6.2 and discusses some issues about the practical implementation of the recommended interventions in Section 6.3. Last, Section 6.4 discusses the results of this research.

6.1. Conclusions

The research goal of this thesis was *"To analyse the current planning of external logistics, and assess interventions to improve these at the laboratories and pharmacy of Deventer Hospital."*

To achieve our goal, we examined Deventer Hospital's current planning of external logistics, i.e., the volume and clients of the laboratories, the transport process of samples, the transportation modes for the transport of samples towards DH, and the logistical flows of the laboratories. In the next step we performed a literature study about the problem DH is facing, as well as interesting algorithms for the model.

We addressed two delivery options that are suitable for the logistical network of DH: point-to-point and hub-and-spoke. In addition, we came up with a list of other decisions that are relevant for the logistical network. We argued on those decisions; which ones to include and which ones to exclude from the scenario analysis. In total, we found 39 interesting scenarios to be evaluated in a scenario analysis.

The scenario analysis shows that there are various possibilities for successfully improving the efficiency of the logistical planning of Deventer Hospital. It turns out that the current situation of Deventer Hospital can be improved, based on both criteria, costs and service level. In addition, it turns out that the hub-and-spoke model outperforms the point-to-point delivery option based on costs. We conclude that using the hub locations of Raalte and Rijssen will yield the highest savings if phlebotomists are performing the transport between hubs and Deventer Hospital. In case Dimence Group performs the transport, even more savings will be achieved if we add Bathmen, Twello or both locations to the set of hubs. This depends on the frequency of visiting the pick-up locations of the microbiology and pathology.

Based on the service towards clients and patients of DH, the hospital should include the pick-up locations of the other laboratories on a daily basis. Due to the small difference in costs between including the pick-up locations on a daily basis and excluding them from the routes. When the focus is on cost, DH should include the orders on an interval basis instead of on a daily basis or excluding them. A major drawback of the interval basis is that the service towards the clients and patients remains almost the same. The orders will not arrive earlier at the hospital than in the current situation. The only advantage will be that the orders are picked-up by phlebotomists instead of patients or PostNL, and therefore DH has more control over the logistical process of the samples.

Since the hub-and-spoke model outperforms the point-to-point delivery option we have to argue on what the best transportation facility will be between hub locations and DH. We conclude that using Dimence Group yields higher savings than using phlebotomists and in case Dimence Group can incorporate the addresses of the hub locations in their existing routes, even larger savings can be achieved for Deventer Hospital. These additional savings are dependent on the routes of Dimence Group. The more combined transport between Dimence Group and Deventer Hospital, the higher the savings will be. The additional savings for Deventer Hospital can reach to an amount of €150 per week in case all hub locations are used.

Finally, the model has shown that using more iterations will result in better solutions for the scenarios. The difference between the initial solution and performing 10,000 improvement iterations lies between 6 and 7 hours per week and between 10,000 and 50,000 improvement iterations between 6 and 9 hours. There is a significantly difference in the total hours used by phlebotomists for driving the routes between none, 10,000 and 50,000 improvement iterations. Every hour that could be reduced from the objective function means an additional saving of €43.75. The current manual planning of routes is by no means the optimal solution, which means that automating and optimizing the routes will yield higher savings for DH.

Table 6.1 presents the most promising scenarios of the scenario analysis. Within scenario 10, 11 and 13 the samples of the other laboratories are picked-up on a daily basis, which results in a higher service level towards clients and patients of DH compared to the other scenarios. Within scenario 16, 17 and 19 the samples are picked-up on an interval basis, which yields higher savings (see last column, representing the additional savings compared to the current situation) compared to the other scenarios. Within each trio of scenarios, there is a difference in the set of hub locations. Larger savings can be achieved, when using three or four hubs instead of two hubs. However the additional savings are relatively small. The commissioning of the third and fourth hub would probably costs more than the additional savings.

Scenario	Delivery option	Microbiology/ Pathology pick-up locations	Frequency	Difference current situation (WEEK 6)	Difference current situation (WEEK 41)
10	DH, Raalte, Rijssen, Twello, Bathmen	With	Daily	€ 468.67	€ 476.00
11	DH, Raalte, Rijssen, Twello	With	Daily	€ 455.24	€ 453.84
13	DH, Raalte, Rijssen	With	Daily	€ 381.80	€ 383.03
16	DH, Raalte, Rijssen, Twello, Bathmen	With	Interval	€ 711.31	€ 670.40
17	DH, Raalte, Rijssen, Twello	With	Interval	€ 684.14	€ 628.75
19	DH, Raalte, Rijssen	With	Interval	€ 617.78	€ 585.98

Table 6.1: Most promising scenarios with 10,000 iterations

6.2. Recommendations

From the conclusions, based on service level, we recommend to use the hub-and-spoke delivery option with two hubs (Raalte and Rijssen) and include the pick-up locations of the other laboratories on a daily basis. The transport should be arranged by Dimence Group, due to the fact it outperforms phlebotomists based on costs. This scenario increases the service level towards the clients and patients of DH enormously, subsequently it reaches savings of approximately €380 per week. Larger savings can be achieved, when using four hubs instead of two hubs. However the additional savings are relatively small. To roll out and implement two additional hubs will probably cost more than the additional savings.

In order to maximize the profits, we recommend to use the hub-and-spoke delivery option with the same two hubs, but instead of including the pick-up locations on a daily basis, we propose to do this on an interval basis. The additional savings are €200 up to €235 per week.

Furthermore, for every scenario, we recommend to keep sending samples outside the catchment area to the hospital by means of the service of PostNL/Cycloon. It is abundantly clear that driving towards those locations will yield much higher costs than the transportation costs of PostNL/Cycloon.

6.3. Implementation

This section examines the practical issues related to the implementation. We start by the willingness to participate, followed by peaks of sample deliveries at the laboratories, software package, an alert from the general practitioner, and less freedom for phlebotomists.

Willingness to participate

The most important issue with implementing the proposed scenario is the willingness of the departments to participate in the project. There will be major changes but also small changes in the current logistical planning of the laboratories. The operational managers must be willing to implement these changes at their department. From previous projects, it is known that this can cause troubles.

Peaks at the laboratories

The hub-and-spoke model uses hub locations for the collection of samples from different service points. Since the samples of several service points are collected at one location, they are transported in one (large) batch towards the hospital. This is in contrast with the current situation were phlebotomists arrive in quick succession. Since there will be less arrivals and larger batches at the hospital, there will also be higher peaks of sample deliveries at the laboratories. The continuous demand of samples towards the laboratories will change in a more fluctuating pattern (with higher peaks).

Software package

A couple of years ago, the software package Intertour was purchased by the clinical chemistry department. This software package is an interactive planning system, but due to several complications this software package has never been operational. The purchase as well as the contractual maintenance of the software package has given food for thought. On the other hand, the routes as well as the number of routes are growing each year, and due to the yearly growth, manual planning takes longer every time. Avoiding the purchase of another software package is not an option. The manual planning should be replaced with an automated planning. However, due to the previous failure, things have to be sorted out carefully.

Sign from the general practitioner

In the current situation, patients and PostNL are two frequently used transportation modes. Whenever a sample is ready for transportation to DH, the logistical service of a patient or PostNL is used. However, in the proposed scenarios we added the pick-up locations of the microbiology and pathology in the network of the clinical chemistry. We excluded the logistical service of patients and PostNL, and the only useable logistical service is those of the phlebotomists. For these scenarios it is essential which locations for the microbiology and pathology have to be visited, i.e., which locations have samples that need to be collected. We therefore have to receive a sign from the GP that a sample is ready to be picked-up.

Less freedom for phlebotomists

Phlebotomists will get less freedom if the routes are pre-programmed. In the current situation, phlebotomists are free to plan their route, as long as they visit all the locations. In the new proposed scenarios, the routes are pre-programmed. Phlebotomist can resist herein.

6.4. Discussion

This section discusses our research. First, we did not incorporate time windows into the model. This means that every route started at 8:00 o'clock in the morning, i.e., every service point should start at 8:00 o'clock. Appendix A shows that most service points are open at 8:00 o'clock, but several service points are open at a later time. We assume that the differences are not of great importance for the outcome of the model due to the fact that many of the routes are finished far before twelve o'clock. This means that routes could start at 8:15 or 8:30 instead of 8:00 o'clock.

Second, in the model of the scenario analysis we had to retain the opening hours as well as the number of phlebotomists at a specific service point according to Appendix A and B. Another setting of opening hours and number of phlebotomists per service point may be beneficial, and may be an interesting option to investigate in a further research.

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Appendix A: Opening hours service points

Opening hours service points					
City	Monday	Tuesday	Wednesday	Thursday	Friday
Deventer: Gezondheidscentrum Jozef	08.00 - 12.30	08.00 - 12.30	08.00 - 12.30	08.00 - 12.30	08.00 - 12.30
Deventer: Gezondheidscentrum Borgele	08.00 - 08.30	08.00 - 08.30		08.00 - 08.30	08.00 - 08.30
Deventer: Woonzorgcentrum St. Jurriën				08.00 - 09.00	
Bathmen: Verzorgingshuis " 't Dijkhuis"	08.30 - 09.00	08.30 - 09.00	08.30 - 09.00	08.30 - 09.00	08.30 - 09.00
Colmschate: Medisch centrum	08.00 - 08.30	08.00 - 08.30	08.00 - 08.30	08.00 - 08.30	08.00 - 08.30
Diepenveen: Huize Sparrenheuvel	09.00 - 09.30		09.00 - 09.30		
Epse: Het Wansinkhof	08.30 - 08.45				
Gorssel: Den Oldenhof		08.00 - 09.30	08.00 - 09.30		08.00 - 09.30
Haarle: Multifunctioneel Centrum		08.30 - 08.45		08.30 - 08.45	
Harfsen: Ons Gebouw		08.30 - 09.00			
Heeten: Stevenskamp			08.30 - 09.00		
Holten: Medisch Centrum	08.15 - 09.15	08.15 - 09.15	08.15 - 09.15	08.15 - 09.15	08.15 - 09.15
Laren: Kulturhus 't Kruispunt		08.15 - 08.45	08.15 - 08.45		08.15 - 08.45
Markelo: Thuiszorg	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00
Nieuw Heeten: Timmermanshuis				10.30 - 10.45	
Oene: Kulturhus					10.00 - 10.30
Olst: Het Averbergen	08.00 - 08.30	08.00 - 08.30	8.00 - 08.30	08.00 - 08.30	08.00 - 08.30
Raalte:	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00
Raalte-Noord: Medisch Centrum	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00
Raalte: polikliniek Raalte	10.30 - 12.00	10.30 - 12.00	10.30 - 12.00	10.30 - 12.00	10.30 - 12.00
Rijssen: Buitenpoli DZ	08.00 - 11.00	08.00 - 11.00	08.00 - 11.00	08.00 - 11.00	08.00 - 11.00
Terwolde: Gezondheidscentrum		08.30 - 09.00			08.30 - 09.00
Twello: Medisch Centrum Twello	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00	08.00 - 10.00
Wesepe: Jeugdgebouw	08.30 - 09.00				
Deventer: Dimence Brinkgreven		8:00 - 11:00		8:00 - 11:00	
Zwolle: Dimence Zwolle	8:00 - 11:00	8:00 - 11:00	8:00 - 11:00	8:00 - 11:00	8:00 - 11:00
Almelo: Dimence Westerdok		8:00 - 11:00			8:00 - 11:00
Wilp: Zozijn Wilp	8:00 - 11:00		8:00 - 11:00		8:00 - 11:00

Appendix B: Number of phlebotomists per service point

	Number of phlebotomists per service point				
City	Monday	Tuesday	Wednesday	Thursday	Friday
Deventer: Gezondheidscentrum Jozef	3	3	3	3	3
Deventer: Gezondheidscentrum Borgele	1	1		1	1
Deventer: Woonzorgcentrum St. Jurriën				2	
Bathmen: Verzorgingshuis " 't Dijkhuis"	1	1	1	1	1
Colmschate: Medisch centrum	2	2	2	2	2
Diepenveen: Huize Sparrenheuvel	1		1		1
Epse: Het Wansinkhof	1				
Gorssel: Den Oldenhof		2	1		1
Haarle: Multifunctioneel Centrum		1		1	
Harfsen: Ons Gebouw		1			
Heeten: Stevenskamp			2		
Holten: Medisch Centrum	2	2	2	2	2
Laren: Kulturhus 't Kruispunt		1	1		1
Markelo: Thuiszorg	2	2	2	2	2
Nieuw Heeten: Timmermanshuis				1	
Oene: Kulturhus					1
Olst: Het Averbergen	2	1	2	1	1
Raalte: Hartkamp	1	1	1	1	1
Raalte-Noord: Medisch Centrum	1	1	1	1	1
Raalte: polikliniek Raalte	2	2	2	2	2
Rijssen: Buitenpoli DZ	2	1	1	1	1
Terwolde: Gezondheidscentrum		1			1
Twello: Medisch Centrum Twello	3	3	3	3	3
Wesepe: Jeugdgebouw	1				
Deventer: Dimence Brinkgreven		1		1	
Zwolle: Dimence Zwolle	1	1	1	1	1
Almelo: Dimence Westerdok		1			1
Wilp: Zozijn Wilp	1		1		1
Total:	**27**	**29**	**27**	**26**	**28**

Appendix C: Set of scenarios

Scenario	Delivery option	LMMI/PA	Frequency	Transport hub-DH
1	DH (point-to-point)	Without	-	-
2	DH (point-to-point)	With	Daily	-
3	DH (point-to-point)	With	Interval	-
4	DH, Raalte, Rijssen, Twello, Bathmen	Without	-	Phlebotomists
5	DH, Raalte, Rijssen, Twello	Without	-	Phlebotomists
6	DH, Raalte, Rijssen, Bathmen	Without	-	Phlebotomists
7	DH, Raalte, Rijssen	Without	-	Phlebotomists
8	DH, Raalte	Without	-	Phlebotomists
9	DH, Rijssen	Without	-	Phlebotomists
10	DH, Raalte, Rijssen, Twello, Bathmen	With	Daily	Phlebotomists
11	DH, Raalte, Rijssen, Twello	With	Daily	Phlebotomists
12	DH, Raalte, Rijssen, Bathmen	With	Daily	Phlebotomists
13	DH, Raalte, Rijssen	With	Daily	Phlebotomists
14	DH, Raalte	With	Daily	Phlebotomists
15	DH, Rijssen	With	Daily	Phlebotomists
16	DH, Raalte, Rijssen, Twello, Bathmen	With	Interval	Phlebotomists
17	DH, Raalte, Rijssen, Twello	With	Interval	Phlebotomists
18	DH, Raalte, Rijssen, Bathmen	With	Interval	Phlebotomists
19	DH, Raalte, Rijssen	With	Interval	Phlebotomists
20	DH, Raalte	With	Interval	Phlebotomists
21	DH, Rijssen	With	Interval	Phlebotomists
22	DH, Raalte, Rijssen, Twello, Bathmen	Without	-	Dimence group
23	DH, Raalte, Rijssen, Twello	Without	-	Dimence group
24	DH, Raalte, Rijssen, Bathmen	Without	-	Dimence group
25	DH, Raalte, Rijssen	Without	-	Dimence group
26	DH, Raalte	Without	-	Dimence group
27	DH, Rijssen	Without	-	Dimence group
28	DH, Raalte, Rijssen, Twello, Bathmen	With	Daily	Dimence group
29	DH, Raalte, Rijssen, Twello	With	Daily	Dimence group
30	DH, Raalte, Rijssen, Bathmen	With	Daily	Dimence group
31	DH, Raalte, Rijssen	With	Daily	Dimence group
32	DH, Raalte	With	Daily	Dimence group
33	DH, Rijssen	With	Daily	Dimence group
34	DH, Raalte, Rijssen, Twello, Bathmen	With	Interval	Dimence group
35	DH, Raalte, Rijssen, Twello	With	Interval	Dimence group
36	DH, Raalte, Rijssen, Bathmen	With	Interval	Dimence group
37	DH, Raalte, Rijssen	With	Interval	Dimence group
38	DH, Raalte	With	Interval	Dimence group
39	DH, Rijssen	With	Interval	Dimence group

Appendix D: Results week 6 and 41 with 10,000 iterations

Scenario	Delivery option	Microbiology/ Pathology pick-up locations	Frequency of visiting	Initial	Average 10,000 iterations	Improvement 10,000 iterations	Initial	Average 10,000 iterations	Improvement 10,000 iterations
				WEEK 6			WEEK 41		
1	Point-to-Point	Without		487,6	481,4	6,2	479,8	473,6	6,2
2	Point-to-Point	With	Daily	507,4	500,1	7,4	498,4	491,2	7,2
3	Point-to-Point	With	Interval	499,8	492,8	6,9	492,5	485,8	6,7
4	DH, Raalte, Rijssen, Twello, Bathmen	Without		464,7	458,8	5,9	456,7	450,8	5,9
5	DH, Raalte, Rijssen, Twello	Without		466,4	460,4	6,1	458,7	452,9	5,8
6	DH, Raalte, Rijssen, Bathmen	Without		467,1	460,5	6,6	459,0	453,2	5,8
7	DH, Raalte, Rijssen	Without		468,8	462,5	6,3	461,0	455,4	5,6
8	DH, Raalte	Without		477,2	471,2	5,9	469,6	463,5	6,1
9	DH, Rijssen	Without		478,1	471,5	6,5	469,9	463,9	6,0
10	DH, Raalte, Rijssen, Twello, Bathmen	With	Daily	484,6	477,3	7,3	475,7	469,4	6,3
11	DH, Raalte, Rijssen, Twello	With	Daily	486,2	478,5	7,7	477,5	470,8	6,7
12	DH, Raalte, Rijssen, Bathmen	With	Daily	486,8	479,3	7,5	477,9	471,4	6,5
13	DH, Raalte, Rijssen	With	Daily	488,4	481,1	7,3	479,7	473,3	6,4
14	DH, Raalte	With	Daily	497,0	489,7	7,3	488,1	481,5	6,6
15	DH, Rijssen	With	Daily	497,6	489,4	8,2	488,7	482,0	6,7
16	DH, Raalte, Rijssen, Twello, Bathmen	With	Interval	477,2	470,6	6,6	469,6	463,7	5,9
17	DH, Raalte, Rijssen, Twello	With	Interval	478,7	472,1	6,7	471,4	465,6	5,8
18	DH, Raalte, Rijssen, Bathmen	With	Interval	479,4	473,0	6,4	472,0	465,7	6,2
19	DH, Raalte, Rijssen	With	Interval	481,0	474,5	6,5	473,7	467,5	6,3
20	DH, Raalte	With	Interval	489,6	483,4	6,2	482,1	476,2	6,0
21	DH, Rijssen	With	Interval	489,9	483,6	6,4	482,8	476,6	6,2