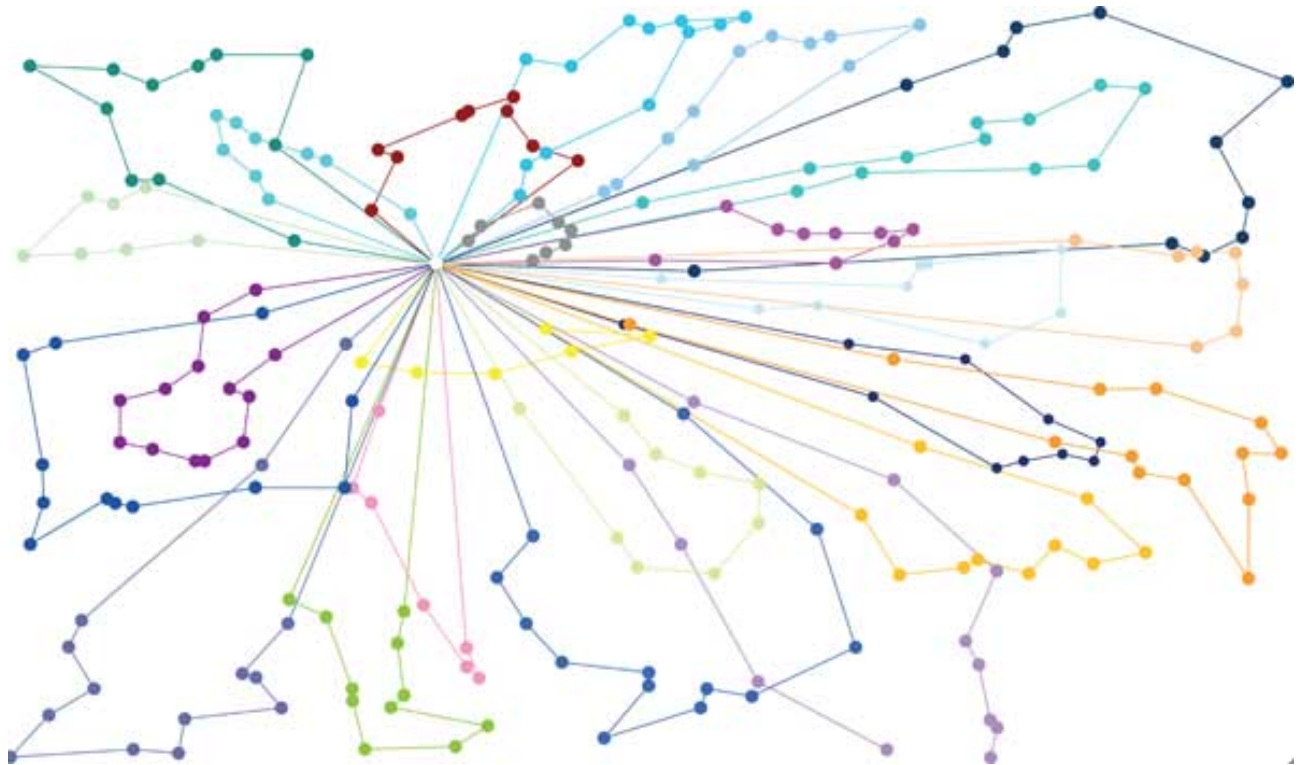


Master Thesis



- Vehicle routing problem applied for
demand controlled waste collection -

GRA 19003

**Master of Science in Business and Economics:
Logistics – Supply Chains and Networks**

Supervisor: Mehdi Sharifyazdi

Date of Submission
29.08.2014

BI Norwegian Business School, Oslo

Deadline
01.09.2014

“This thesis is a part of the MSc Program at BI Norwegian Business School.
The School takes no responsibility for the methods used, results found and conclusions drawn”

Acknowledgement

This thesis is a submission to BI Norwegian Business School and completes our MSc degree in Logistics – Supply Chains and Networks, and thereby rounds out our five-year long education. The process of writing this thesis has been challenging, however interesting. We have learned a lot and know to this day that this is an experience we would not be without.

We would like to thank Renovasjonsetaten and Sørumsdal, which provided us with some necessary data needed for this thesis and giving us this opportunity. We would also like to give a special thanks to the chauffeur who let us participate on a route, and provided us with a lot of interesting information needed to understand the complexity of the work.

The project has been very challenging and we would not have made it without the help of our supervisor Mehdi Sharifyazdi. His competence, guidance, time and insightful feedback have been a huge part of this thesis.

At the end we will like to thank our partners and family for good support and positive enthusiasm during the work with this Master Thesis.

Katrine Lunde

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Oslo, august 2014

Summary

The main purpose of this thesis is to look into the possible improvements by switching from fixed to demand controlled routes.

In cooperation with Renovasjonsetaten (REN) and Sørumsdal Transport we have looked into the collection process of glass and metal waste in the Oslo area. We have studied if there is a possible improvement in the concern of total driving distance and service level by switching from static to dynamic collection routes by investing in sensors in the containers.

We have based our methodology around management science and operations research. The developed models are based on the theory around Vehicle Routing Problem, and solution procedures as the Nearest Neighbor Algorithm and Clarke and Wright's Savings Algorithm. Simulation for a whole year has been performed in order to compare the two different methods.

The results show that there are possibilities to improve the collection of glass and metal waste by eliminating the driving to both empty and half full waste containers, and prioritizing the containers that are filled above 80% of their capacity. The results also show that by installing sensors it becomes easier to utilize the waste containers more and save time in the collection process.

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CHAPTER 1:

INTRODUCTION

1.0 Introduction

The first part of this master thesis defines the problem statement and main objective. In addition, it comprises an introduction of the case companies: Renovasjonsetaten and Sørums Transport. It finishes off by introducing the research objective and the importance of the topic.

1.1 Motivation

The motivation behind this thesis has been gradually built up during the two years studying for our master degree at BI Norwegian Business School. Our interest for problem solving and planning, organizing and administration of real life problems resulted in a Major in Logistics – Supply Chains and Networks. The major introduced us for many interesting courses, both quantitative and qualitative, and provided us with an extensive competence within all fields of logistics. However, the quantitative approach of logistics quickly caught our attention. This involved two of the mandatory courses, namely Operations 1 and 2. Therefore, as the time for deciding upon a topic for the master thesis arrived, there was no doubt. We wished to explore an optimization problem by using the quantitative tools we had developed through our major and see if we could apply these theoretical frameworks to a practical problem. On request by Renovasjonsetaten, we have therefore studied a reversed logistic optimization problem within the collection of glass and metal waste in the municipality of Oslo.

Furthermore, we had to choose a supervisor for our master thesis. As our thesis concerns an optimization problem, Mehdi Sharifyazdi was an obvious choice. We believed he could be an important resource in the process of writing our thesis. In addition to that, he has taken over as course leader for the two operations courses. We have continuously been prepared for the task at hand during the courses of our master study, and combined with the attained knowledge and good guidance we consider ourselves to be able of solving the objective of this thesis.

The thesis has been done in collaboration with two companies: Renovasjonsetaten (hereafter referred to as REN), and Sørums Transport (hereafter referred to as Sørums). REN is considering installation of sensors in the containers for glass and metal waste. The sensor shows how full the waste containers are at all times and

can help in deciding how often the containers have to be emptied. Thus, REN wants to look into the possible improvements by switching from fixed to demand controlled traffic routes. The purpose of the thesis is therefore to study the collection of glass and metal waste in the municipality of Oslo, with the overall goal to minimize the resulting driving distance, decrease frequency of visiting containers that are not full enough, and improve service level. Further, the purpose is to compare the results in the current situation and the case where sensors are installed. Appendix 1 illustrates the municipality of Oslo, which is the area where the collection of glass and metal waste are executed. The service level for each container is defined as the proportion of time where the capacity of the container is utilized below 80%. The service level for customers is defined as the proportion of time where the capacity of the container is utilized below 100%.

Fixed traffic routes will further be referred to as the static case and implies that the current routes are the same week after week, and are based on waste containers historical filling rates (how full the containers were when emptied). On the other hand, demand controlled routes will be referred to as the dynamic case, meaning that the routes are daily determined by information received from container sensors about how full they are every day. Both the static and dynamic method is elaborated in chapter 5.2 and 5.4.

In this way, as described above, the master thesis is a great challenge and opportunity to acquire more knowledge about intricate transportation models and route planning problems.

1.2 The Companies

1.2.1 Renovasjonsetaten

REN, which is the Agency of Waste Management in Oslo, governs the City of Oslo's waste disposal such as paper-, food-, plastic- and residual waste as well as glass and metal waste, and garden- and hazardous waste. REN is responsible for the collection and emptying of paper-, food-, plastic- and residual waste, in which together constitutes approximately 70% of household waste. This requires more than 7 million emptying's of collection devices per year. However, removal and transport of glass and metal waste is outsourced to private waste disposal companies on tenders from REN, which it has been since 1992. The residents

themselves provide for bringing approximately 30% of generated waste volume, such as glass- and metal packaging, from the households to different collection points and facilities for glass and metal waste. Private waste disposal companies empties the collection points and transport the waste to recycling stations (Renovasjonsetaten 2013).

The agency is headquartered at Haraldrud, and manages recycling stations, mini-recycling stations and garden centers in Oslo (Renovasjonsetaten 2013). The thesis has been done mainly in collaboration with the department responsible for the collection of glass and metal waste. REN is responsible for choosing the correct contractor to carry out the collection of glass and metal waste, and REN puts this task on tender every fourth year. The goal, as specified in the contract, is to collect at least 7-8000 tons of glass and metal waste and the level of waste in the containers shall never exceed 80%. Consequently, REN operates with 80% container utilization, meaning, as already mentioned, that the containers never shall exceed 80% of their capacities. Results from 2013 shows that 15% of the containers were emptied at 80% of their capacity, 25% were emptied at a higher level, while 60% were emptied before the containers had reached 80 % of their capacity (Renovasjonsetaten 2014). The service level is today approximately 85%. However, these results show that the utilization of the containers is not at an optimum in the current situation, and it therefore exist possible improvements to utilize the containers better.

1.2.2 Sørums Transport

Sørums was established in 1986 and currently owns 37 vehicles and accesses 6 hired vehicles. In 2013 they had a turnover on approximately 100 millions NOK and transported 500.000 tons of various products in total. Sørums is a transportation company specialized on transport of limestone into watercourses. Its most important areas of transportation are bulk transport, mass transportation and rental and sale of transportable silos. Today, Sørums is one of Norway's leading bulk carriers. Bulk transport is very environmental friendly and an efficient solution as the loading and unloading takes place in a closed system. It contributes to savings in logistics and in the usage, because other packaging is not required (Sørums-Transport 2014).

Sørum has been responsible for collecting glass and metal waste on tender for the municipality of Oslo since 2002. Sørum is responsible for providing vehicles in the execution of the collection process. In order to perform this quite important environmental job, Sørum uses two purpose-built crane- and hook trucks that continuously empty the waste containers. Figure 1 shows the vehicle used for collecting glass and metal waste.



Figure 1: Vehicle Used For Collection of Glass and Metal Waste

When the capacity of a vehicle is fully utilized it drives back to the depot at Østre Aker Vei 24C. The full container is changed to one that is empty before the driver continues on the route. Sometimes the drivers have two shifts, meaning that the vehicle drive to Syklus (Onsøy), which is the recycling station for glass and metal waste, and empties the containers before driving back to Oslo starting on a second shift (within the time window). In 2013, Sørum collected 8497,67 tons of glass and metal waste in the Oslo area. Table 1 shows total tons of glass and metal waste collected the last six years.

Year/Month	2008	2009	2010	2011	2012	2013	2014
January	709,78	706,24	641,05	689,36	811,22	978,38	916,54
February	590,97	451,74	491,38	559,40	643,12	587,76	654,36
March	488,66	552,18	687,98	682,58	636,26	642,08	669,44
April	538,88	586,18	577,94	583,82	625,84	717,92	842,88
May	544,60	489,44	587,78	716,04	756,49	839,60	
June	534,04	640,56	615,58	646,27	682,76	580,68	
July	455,84	538,84	528,33	522,16	584,50	675,04	
August	454,00	484,48	558,91	609,28	667,04	599,99	
September	539,20	552,60	582,60	628,78	559,50	677,00	
October	484,56	521,23	546,26	577,06	682,70	761,18	
November	567,20	595,68	645,92	713,30	755,22	649,10	
December	601,08	617,90	671,08	696,92	507,68	788,94	
Total:	6508,81	6737,07	7134,81	7624,97	7912,33	8497,67	3083,22

Table 1: Total Amount of Glass and Metal Waste Collected the Last Six Years (tons)

The table illustrates an increasing trend in the waste of glass and metal implicating the importance of an effective and efficient collection process.

1.3 IT Systems in REN

REN is considering a huge investment in sensors in order to acquire more control over and optimize the collection process. The sensors are connected to the program Swisslogix Integra, and the containers that have a sensor installed will show on the map in the program. If the containers are under 60% full the container has a green light. If it goes above 60% the light turns yellow. In cases where the containers are getting closer to 80% full the light switches to red and tells that it is necessary to empty the container immediately. Today only four containers are using sensors as a trial for the project. One is positioned outside the city center far up in the north of Oslo (Sørkedalsveien), while the other three is positioned in the city center around St. Hanshaugen.

WebDeb is a customer information and control system and serves as an ordering tool among the administration department, operations department and the customer square at REN, and external suppliers as well as monitoring of suppliers. WebDeb is an online map solution of all collection points at REN's homepage where the customers can look up their nearest collection point(s).

The IT system that communicates with the sensors must be capable to communicate with REN's and WebDeb, via web services. Consequently, the system has to fulfill the following needs:

- Notify given filling rate for a given sensor. The notification should as a minimum contain sensor ID and given filling rate.
- Notify when given collection containers are not emptied/cleared after a given number of hours, i.e. the filling rate goes from notification level back to zero.
- Display the location of all collection containers with given filling rate/service level in a map application in WebDeb.
- Produce data that are reliable and correct.
- Secure data so that they will not be lost.
- The system shall not be out of service more than 2 hours.

In accordance to this, the fleet management system shall be able to, based on the real time information received from sensors, set the optimal driving route for emptying.

1.4 Research Question

In order to structure and investigate the problem at hand, a research question has been developed. The primary focus is on the service level improvements and economical aspects associated with the transportation such as to minimize the driving distance of the collection process. However, it does not apply to the distance used on driving from depot to Syklus (Onsøy). We will only look into the driving distance covered in Oslo. Accordingly, the research question can be formulated as follows:

“How can installation of sensors improve service level and decrease driving distance of the collection process of glass and metal waste in Oslo?”

1.5 The Research Objective

The aim of this thesis is to develop a decision-making model for the collection process of glass and metal waste in both a static and dynamic case in the municipality of Oslo, and thereafter search for an optimal solution. To be able to optimize and formulate the model in the best possible way, initially previous theories and methods have been used as a basis. Afterwards simulations are performed. This makes it possible to compare the results of the static and dynamic method and look into differences in order to find good solutions and thereafter provide a recommendation for REN.

Literature regarding transportation and route optimization is fairly extensive, with a diversity of different fields of focus. However, it is always need for new studies of various models and systems of different angles verifying the applicability of present theory. Thus, it has not been studied an all-new field within transportation and route optimization, but rather how valuable and helpful present theory is.

The theory within the field of reverse logistics and route planning is adequate and several fields are of interest for this thesis. This thesis is built upon theory within two main fields: *Optimization* and *Simulation*. More precisely, it considers the optimization of a vehicle routing problem mainly assessing two solution techniques: Nearest Neighborhood Heuristics and Clarke and Wright Savings Algorithm. In the simulation a Discrete-Event Simulation is performed.

1.6 Importance of Topic

The results of this thesis are of interest for REN as they are considering installation of sensors in the waste containers and this thesis is a step further in the evaluation and decision-making process. However, the investment will not be implemented before 2016. The model in question is generated for a real life business case. It considers real time values of distance, demand and collection frequency associated with the collection process. Therefore, it is of interest for REN to see how the installation might impact on the collection process of glass and metal waste. REN's interest therefore might be seen as a reassurance of the importance of developing a model whit the conditions described above. The results might contribute to less travel distance and thereby less pollution, better service level and reduced costs for both REN and Sørum.

Nevertheless, the relevance for the transportation industry itself is rather restricted. Others might already have used the same basic theory and structure although it most likely differs in variables used and type of product or service. Consequently, this thesis can only serve as indicator and pin pointer. However, it might be more relevant for the waste collection industry as the data will be more similar.

1.7 Outline

The paper is organized as follow. The next chapter, chapter 2, gives a presentation of the industry and the current situation, as well as some of the main challenges REN faces. Chapter 3 presents the methodology used in this paper. Chapter 4 provide some important definitions, literature and models in which are relevant to answer the research question in this master thesis. Further, chapter 5 illustrates and explains how the two research methods, static and dynamic, have been developed; the techniques that have been used and the assumptions applied to develop this. Chapter 6 presents the results of the simulation in both the static and dynamic method, and also includes a comparison of the main results. In the end chapter 7 finishes off with recommendations for REN, further research, and final conclusion.

CHAPTER 2:

THE INDUSTRY

2.0 The Industry

This chapter provides a brief explanation of the industry and the current situation, and finishes off with a presentation of some of the main challenges they face.

2.1 The Industry and the Current Situation

According to Urban Ecology program 2011-2016 emissions regarding waste management in the municipality of Oslo shall be reduced by at least 80%. In addition, greenhouse gasses (GHG) due to transportation shall be reduced by at least 50% within 2030. The municipality of Oslo has a main goal to facilitate working in the city without the use of vehicles and urban spaces should be free of littering. Based on this, REN has the purpose and strategy to optimize the existing solutions by strengthening the current provision of services. Furthermore, its main goal for the material recycling is to recycle 50% of residual waste during 2014. The waste collection industry in general involves collection, reception, storing, processing, recycling and other handling of hazardous waste. The municipality of Oslo controls all of the collection processes of waste, thus there are no other actors in the market. As this thesis concerns only the collection of glass and metal waste, the situation of this will be explained further. The operations and process in which are included in the collection of glass and metal waste in Oslo are marked with a circle in appendix 2. In today's situation Sørsum is responsible for planning and mapping the collection routes. This is based on twelve years of knowledge. The routes are static, fixed and divided in geographical sections. Sørsum gets paid per tonnage glass and metal waste delivered at Syklus' facility. In addition, Sørsum gets paid for waiting time at the receiving facility.

As of January 2014 REN has deployed 1003 units in different sizes for the collection of glass and metal waste. This is illustrated in table 2. The units are deployed in public rooms and private properties as well as in housing associations. Some of the collection points are deployed with two units. Consequently, the collection volume varies from 800 liters to 8000 liters at the different collection points.

Liters	Collection Points	Units
4000	482	545
2500	20	22
1100	104	177
Private	182	188
Sum Large	788	932
800	63	71
Sum Small	63	71
Sum All	851	1003

Table 2: Number of Collection Units in Oslo

Emptying rate varies from once every four week, to one time every week. This implies that the emptying and collection volume varies in volume from 800 liters every four week, to 8000 liters every week at the different collection points. The units deployed in public rooms are cleaned one to three times per week.

REN has a goal to make sure that 90% of the population in Oslo should have less than 300 meters to nearest collection point (in linear distance). Surveys indicate that the availability is important for people in order to use the collection points. Therefore, REN has to make sure that the service is easily accessible. In order to establish new and retain existing collection points, they cannot cause littering and untidiness in peoples local environment. Unpredictably use of the collection points makes it difficult to constantly avoid that some of the collection points is not emptied in a timely fashion. Consequently, frequent emptying and tidying is not sufficient in order to avoid bottles outside the waste containers at the collection points.

The responsibility for bottles and littering around the waste containers varies between REN and the driver from Sørums. If the waste container is full the driver is responsible for cleaning up, which is time-consuming for the performance of the process. However, if it is bottles and littering around the waste container and the container is not completely full, REN is responsible for cleaning up. The driver from Sørums calls in to REN, which sends out a patrol that takes care of the tidying.

2.2 Main Challenges in the Current Situation

Although the collection process might seem to be simple and straightforward there are some main challenges that REN are facing. These challenges are inefficient and time-consuming.

2.2.1 Too Late Emptying

The consequence of too late emptying is bottles left outside the waste containers at the collection points. This attracts other littering and harms REN's reputation, complicates maintenance of established collection points and creates resistance against new deployments. REN do not have any opportunity or tools to help them prevent overflowing containers today, and is therefore dependent on the scheduled emptying rate to be sufficient. Nor does Sørum have any overview of the filling rate; it is based on historical data. Consequently, the collection points will not always be emptied in time.

2.2.2 Resource Use on Complaint Handling

REN receives a number of inquiries from the general public in which it is stated that a collection point is full and needs to be emptied. However, this is not always correct. Often waste have been placed outside the waste container even though it is not full, which results in wasted journeys for the carrier and emptying of half full containers. Due to the many cases of wasted journeys for the carriers, REN do control the waste containers before it is requisitioned for emptying or tidying if there is doubt about what the conditions applies. This process is resource- and cost intensive. REN uses proportionately a lot of resources on complaints from the crowd in order to avoid sending out the wrong operator to effectuate the complaint. However, not all of the complaints are being controlled, which implies that some of the complaints are sent to wrong operator. This again causes unnecessary motoring and time spent for REN and carrier.

2.2.3 Contract Supervision

REN has currently no control regarding when the waste containers are being emptied. According to contract with carrier (Sørum), demands have been made regarding utilization. The requirement states that every collection point should not be emptied no later than a utilization of 80%. However, the irregularly use of the many collection points makes it difficult for Sørum to fulfill this certain requirement. In addition, it is challenging to follow up the carrier, as REN is not

able to monitor all of the collection points at all time. REN is often dependent on feedback from the crowd, but then the damage has already occurred. REN has no overview of when the waste containers actually are emptied. Controls are performed by REN, but are otherwise dependent on the carrier's reports. This involves little control with actual emptying's and how much each of the collection points are used by the customers.

2.2.4 Route Planning

REN do not interfere in how the routes are conducted as long as the carrier fulfills its obligations in the contract. The route planning is not optimized, leading to an environmentally and cost-related expenditure.

2.2.5 Environmental and Cost Effective Services

For the carrier, it will entail increased costs and more driving, as he/she does not have an overview of the service level of each of the waste containers. According to reports from carrier, approximately 60% of the containers are emptied at a service level of 60% or lower and some of the points is visited unnecessary many times making the process more time-consuming. The carrier lacks a good aid to optimize the collection of glass and metal waste. This in turn implies a more expensive service for REN. Today's system makes it difficult for REN to assess other payment methods such as payment per emptying or combined variants.

This chapter presents the industry and some main challenges REN faces. The next chapter presents the methodology used in this thesis and looks into the data needed for the research at hand.

CHAPTER 3:

**RESEARCH
METHODOLOGY**

3.0 Research Methodology

This chapter presents the methodology for this thesis. It first explains some of the main approaches used in the thesis (optimization and simulation), then looks into research strategy and the research method before finishing off with an explanation of data collection and how to ensure quality.

The main area of this master thesis is focused on special part of logistics called Operations Research (O.R), also known as management science. Hillier and Hillier (2011)(p2) defines management science as “*the discipline that attempts to aid managerial decision making by applying a scientific approach to managerial problems that involve quantitative factors*”. Sokolowski and Banks (2012) distinguish between soft and hard O.R. “Soft O.R” considers qualitative data while “Hard O.R” focuses on quantitative data. “Hard O.R” include game theory, decision analysis, optimization, simulations and queuing theory as they are based on equations and use numbers within their processes. This thesis focuses on optimization and simulations. Optimization is a “*collection of analytical techniques that focus on the best way of doing something*” (Sokolowski and Banks 2012)(p.187). Simulation models on the other hand are descriptive models that enable the possibility to study the dynamic behavior of different systems, for instance a supply chain (Shapiro 2007).

A model is defined by Pidd (1999)(p.120) as “*an external and explicit representation of part of reality as seen by the people who wish to use that model to understand, to change, to manage, and to control that part of reality in some way or another*”. He further argues that skills in modeling is one of the key success factors in operations research and presents six principles of good modeling:

1. Model simple, think complicated
2. Be parsimonious; start small and add
3. Divide and conquer; avoid mega models
4. Use metaphors analogies and similarities
5. Do not fall in love with the data
6. Model building may feel like muddling through

3.1 Optimization

Biegler (2010) defines optimization in a mathematical context as maximizing or minimizing a function, where the function has a set of variables that are subject to a set of constraints. In other words, it is to find the best possible solution to a function describing system behavior, within the systems constraints. This task requires the following elements:

- 1) A set of defined variables that appear in the predictive model
- 2) An objective function that provides a scalar quantification performance measure that needs to be minimized or maximized.
- 3) A predictive model to describe the behavior of the system, and also to express the limitations or constraints of the system.

Bazaraa, Sherali et al. (2013) states that the main goal with assessing an optimization problem is to develop efficient computational schemes for solving the problem at hand. The idea of optimization is to find the combination of values for defined variables, which satisfies the constraints given by the predictive model and at the same time, maximizes or minimizes the objective function.

In this paper two models are developed to optimize the collection of glass and metal waste for a static case and a dynamic case with the purpose to minimize the driving distance and increase service level.

3.2 Simulation – An Operational Research Technique

Simulation is one of the most frequently used tools to observe how supply chains behave, emphasize its efficiency level and evaluate new management systems in a short time period. Furthermore, a simulation model has the advantage to provide estimates of the current systems effectiveness and efficiency, and assess how changes in various input parameters impact the final results in processes where it might be either too costly or impossible to obtain real-life observations (Bottani and Montanari 2009, Manuj, Mentzer et al. 2009).

Shapiro (2007) distinguishes between deterministic simulation models and stochastic simulation models. A deterministic simulation model describes a system's dynamic behavior assuming there are no random effects, while a stochastic simulation model describes the behavior when there are random effects

and the researcher has no control over the random component. There exist various versions within these two main fields of simulation. Appendix 3 illustrates the hierarchical classification. The variables in this thesis change immediately at separated points in time and are therefore characterized as a discrete-event simulation (Babulak and Wang 2008).

3.2.1 Discrete-Event Simulation

Discrete-event simulation is a computer-based decision-making tool, which quantify the real-life, imitates its dynamics on an event-by-event basis, and produces thorough performance reports (Babulak and Wang 2008). According to Sokolowski and Banks (2009) discrete-event simulation can be defined “*as the variation in a model caused by a chronological sequence of events acting on it*”. Events is considered as instant incidences, which might lead to variations or changes in the state of the system. Furthermore, the state of the system is, in this manner, known as the variables in which describes the current system in any given moment in time. These variables are called state variables. Both the static and dynamic methods are characterized by random variables because the demand for each waste container varies everyday. Consequently, the Discrete-Event Simulation is suitable as it changes the state variables at separate point in time as the event occurs irregularly (Sokolowski and Banks 2009).

In order to compare the two different routing systems, simulations of the static and dynamic method are performed. This makes it possible to provide REN with a potential solution as it enables a comparison and analysis of the results attained. Sokolowski and Banks (2009) present the concepts of a Discrete-Event simulation as follows:

1. First of all, it is necessary to define the state variables when one shall build a model of Discrete-Event Simulation
2. Secondly, the quantifiable system attributes at any given point in time is described by a state
3. Lastly, the state of system is altered by incidence of the event in which each is arranged for execution and executed at a specific time

3.3 Research Strategy

The meaning of a research strategy is to generalize and orientate the business research. Thereby getting a clearer picture and help to better organize the research methods and approaches to observe, collect, analyzing and deducing the data. Furthermore, the research strategy may be divided into quantitative and qualitative research. Quantitative research is often a wider examination and may be understood as data collection consisting of quantification and measurements, while qualitative research entail words and emphasis non-quantifying methods where it might be easier to observe a real situation rather than evaluating theory (Bryman and Bell 2011). However, the distinction between the two approaches is superficial, although important.

The research strategy in this thesis is mainly quantitative. Quantitative modeling has usually been the basis of solving real-life problems within operations management and optimization, and has been the foundation of most of the initial research in operations management (Bertrand and Fransoo 2002). Operations Management is defined by Bertrand and Fransoo (2002)(p.241) as “*the process of design, planning, controlling and executing operations in manufacturing and service industries*” This study is based on quantitative data related to the collection of glass and metal waste, such as capacity, capacity utilization and distance between collection facilities. The developed models are used to simulate different solutions for the research problem in question. Firstly, based on the average demand of the waste containers, a routing algorithm is designed for the static case. The algorithm is evaluated with regards to driving distance and service level by simulation where demand will be randomly generated. Secondly, for the case where sensors are installed, another algorithm is developed. Given the real-time data received from the sensors (about how full the containers are), the algorithm generates routes on a non-routine basis. This algorithm is evaluated as well by simulation with the same random demands generated for the first case. The total driving distance of the two algorithms is then compared and analyzed.

Even though the main strategic approach is quantitative also some qualitative research to complement the collected quantitative data is performed. The researchers were allowed to join a collection route, which provided them with the opportunity to have a non-formal interview with the chauffeur and also observe

how the collection process is carried out. This resulted in a lot of important information because the chauffeur has a lot of tacit knowledge and experience being the one who actually performs the tasks. Communication with delegates from both participating companies was also performed. Qualitative research could be helpful as a source to understand how one can use the quantitative data or apply the data in proper ways (Bryman and Bell 2011).

Adoption of the research strategy cannot alone generalize the business research, and along with the business research there are important decisions regarding research method to be taken into account.

3.4 Research Method

The structure and method for how this thesis have been performed is based on a framework presented by Mitroff, Betz et al. (1974) on how to embark on operational research based on quantitative modeling. This framework consist of four phases; conceptualization phase, modeling, model solving and implementation. The whole process is presented in figure 2. The three first stages explain the steps of the method used.

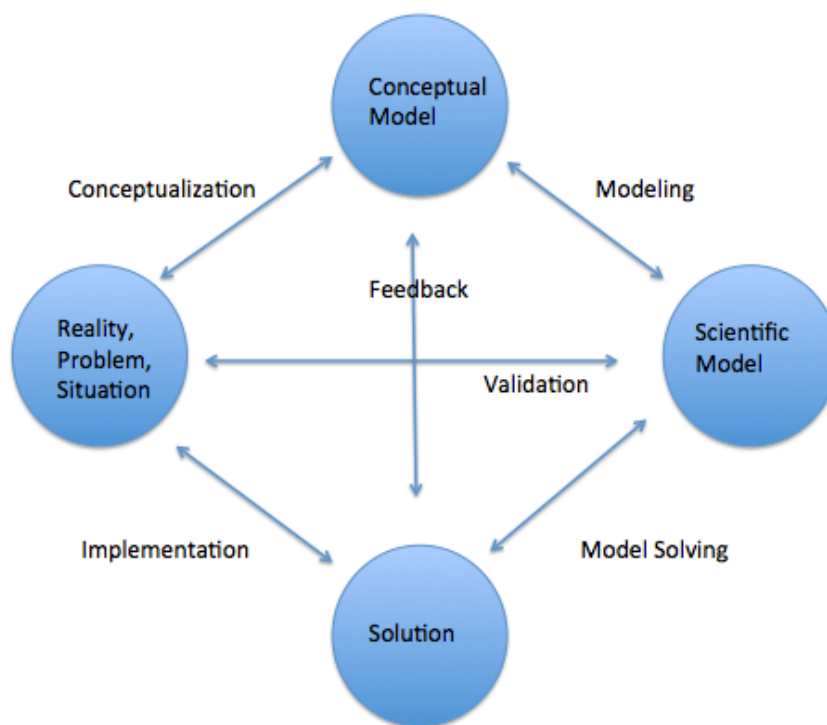


Figure 2: Research Method

In the conceptualization phase one makes a conceptual model of the problems that are being studied, and the researcher makes decisions about the variables included in the model. The scope of the problem and model to be addressed is also defined in this phase. This is related to the problem at hand as this is where existing theory and which variables to use are chosen and applied in the developed model.

Building the actual model and defining the relationship between the variables is done in the modeling phase. This is done in accordance with the conceptual model. Regarding this thesis, this is where the mathematical model has been developed based on the relevant theory and variables determined in the previous phase.

The model is then used to solve the problem in the model-solving phase, before the implementation phase begins. In order to solve the model in question, different techniques and a computer program called Matlab has been used. In this phase, applying heuristic techniques to find a solution to the current model and simulation is performed to be able to achieve results and compare them.

Given that the prior phase provides positive results that might be used in the current situation, this is conducted in the implementation phase. However, this phase has not been carried out in this thesis, as the project is not being executed before 2016.

In addition, the framework involves one horizontal and vertical axis. The horizontal axis displays the importance of validity, as it is vital to keep the gap between the model and reality as small as possible. The vertical axis is associated with feedback. To make the model as fit to the problem as possible, one must change and improve the conceptual model throughout the whole process (Mitroff, Betz et al. 1974).

Sokolowski and Banks (2012)(p.20) suggest “a *methodology to be used in the analysis of a system to observe its behavior, answer a research question or serve as proof of a hypothesis*”. It is a six-steps framework and consists of the following phases.

1. Developing the Research Question and Methodology
2. Research
3. Mapping Data
4. Selecting a Modeling Paradigm and Executing the Model
5. Responding to the Research Question
6. Model Validation

The two frameworks presented above serves as the basis for this master thesis.

3.5 Data Collection

Data is divided in primary and secondary data. Primary data are characterized by being collected and specifically tailored to answer a specific problem (Gripsrud, Silkoset et al. 2010). It can be obtained through communication with people, observing people and in document analysis. The advantage with primary data is that it is collected specifically for the problem at hand. However, it is both time- and labor intensive.

Secondary data is generally used when one wants to obtain information about a narrow topic, but also are in need of a lot of information. This type of data is good to use if it is difficult to obtain primary data. The hallmark of secondary data is that it is collected by others and often for another purpose. The use of the data is thus a secondary application (Gripsrud, Silkoset et al. 2010).

The actual data collection can be done in different ways. Crowther and Lancaster (2009) present these alternatives of how to collect data:

1. Secondary data collection
2. Case Studies
3. Experimentation
4. Observation
5. Interviews/surveys
6. Action Research
7. Randomly generation of data

Most of the data is provided by REN and Sørum, and thereby is considered to be secondary data. As already mentioned, this might have some drawbacks because the researchers themselves do not collect the data. The data might have been collected for another purpose, might not be up to date, too general or incorrect. However, the positive side is that one might save time and costs by collecting secondary data. Secondary data in the thesis consist of the address list containing all collection points and general documents concerning the contract and project. Primary data will mainly be the attained distances between each collection point, the distribution of the current routes and the waste containers filling rate as these are collected especially to answer the problem at hand. The filling rates in the simulation have been randomly generated, meaning that the filling rate is not the same for each simulation. It was impossible to obtain real data on how full the containers actually are each day when emptied. The researchers have only received historical data. Additionally, the researchers have collected data by attending and observing a route and by non-formal interview with the chauffeur. Input data is further explained in section 3.6.

3.6 Input Data

Real life data are important to collect to be able to formulate the models and carry out the simulations. Some of the most important are presented below. The data about containers are given from Renovasjonsetaten. This information includes a unique number for each container, and this number has been used to differentiate between containers and is set as the “containers name”.

3.6.1 Location and Distance

The location address of the waste containers is acquired as secondary data from REN, and is visual in the internal online system WebDeb. Coordinates are found in accordance with the addresses by using Google Maps. To be able to see which containers are directly linked without crossing any other collection point, “WebDeb” and Google Maps is used. To find the distance between the containers that is directly linked, Google Maps is used again. It has only been applied directly linked distances in order to find the shortest route and because of the different techniques used to solve the models. The solving techniques used in this thesis have the purpose to find a relatively good solution, not necessary an optimal solution, and therefore need the information regarding which waste containers that

are located nearest each other without crossing any other waste containers.

However, the distances will not be 100% correct as the waste containers most likely is not located at the exact same point that Google Maps has used as measure for distance. All addresses, as well as the corresponding coordinates and distances, are collected in an excel sheet and used as input for the developed model. The excel sheets can be found on the CD that follows this master thesis.

3.6.2 Utilization of Containers

One of the most important pieces of data collected in our study concerns the utilization of the waste containers. Historical data of how full containers have been when they are emptied are delivered from Sørsum to REN each month. After emptying each container, the driver registers the level of glass and metal waste of each container. If a container is emptied several times a month the average utilization is the given data. By collecting this historical data it is possible to calculate the average liter demanded and standard deviation per container each day.

3.6.3 Routes

The current routes used by Sørsum are not known. However, during the observation of a collection route the researches experience and got insight to how the routes are planned and executed. Consequently, the researchers have structured the current routes according to the information received from Sørsum. First of all, the routes are distributed geographically between two chauffeurs. Two chauffeurs are what Sørsum actually uses in real-life. Thus, the researchers divided Oslo into two geographical sections between the two drivers such that both are responsible for collecting glass and metal waste in each of the two sections. This is described in greater detail in chapter 5.2.1.2. Further, the chauffeur receives a list at the beginning of the week of all containers that must be visited and emptied in a specific geographical section during the week. Table 3 illustrates the route that was observed. As can be seen not all containers was emptied during the route because the filled level were below 10%.

Number	Address	Comment
0	Østre Aker Vei 18-24	Depot, started with 3/4 full container
320	Jorinesvei 10	
595	Ruths Vei 27	
594	Ruths Vei 4	
509	Nybrottveien 1	
297	Idas Vei 54	
704	Stovnerveien 54	
789	Johnny Svorkmosvei 54	
703	Stovnerlia 19	
140	Fossumberget 54	
702	Stovner Senter v/Varemottak	
142	Fossumveien 60	
0	Østre Aker Vei 18-24	Depot, changing full container
229	Haugenstua (Sigurd Astrupsvei)	This one was supposed to be emptied first
728	Tante Ulrikkes Vei 1	
729	Tante Ulrikkes Vei 42	
303	Jacobine Ryes Vei 14	
111	Ellen Gleditch Vei 14	
454	Martha Tynes Vei 2	
736	Tokerudberget 5	
791	Tokerudberget/Vestlisvingen	
300	Inga Bjørnsonsvei 76	Not emptied
792	Nico Hambros Vei 57	
793	Vestlisvingen 196	
790	Vestlisvingen 184	
434	Margrethe Parms Vei 1	Not emptied
329	Karen Platous Vei 31	Not emptied
141	Fossumveien 4	Not emptied
77	Bånkallstubben 1	
566	Ragnhild Schibbyes Vei 4	
196	Rosenbergveien 2	
324	Kalbakkveien 2	
403	Erich Mogensønsvei 38	
124	Erich Mogensønsvei 20	
404	Linderudveien	
900	Linderudsletta 1	Not emptied
650	Sletteløkka 5a	
599	Rødbergveien 76	
0	Østre Aker Vei 18-24	Depot, changing full container

Table 3: Route, Thursday 03.07.14

3.6.4 Schedules and Time window

For the time being there exist emptying every week, every second week and every fourth week. There exist a time window for when it is possible to collect the waste. It is only possible to collect Monday, Tuesday, Wednesday, Thursday, Friday and Saturday between 06.00 AM and 10.00 PM. Certain holidays are also excluded from the possible time window. This is specified in the contract from REN to Sørum. This thesis does not take holidays into account.

3.6.5 Capacity (Vehicle and Containers)

As mentioned before, Sørum has two vehicles that continuously empty the waste containers. The capacity of one vehicle container is 35m³. As both vehicles have the same capacity, there is a total capacity of 70m³. In periods when there is a lot of glass and metal waste to collect Sørum has a crane truck available to pick up two full containers to bring to Syklus (Onsøy) and empty them before bringing them back to the depot. However, seasonal fluctuation where the volume is much higher is not of concern in this thesis. This is further elaborated in chapter 7 under limitations.

The waste containers is as mentioned owned by REN and there are 1003 of them stationed around Oslo distributed between 851 collection points. Consequently, some of the collection points consist of two waste containers. The capacity of the containers varies from 800, 1100, 1500, 2500, 3000, 3500, 4000 to 5000 liters. Moreover, there exist two types of containers: glass modules and waste wells (figure 3 and 4). Both types of vehicles can collect all sorts of containers.



Figure 3: Example of a Glass Module Container



Figure 4: Example of a Waste Well Container

3.7 *Quality Ensuring*

The quality of the data is vital when doing research. It is therefore important to take into account validity, reliability and generalizability when data is collected.

3.7.1 *Validity*

In a quantitative research one are concerned with measurement validity. Validity can be defined as “*the degree to which a measure accurately represents what it is supposed to*” (Hair 2010)(p.7). Does the measures of the model really measure that model? Being able to understand what to measure and do the measuring as correct and accurate as possible is crucial in order to ensure validity of the data. Therefore, to make sure that driving distance and service level are measured accurately it is important to be careful with the information that is conducted as inputs.

As mentioned, most of the data is secondary and it might therefore be difficult to make sure if it is accurate. Though, the secondary data that is collected in this thesis (schedules and time windows, location address, vehicle and container capacity and utilization of waste containers) is obtained from the respective companies and is therefore considered to have a secured validity.

The collected primary data is also considered to have a fairly validity as it is developed for the problem in question and have the purpose to measure the models at hand. However, as the data might not be 100% accurate, the validity is impaired.

3.7.2 *Reliability*

Reliability is concerned with the question of whether the results of a study are repeatable, and can be defined as “*the degree to which the observed variable measure the “true” value and is “error free”*” (Hair 2010)(p.8).

The reliability regarding how the distances are collected and the routes distributed is weakened. This is because the variables are not measuring the “true” value and it might be some errors in the dataset. When it comes to the generated filling rate the reliability is poor. As the numbers are generated each day the numbers are different for each simulation and therefore is difficult to be replicated. However,

the filling rates will be documented thoroughly throughout the simulations, which enhances the reliability a little bit.

3.7.3 Generalizability

Generalizability refers to the extent of which the results from the data can be generalized to other situations. The methods developed in this thesis are difficult to standardize to transportation problems in general as some of the inputs (filling rate) is changing from day to day. However, it might be transferred to other waste collection problems, especially in major cities.

3.8 Data Analysis

The variables that will be collected from secondary- and primarily sources are pure numbers and can be directly put into the developed model. Further, the outcome of the simulations will be analyzed with the basis of comparing service level and total driving distance. The main task with regards to data analysis will be to compare the two different routes that are an option in order to identify the most efficient and effective of them. Thus, the parameters that have been analyzed in addition to total driving distance and service level are overcapacity, capacity utilization and container level.

This chapter presented the methodology used in the thesis and provided information about the data needed as input for the research. The next chapter looks into different theories that the thesis is built upon.

CHAPTER 4:

THEORY

4.0 Literature Review

All over the world case studies concerning the optimization of traffic routes served by a fleet of vehicles within waste collection has been conducted. However, no such research has been done in Norway. Optimization of waste collection is one of the most difficult operational problems faced by local authorities in any large city. This thesis is based on O.R. and mathematical techniques, studying the optimization of a real-world reverse logistics collection problem. This chapter provides an introduction of different theories that are used in this master thesis.

4.1 Reverse Logistics

Reverse logistics is an important topic all over the world, often seen in many different settings and meanings. It refers to taking back products for reuse, recovery and waste management. Usually one classifies reverse logistics in three categories: commercial returns (change of mind, unsold products), market driven product returns (leasing, product recalls) and waste handling (products at end-of-life) (Rogers and Tibben-Lembke 2001). Rogers and Tibben-Lembke (2001)(p.130) defines reverse logistics as: *“The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal”*. On the other hand, Fleischmann, Bloemhof-Ruwaard et al. (1997)(p.2) states that reverse logistics is considered as the *“logistic activities all the way from used products no longer required by the user to products again usable in a market (...) involves the physical transportation of used products from the end user back to a producer, thus distribution planning aspects. The next step is the transformation by the producer of the returned products into usable products again”*. This indicates that reverse logistics mainly consist of two aspects: collection process and reprocessing (Jahre 1995). Collection of glass and metal waste are activities associated with products at their end-of-life. This thesis therefor covers the category for waste handling and the processes involved. Figure 5 gives an illustration of how the reversed logistics channel appears in this thesis.

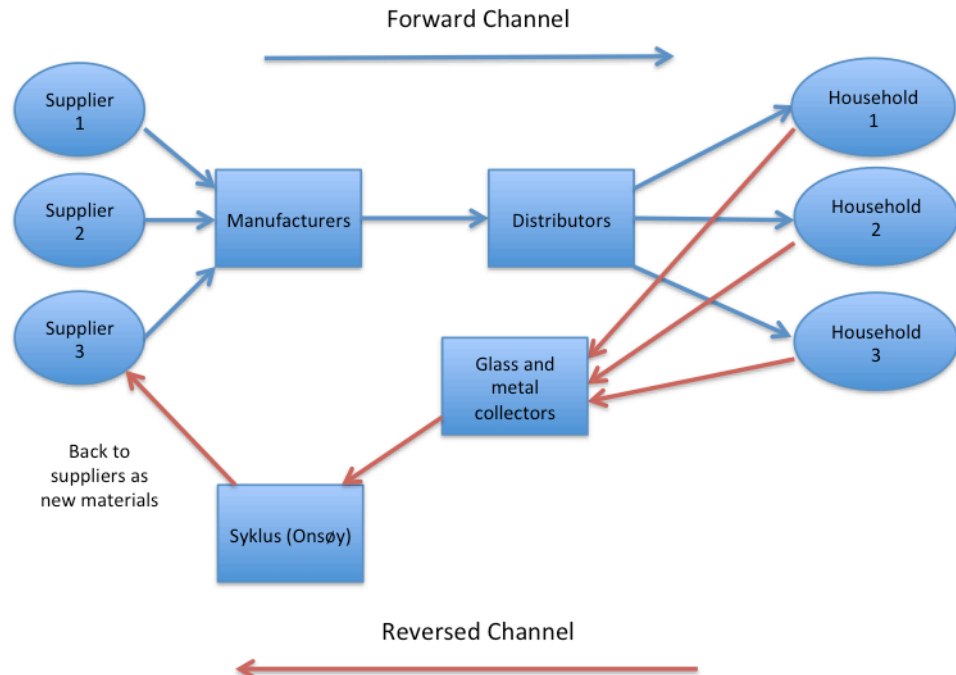


Figure 5: The Reverse Logistics Channel for Glass and Metal Waste Collection

Many researchers have studied optimization of the reverse logistics channel. Mourão and Almeida (2000) studies the collection of refuse in Lisbon and presents two lower-bounding methods and a heuristic method to solve a capacitated arc routing problem. Bommisetty (1998) addresses the issue of collecting recyclable material in a large university campus with many buildings. The objective in this study is to minimize collection distance. Álvarez-Valdés, Benavent et al. (1993) presents a computerized system for urban and suburban garbage collection as a solution of a specific routing problem. The model has the intention to function as a decision system and assist organizers when designing efficient collection routes. Furthermore, the challenge they meet is to construct the traffic routes for the vehicles while considering several constraints such as traffic regulations and personnel's working time due to minimize total driving distance.

In the reverse logistics of glass and metal waste, transportation plays an important part and is crucial to be able to obtain the best possible service level for the customers. Optimizing the transportation distance can reduce cost, increase service level and provide the most environmental alternative by reducing pollution due to less driving.

4.2 Vehicle Routing Problem

The vehicle routing problem (VRP) that was first presented as the “Truck Dispatching Problem” by Dantzig and Ramser (1959) has become one of the most extensively studied problems in combinatorial optimization, and it has a significant part in distribution management (Cordeau, Gendreau et al. 2002). The VRP is often used in problems concerning delivery or collection of goods and for real-world problems occurring in a transportation system such as solid waste collection, routing of salespeople and maintenance units, street cleaning among others. VRP concerns “*the transport between depots and customers by means of a fleet of vehicles*” (Rizzoli, Montemanni et al. 2007)(p.135). Rizzoli, Montemanni et al. (2007) states that VRP can be formulated as to find optimal routes for a fleet of vehicles that perform an assigned task on a number of spatially distributed customers. To solve the problem one must find the best route serving all customers using the fleet of vehicles, fulfill all operational constraints and minimize total driving distance. Toth and Vigo (2002) agrees and argues that a VRP solution contains a set of routes performed by a vehicle starting and ending at one depot, with the purpose to fulfill customer requirements, satisfy the operational constraints and minimize the distribution costs. Elements that could define and constraint each model of VRP are the *road network*, *the vehicles*, *drivers*, *depots* and *the customers* (Rizzoli, Montemanni et al. 2007). In more detail, each VRP can be characterized by location, demand, time (travel time, time windows and loading/unloading), home depot, capacity (vehicle: weight or volume it can load; containers: volume), compartments in the vehicles, collection containers, subset of arcs of the road graph, costs (vehicle: per distance unit, per time unit, per route), traffic, environment, uncertainty, season, working time/number of workers and fill rate. Many of these characteristics are found in this master thesis. Typically, VRP has the objective of minimizing (global) transportation costs (travelled distance or travel time, fixed costs associated with vehicles and the corresponding drivers), minimizing number of vehicles (or drivers), balancing of the routes (travel time and vehicle load), or minimizing penalties due to partial service (Toth and Vigo 2002). However, VRP is just a generic name on a whole class of problems concerning different aspects. Toth and Vigo (2002)(p.5-10) distinguish between:

-
1. Capacitated VRP (CVRP) is characterized by deterministic demand, which is known beforehand, and might not be split, and all customers correspond to deliveries. In addition, all vehicles are identical, based at one single central home depot and only the vehicle capacity is imposed as a constraint. The goal is to minimize total cost based on number of routes and their length or travel time in order to serve all customers.
 2. Distance-Constrained VRP (DCVRP) is concerned with a maximum length (or time) and vehicle capacity as constraint for each route. Here the objective is to minimize total length or duration of the routes, when service time is involved in travel time of the arcs, as well as to minimize total cost.
 3. VRP with Time Windows (VRPTW) is an expansion of CVRP where the capacity constraint still is imposed and each customer is in conjunction with a time interval. The goal with this version is to detect a collection of precisely K simple circuits with minimum costs such that:
 - a. The depot vertex is visited by each circuit
 - b. Each customer vertex is visited by exactly one circuit
 - c. Total demand of the vertices visited by one circuit do not exceed the vehicle capacity
 - d. The service starts within the time window (a_i, b_i) for each customer i and the vehicle stops for s_i time instants
 4. VRP with Backhauls (VRPB) extends the CVRP by splitting the customer set into two subsets. First subset contains n *Linehaul customer*, where each customer requires a given amount of product to be delivered. Second subset contains m *Backhaul customers* in which a given amount of inbound product must be retrieved. Anytime a route operates with both types of customer, all linehaul must be visited before backhaul customers. VRPB search to find a collection of precisely K simple circuits with minimum cost such that:
 - a. The depot vertex is visited by each circuit
 - b. Each customer vertex is visited by exactly one circuit
 - c. The sum of demand for linehaul and backhaul customers visited by a circuit do not separately exceed the vehicle capacity
 - d. All linehaul customers go in front of backhaul customers in each circuit
 5. VRP with Pickup and Delivery (VRPPD) describes a version where each customer i is related to two quantities d_i and p_i . This constitutes the demand of
-

homogenous commodities to be delivered and picked up at customer i . Also here the aim is to find a collection of precisely K simple circuits with minimum cost such that:

- a. The depot vertex is visited by each circuit
 - b. Each customer vertex is visited by exactly one circuit
 - c. As it is assumed that delivery is performed before pickup, current load of the vehicle along the circuit must be nonnegative and may never exceed the vehicle capacity
 - d. For each customer i , the customer O_i (the vertex origin of the delivery demand), when different from the depot, must be served in the same circuit and before customer i
 - e. For each customer i , the customer D_i (the vertex in which is the destination of the pickup demand), when different from the depot, must be served in the same circuit and before customer i
6. A last version is a combination between two or more of the mentioned VRP's. Appendix 4 illustrates how all the versions of VRP are interconnected and combined.

This thesis is based on a combination of VRP problem. It considers both capacity constraints and time windows.

The classical VRP is defined on a graph $G = (V, A)$, where $V = \{V_0, \dots, V_n\}$ is vertex set, and $A = \{(i, j): i, j \in N\}$ is an arc set. Usually vertex V_0 represents a depot, while the rest represents customers. Associated with A are usually a cost matrix (C_{ij}) and a travel time matrix (T_{ij}) . Each vertex (except the depot) has a non-negative demand q_i and a service time t_i . The classical VRP model assumes that all vehicles are identical and have the same capacity. The total capacity of the vehicles is Q (Cordeau, Gendreau et al. 2002). Cordeau, Gendreau et al. (2002) also presents five constraints to the classical VRP that also fits for this thesis:

1. Vehicles are identical and have the same capacity
2. Each route starts and ends at the depot
3. Each customer is visited exactly once by exactly one vehicle
4. The total demand of each route does not exceed Q

-
5. The total duration of each route (including travel and service times) does not exceed a present limit D
 6. The total routing cost (driving distance) is minimized

An example of a mathematical formulation for a VRP is presented below:

Indexes:

$$k = 1, \dots, K$$

$$i = 1, \dots, N$$

$$j = 1, \dots, N$$

Parameters:

c_{ij} = Travel Cost, travel time or travel distance

t_{ij} = Travel time between nodes i and j

q_i = demand at node i

Q = Total capacity vehicle

D = Total available duration time

K = Number of identical vehicles

Decision variable:

$$x_{ij}^k = \begin{cases} 1 & \text{If vehicle } k \text{ travels from node } i \text{ to } j, \text{ where } i, j \in \{1, 2, \dots, N\} | i \neq j, \text{ and } k \in \{1, 2, \dots, K\} \\ 0 & \text{Otherwise} \end{cases}$$

Minimize:

$$\min z = \sum_{i=0}^N \sum_{\substack{j=0 \\ j \neq 1}}^N \sum_{k=1}^K c_{ij} x_{ij}^k \quad (1)$$

Subject to:

$$\sum_{i=0}^N \sum_{k=1}^K x_{ij}^k = 1 \quad \forall j \in \{1, \dots, N\} \quad (2)$$

$$\sum_{j=0}^N \sum_{k=1}^K x_{ij}^k = 1 \quad \forall i \in \{1, \dots, N\} \quad (3)$$

$$\sum_{i=0}^N x_{ip}^k - \sum_{j=0}^N x_{pj}^k = 0 \quad \forall p \in \{1, \dots, N\}, k \in \{1, \dots, K\} \quad (4)$$

$$\sum_{j=0}^N q_j \left(\sum_{i=0}^N x_{ij}^k \right) \leq Q \quad \forall k \in \{1, \dots, K\} \quad (5)$$

$$\sum_{i=0}^N \sum_{j=0}^N t_{ij} x_{ij}^k \leq D \quad \forall k \in \{1, \dots, K\} \quad (6)$$

$$\sum_{j=1}^N x_{0j}^k \leq 1 \quad \forall k \in \{1, \dots, K\} \quad (7)$$

$$\sum_{i=1}^N x_{i0}^k \leq 1 \quad \forall k \in \{1, \dots, K\} \quad (8)$$

$$x_{ij}^k \in \{0,1\} \quad \forall i, j \in \{1, \dots, N\}, k \in \{1, \dots, K\} \quad (9)$$

- 1) This is the objective function, it minimizes total distance travelled, travel cost or travel time
- 2) Degree Constraint, each node must be visited exactly once
- 3) Degree Constraint, each node must be visited exactly once
- 4) Route Continuity, once a vehicle arrive a node, it must also leave that node
- 5) Service Customer demands cannot exceed vehicle capacity
- 6) Route length cannot exceed maximum route length
- 7) Each vehicle is scheduled no more than once
- 8) Each vehicle is scheduled no more than once
- 9) The decision variable is a binary variable

Many VRP studies have been conducted through out the world concerning the collection of household waste, both dynamic and static. Teixeira, Antunes et al. (2004) studied the route planning of vehicles for the collection of urban recyclable waste in Portugal. The objective of problem in their research is a PVRP. In Italy Ghiani, Guerriero et al. (2005) performed a study about waste collection in a small town. Their objective function was to minimize total distance travelled by vehicles. The main difficulties they had to tackle included small and narrow streets where only small vehicles could drive, a time window constraint to avoid traffic congestion and difficulties with some vehicles not being able to unload some of the containers. They modeled the problem as an arc routing problem and by using the well-known cluster-first, route-second approach they came up with a computerized system which allowed one to avoid overtime and to accomplish a reduction in total cost of about 8%. Real world applications of the problem include two important dimensions, evolution and quality. This is presented in table 4.

		Information Quality	
		<i>Deterministic input</i>	<i>Stochastic input</i>
Information Evolution	<i>Input known beforehand</i>	STATIC AND DETERMINISTIC	STATIC AND STOCHASTIC
	<i>Input changes over time</i>	DYNAMIC AND DETERMINISTIC	DYNAMIC AND STOCHASTIC

Table 4: Dimensions in Real World Application of the Vehicle Routing Problem

Pillac, Gendreau et al. (2013) distinguish between deterministic and stochastic input. The input can be different in different cases; in this master thesis the input is demand (which also is the most usual). Deterministic and stochastic vehicle routing problems differ from each other because there is an element of variability within the system in question in the stochastic version. There is also a difference between static and dynamic information, concerning whether the information is known beforehand or not. What characterizes the static and deterministic problem is that all input is known beforehand and the vehicle routes do not change once they are in execution. Static and stochastic problems on the other hand have input partially known as random variables, and they are not revealed until during the execution of the routes. Minor changes, such as driving back to depot or skipping a customer is allowed. In dynamic and deterministic problems all input is unknown and are only revealed during the design or execution of the routes. Due

to technological support, changes in the routes can be made. The last type of problem, dynamically and stochastic, is similar to the previous problem with part of the input unknown and revealed dynamically during the execution of the routes. However, with the deterministic category, exploitable stochastic knowledge is available in the dynamically revealed information. The routes is also changeable during the execution due to technological support (Pillac, Gendreau et al. 2013).

Wilson and Colvin were the first to study a dynamic vehicle routing problem. They studied a single vehicle DARP (dial-a-ride-problem, involving moving people between locations). Customer requests are trips from an origin to a destination that appear dynamically. Using insertion heuristics their approach are able to perform well with low computational effort. Psaraftis later presented the concept of immediate request. It can be explained as a customer requesting service always wanting to be served as fast as possible, which requires immediate re-planning of the present vehicle route (Pillac, Gendreau et al. 2013).

Johansson (2006) studies a case in Sweden where the recycling containers have been fitted with level sensors and wireless communication equipment. He looks into four different scheduling and routing policies (dynamic and static) and performs an empirical study on the downtown recycling station system in Malmoe. The conclusion in the paper is that dynamic scheduling and routing have lower operating cost, shorter collection and hauling distances, and reduced labor hours compared to a regular static case. A more recent study conducted by Rovetta, Xiumin et al. (2009) consider early detection and evaluation of waste through containers with sensors. The key of the system presented is for the stand-alone devices to gather data from inside each single waste container and use this information in tasks regarding organizing and planning. The most important result of the study was related to calculation of waste weight and volume. This thesis also focuses on the application of sensors in the waste containers, but looks into the effect on service level and total driving distance rather than calculations of waste weight and volume. Fleischmann, Gnutzmann et al. (2004) studies a dynamic vehicle routing based on online traffic information. They present a structure of the dynamic routing system and its environment. Moreover, the focus in this study is the dynamic travel time information requiring the dynamic shortest possible path calculations. Firstly, the study considers and explores the

performance of well-known deterministic algorithms in a dynamic planning situation. Secondly it postulates a framework for how to use online travel time information in planning algorithms such as a traffic management system.

4.3 Solution Methods for VRP

Solution procedures for the vehicle routing problem is often divided into two types, exact methods and heuristics/metaheuristics. The advantage of using an exact method is that it always gives the globally optimal solution, while the disadvantage is time inefficiency. Branch and Bound, Branch and Cut, Cutting planes algorithm and Brute-force search are the most well known exact methods. Heuristics and metaheuristics do not provide feasible solutions that are proved to be optimal in a global sense. Instead, in lesser time they provide good solutions. The minus side is that this gives the disadvantage of reaching a local optimum and stopping, not searching for a better solution. The plus side of using a heuristic or metaheuristic is that they can be applied to problems for which no other methods are known.

The most common heuristic methods are:

1. Ant colony optimization
2. Bees algorithm
3. Clarke and Wright savings heuristic
4. Fisher and Jaikumar heuristic
5. Genetic algorithms
6. GRASP
7. Hopfield net
8. Local search and Generalized local search
9. Nearest neighbor heuristic
10. Quantum annealing
11. Reactive search
12. Self-organizing map
13. Simulated annealing
14. Swarm intelligence
15. Sweep algorithm
16. Tabu search

According to Cordeau, Gendreau et al. (2002) the VRP is a hard combinatorial optimization problem, and very few can be solved to optimality. They argue, “*to this day, it seems that no exact algorithm is capable of solving instances in excess of 50 customers*” (Cordeau, Gendreau et al. 2002)(p.512). The reason for this is because the sharp lower bounds on the object value are hard to derive, which means that partial enumeration based exact algorithms will have a slow convergence rate. Because of this heuristics (or metaheuristics) are usually used in practice. VRP heuristics are usually measured against accuracy and speed. Cordeau, Gendreau et al. (2002) argues that simplicity and flexibility are also essential attributes of a good heuristic.

Accuracy means “*the degree of departure of a heuristic solution value from the original value*” (Cordeau, Gendreau et al. 2002)(p.513). The first issue concerning accuracy is the problem of rounding. Is it necessary to use all decimals or would the solution be only a little affected if it is rounded. Consistency is the second issue related to accuracy. The solvers want to have a heuristic that performs well at all time, not very well at one time and very poorly the rest of the time. One last issue concerning accuracy is that the researchers want an algorithm that produces a good solution at an early stage and then produces solutions of increasing quality throughout the execution compared to one final answer after a long computational time.

The importance of speed depends on the planning level at which a problem is solved, and on the required degree of accuracy.

Simplicity is the first extra attribute that Cordeau, Gendreau et al. (2002) presents in their paper. They argue that many VRP heuristics are not implemented because they include too many parameters and are too complicated to code. Not only the numbers of parameters is crucial but the parameters also have to make sense to the end-user. The last attribute that is added concerns flexibility. “*A good VRP heuristic should be flexible enough to accommodate the various side constraints encountered in a majority of real-life applications*” (Cordeau, Gendreau et al. 2002)(p.514).

4.3.1 Nearest Neighbor Heuristic

In the static case, the nearest neighbor algorithm has been used in order to optimize the routes. The nearest neighbor problem is one of the simplest ways of finding a good solution to a route and is also known as the “next best method” (Bandyopadhyay and Sajadi 2014). Interviews and observation shows that this is the way Sørum plans their current routes today, and the algorithm is chosen on the foundation of this. Bandyopadhyay and Sajadi (2014) defines the algorithm like this: “*Given a collection of data points and a query point in an m -dimensional metric space, find the data point that is closest to the query point*”. The algorithm starts at one of the vertex in the network and then always adds to the tour the nearest not yet visited vertex, and terminates when every vertex has been added.

Nuortio, Kytöjoki et al. (2006) performed a study about optimizing vehicle routes and schedules for collecting municipal solid waste in Eastern Finland. They describe what might be regarded as a Stochastic Periodic Vehicle Routing Problem with Time Window and limited number of vehicles (SPVRPTW). Further they propose an optimization model of how to design vehicles routes and schedules for collecting municipal solid waste in Finland by using a neighborhood metaheuristic variable. Hence, the objective of the study was to minimize the driving distance and plan the collection activities for each of the vehicles. The findings of the study demonstrate that it is possible to gain a cost reduction by using this method compared with the current practice.

4.3.2 Clarke and Wright's Savings Algorithm

Clarke and Wright (1964) present an algorithm for the solution of the classical vehicle routing problem based on a so-called savings concept. It merges two routes, and uses one vehicle rather than two. As an example picture two customers i and j . They have a distance c_{i0} and c_{0j} from the depot and c_{ij} from each other. If delivered separately the total distance is $2c_{i0} + 2c_{0j}$, but if they are merged into one route the total distance would be $c_{i0} + c_{0j} + c_{ij}$. There is a “saving” in mileage of $s_{ij} = c_{i0} + c_{0j} - c_{ij}$. The remaining customers are then placed on routes on which they can be linked until a constraint (capacity or maximum route length) is reached (Rand 2009). This is illustrated in figure 6.

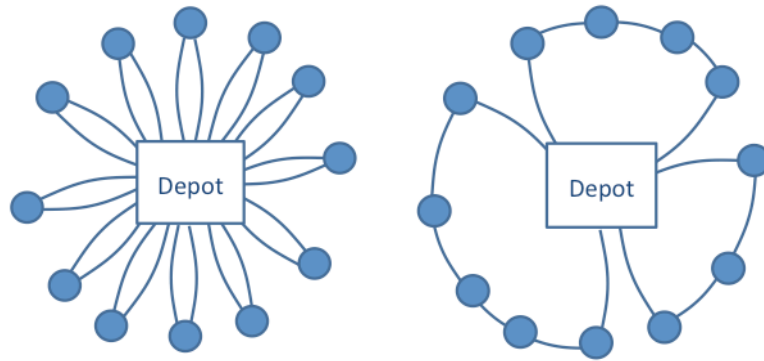


Figure 6: Illustration of the Clarke and Wright's Savings Algorithm

The savings algorithm is one of the best-known VRP heuristic, and is still widely used in practice to this day. This is mostly due to its speed, simplicity and ease of adjustment to handle various constraints in real-life applications (Doyuran and Çatay 2011). Extensive testing however shows that it is not the most accurate algorithm. Another negative side is that it is not very flexible, but it has the flexibility to be extended to a specific problem.

Several authors have proposed enhancements of the algorithm, and they may be formulated as adaptations to the savings formula usually made to speed up computation time and improvements in the route merging process. Doyuran and Çatay (2011) presents an overview of the recent developments of Clarke and Wright savings heuristics, but Cordeau, Gendreau et al. (2002) argues that given the present level of computer technology and the fast running time on medium instances the improvements are becoming irrelevant.

Cordeau, Gendreau et al. (2002) compare different classical heuristics for VRP and concludes that Clarke and Wright has the advantage of being very quick and easy to implement compared to the other alternatives. None of the classical heuristics however fares very well on accuracy and flexibility. A summary of the comparison is given in table 5.

Classical Heuristics	Accuracy	Speed	Simplicity	Flexibility
Clarke and Wright (CW)	Low	Very High	Very High	Low
Two-Matching based Methods	High	Very Low	Low	Low
Sweep	Low	Medium-High	High	Low
1-Petal	Low	High	Medium	Medium
2-Petal	Medium	Medium	Medium	Medium
Fisher and Jaikumar (FJ)	Difficult to assess	Medium	Low	Low
Location Based FJ	Medium	Low	Low	Low

Table 5: Assessment of some of the main VRP heuristics

The dynamic method will be based on Clarke and Wrights Savings Algorithm due to the speed and simplicity of running it. REN is not going to use the methods they just want to look into possible improvements. The algorithm has to be solved every day for 56 weeks during the simulation, and therefore the main criteria is that the algorithm has to be quick and easy to use.

Because of today's possibility of carrying out the vehicle routing dynamically, opportunities of reducing operational costs, improve customer service and reduce environmental impact arises. This thesis first looks into a static and stochastic vehicle routing problem, and afterwards investigates the possible improvements by using a dynamic schedule. In the static case the nearest neighbor heuristic will be used to solve the problem, while in the dynamic case the Clarke and Wright's savings algorithm will be used. In both cases a customized version of the algorithms are used. Afterwards simulations in each case is performed (at the same time, but independently) and compared.

CHAPTER 5:

**DEVELOPING THE
ROUTES AND
COLLECTING THE
WASTE**

5.0 Developing the Routes

In this chapter a description of the developed static and dynamic method will be presented. The methods have been constructed with much help from our supervisor Mehdi Sharifyazdi. The objective of both the methods is to minimize total driving distance for the trucks that collect the glass and metal waste and achieve the highest possible service level at this distance. Method 1 is based on the static case, while method 2 is focused on the dynamic case.

5.1 Floyd-Warshall Algorithm

Both Aini and Salehipour (2012) and Ridi, Torrini et al. (2012) argues that the Floyd-Warshall algorithm is one of the easiest and most widely used algorithms for finding the shortest path between every two node i and k in the network N . The Floyd-Warshall algorithm is therefore used to find the shortest path between every two glass and metal waste container in the Oslo area. The input is given as a matrix where the distance between all the containers that are directly linked is given. The output is two matrices where the first matrix shows the shortest distance between every pair of containers and the other the shortest routes (sources and sinks) between every two arbitrary nodes i and k . Even though the algorithm seems simple, it requires a lot of calculations. Given a network with n nodes, the algorithm requires the D_j and the R_j matrices to be calculated $n + 1$ times starting from D_0 and R_0 , where each has $n^2 - n$ entities (Aini and Salehipour 2012). The algorithm is described below.

Step 1

Set D_j and R_j as two square $n \times n$ matrices, where j is the stage number and n is the total number of nodes in the network.

Step 2

For $j = 0$ calculate D_0 and R_0 :

$D_0 = [d_{ik}]$, where

$$d_{ik} = \begin{cases} d_{ik} & \text{if there is a direct route connecting node } i \text{ to the node } k \\ \infty & \text{if there is no direct route connecting the node } i \text{ to the node } k \\ 0 & \text{if } i = k \end{cases}$$

Step 3

For the remaining $j = 1, \dots, n$ calculate the D_j and the R_j matrices as follows.

Note that from now on we derive the entities of the D_j and the R_j matrices on the basis of the entities of the most recent previous matrices, i.e. the D_{j-1} and the R_{j-1} matrices:

$D_j = [d_{ik}]$ where

$$d_{ik} = \begin{cases} d_{ik} & \text{if } i = k, i = j, k = j \\ \min(d_{ik}, d_{ij} + d_{jk}) & \text{otherwise} \end{cases}$$

$R_j = [r_{ik}]$ where

$$r_{ik} = \begin{cases} k & \text{if } i = k, i = j, k = j \\ k & \text{if } d_{ik} \leq d_{ij} + d_{jk} \\ j & \text{if } d_{ik} > d_{ij} + d_{jk} \end{cases}$$

Step 4

Repeat step 3 until the D_n and R_n are yielded

The shortest distances given from the Floyd-Warshall Algorithm is given as input to both the static and the dynamic simulation model.

5.2 Method 1 – The Static Case

In the static case fixed routes are generated. Firstly, the waste containers are assigned to weeks when to be emptied based on a four-week period. This is based on collected data from Sørum. As mentioned before, the waste containers are being emptied in intervals of every week, every second and every fourth weeks. A container assigned to week two that is emptied every second week, is also assigned to week four. Secondly, after assigning the containers to weeks the weeks are split on the two chauffeurs based on geographical sections. These geographical sections are made based on information given by the chauffeur, and this is how it is done in real life. Chauffeur one mainly drives outside the city center, while chauffeur two mainly drives, due to experience, in the city center. The streets are narrower and smaller in the city center than outside in the more open areas. Thirdly, when the containers have been assigned to both of the

chauffeurs, the nearest neighbor heuristic calculates the shortest route for each chauffeur. As mentioned these routes are fixed, and runs for a four-week period. After four weeks the drives starts from the beginning again.

After the routes are made, the chauffeur will start from the beginning of the list and empties every container filled above a 10% level. It takes approximately five minutes to empty one container; this includes checking if the container is above a 10% level and the actual emptying. If the container is not above a 10% level it is not emptied and the time set to check the level of the container is 1,5 minutes. This information is based on real-life experience from the route that was observed. The chauffeur continues until the working hour is up. Every time the container on the vehicle is full during the route (the chauffeur decides that himself based on knowledge and history of filling rate at the next container on the route) he drives back to the depot and changes the container. If the container is not full at the end of the day, he still drives back to the depot and parks the vehicle. The chauffeur will then, on the next day, start with the first container on the list where he stopped yesterday and continue filling the same container on the vehicle that he used the day before. This continues everyday until the list is finished at the end of the week. If there exist containers that are fuller than the capacity of an empty vehicle the chauffeur drives back and forth between the container and the depot until the container is emptied. In cases where there is no more time at the end of the week to finish the route the chauffeur works overtime so that the whole route is finished when he ends the day.

5.2.1 Assumptions

Some assumptions have been made when developing the static routes. They are listed below:

- Travel time is proportional to travel distance
- Congestion does not have any effect on travel time
- Average filling rate are constant during the whole year
- Demand is based on normal distribution

5.2.2 Inputs For the Static Method

Data gathered from REN and Sørsum is used as the necessary input for the model. In accordance to this it has also been made some assumptions. As stated previously, it was not possible to retrieve the current routes that are used today and the researchers had to make their own routes based on the information and assumptions given earlier. This proved to be quite complex and time-consuming. Some of the inputs and data are already discussed under *Input Data* in the *Methodology* chapter. The inputs described here are elaboration and additions to those already mentioned

5.2.2.1 Frequency of Emptying

In addition to the time window (06.00 AM and 10.00 PM), the frequency of how often the containers have to be emptied is given from Sørsum. The week intervals, when to empty, is based on information from 2013 about how often and which week the different containers were emptied. Containers not established yet in 2013 have been assumed to be emptied the same week as the already established collection points located closely, and at a four-week frequency. This is procedure for all new containers.

5.2.2.2 Geographical Sections

The preparation for the routes and allocation of the two geographical sections between the two chauffeurs are distributed it in the following way (this is also illustrated in appendix 5).

Geographical section 1 is distributed to chauffeur 1 in the city center and consist of the following main areas: Stovner, Romsås, Ammerud, Veitvet, Furuset, Høybråten, Ellingsrud, Kalbakken, Bredtvet, Linderud, Gamlebyen, Vålerenga, Kampen, Grønland, Tøyen, Carl Berner, Hasle, Hovin, Ulven, Teisen, Økern, Risløkka, Årvoll, Bjerke, Sinsen, Skøyen, Bygdøy, Frogner, Majorstua, Fagerborg, Torshov, Ila and Grünerløkka.

Geographical section 2 is distributed to chauffeur 2 at the city limits and consist of the following main areas: Etterstad, Manglerud, Ryen, Lambertseter, Nordstrand, Prinsdal, Holmlia, Ljan, Ekeberg, Simensbråten, Voksenåsen, Holmenkollen, Røa, Ullern, Ris, Kjelsås, Grefsen, Sogn, Brekke, Korsvoll, Nordberg, Storo,

Nydalen, Sandaker, Ullevål, Blindern, Vinderen, Bjølsen, Sagene, Skullerud, Bogerud, Bøler, Ulsrud, Oppsal, Trasop, Hellerud, Haugerud and Lindeberg.

5.2.2.3 Location and Distance

The location of and distances between each container is already explained through the Floyd Warshall Algorithm presented in chapter 5.1.

5.3. Routes for the Static Method

The weekly routes for the static model are illustrated in figure 7 and 8. By plotting the coordinates of the containers in Google Earth an illustration is provided. Each week is distributed over a period of six days in accordance with the geographical sections described above, meaning that the chauffeur divides each of the weeks presented below in smaller sections. Furthermore, the routes have not only been distributed based on the containers geographical location, but also in accordance to when the container is required to be emptied. For example, some of the waste containers at Stovner are emptied every week, while others are emptied every second week. Consequently, the chauffeur visits the same geographical area several times during the period of four weeks. The yellow arrow in each of the routes represents the depot, Østre Aker Vei 24C, while the turquoise line represents the distance between the containers (this is not accurate and roads have not been taken into consideration). The pictures are just illustrations of the routes, they are not accurate with how they actually are executed.

5.3.1 Chauffeur 1

Chauffeur one mainly drives in the city center. These routes are distributed on the six available days of the week, meaning that the whole route is not carried out on only one day. Figure 7 illustrates the whole route for week 1 containing all the addresses and places visited during this certain week. For an illustration of week 2-4 with the corresponding list of locations see appendix 7-9.



Figure 7: Route for Chauffeur 1 in Week 1

Corresponding container locations are presented in appendix 6.

5.3.2 *Chauffeur 2*

These routes represent mainly waste containers located outside the city center.

Also here, figure 8 illustrates chauffeur 2's whole route for week 1. For an illustration and overview of week 2-4 and the address list see appendix 11-13.

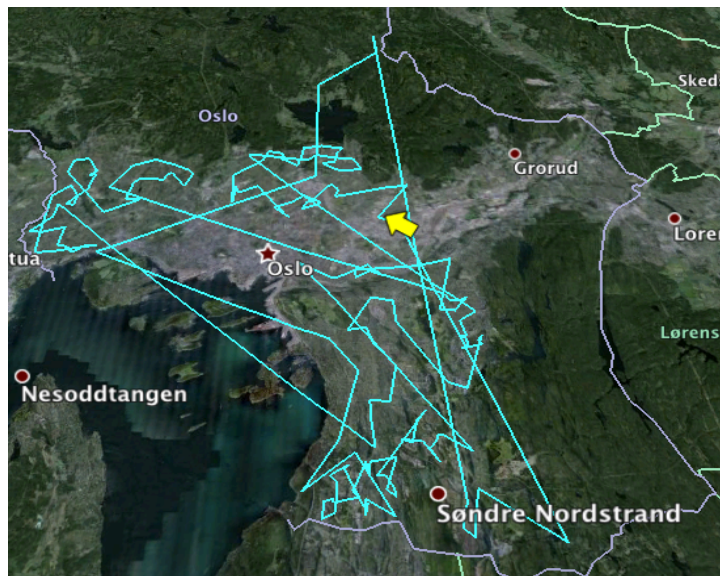


Figure 8: Route for Chauffeur 2 in Week 1

Corresponding container locations are presented in appendix 10.

5.4 *Method 2 – The Dynamic Case*

The routes in the dynamic model is generated daily. It is, as already mentioned, based on the Clarke and Wright Algorithm. Every day the sensor sends updated information about how full the containers are to REN/Sørums. In the initial solution all containers above a certain level (80%) are then assigned to a list. The routing scheduling is then solved by the Clarke and Wright algorithm, meaning

that the biggest saving potential is assigned to each route based on the capacity of the vehicle. When the routes are made the average utilization level of the containers is the basis of which route is executed first. The route with the highest average utilization gets the priority of collection. If containers assigned to a certain day are not emptied the day in question they get transferred to a new route the next day, with a new level. Consequently, the routes are not fixed as they may vary from day to day due to utilization level and capacity of waste containers and the vehicles. In other words, the routes in this model are based on real time data received from the sensors installed in the containers. The Floyd Warshall algorithm is the basis for the distances between all of the containers and thereby the foundations in what order the waste containers are visited combined with the information from the sensors.

The routes are assigned to the chauffeurs in a way that the first route is given to chauffeur 1, while the second route is given to chauffeur 2, the third route are again given to chauffeur 1, and so on. If chauffeur 1 does not have enough capacity (i.e. time) to finish a route it is assigned to chauffeur 2. If chauffeur 2 does not have enough capacity either the route is put away and are assigned to the next day. This route would probably have a higher level of waste the next day, and are therefore provided with higher priority.

5.4.1 Assumptions

Some assumptions have been made when developing the dynamic routes. They are listed below:

- Travel time is proportional to travel distance
- Congestion does not have any effect on travel time
- Average filling rate are constant during the whole year
- Demand is based on normal distribution
- If there are more than one container at a single point the containers have the equivalent capacity of the containers and the filled level is measured accordingly. This means that if there is two containers with 4000L capacity at a single point the total capacity is 8000L. The containers are emptied when the total filled level is above the given parameter (minimum

level of emptying). This could result in one container being full, but not being empty because the level of the second one is too low.

5.4.2 Inputs for the Dynamic Method

This part describes all inputs and assumptions made when formulating the model for the dynamic case.

5.4.2.1 Sensor Information

The sensors send information about how full they are every morning, and then the routes are generated. This information can be compared to the containers demand. This is the variable input when generating the routes.

5.4.2.2 Distance between Containers

Distance between containers is used to minimize the total driving distance. The distance is given in meters.

5.4.2.3 Vehicle Capacity

The capacity of the vehicle is used when assigning containers to a route. One route cannot exceed the capacity of the vehicle. This provides problems when making the routes due to utilization of the vehicle. Some routes may only fill the vehicle 50%. As an example, consider that the vehicle has 100% spare capacity and three routes have been made based on the Clarke and Wright algorithm. One route consists of three waste containers with utilization on 20%, 20% and 30% (=70%, as a percentage of the vehicle capacity not the waste containers capacity). The second route consists of three containers with utilization on 25%, 30% and 30% (=85%). A third route consists of waste containers on 10%, 10% and 20%. In order to fully utilize the capacity of the vehicle the first route with a total of 70% could have assigned two of the containers on route three to the route, however the algorithm does not take this into account. This is a limitation of the algorithm.

5.4.2.4 Waste Container Capacity

The capacity of the containers is necessary to be able to calculate how many containers the vehicle can collect in one route. Based on the information from the sensor, the algorithm can calculate how full the containers are in liters and add it to the vehicle that are collecting it.

5.4.2.5 Minimum Level of Emptying

The minimum level of emptying must be set to be able to decide the containers that go on the list every morning. REN wants to operate with no containers above 80% level, and the minimum level is therefore set to 80%. This parameter will be later referred to as container percentage.

The next chapter provides the simulation of the two methods, and presents results and a comparison between the two methods. A sensitivity analysis is performed before a conclusion is drawn.

CHAPTER 6:

**THE SIMULATION
MODEL**

6.0 The Simulation Model

This chapter presents the simulation of the static and dynamic methods presented in chapter 5. To run the simulation the program Matlab has been used. A short description of the program is found in chapter 6.1. Further this chapter presents the objectives of the simulation, and the constants and constraints included. Afterwards results are presented and discussed, a sensitivity analysis is performed and in the end results based on container level is analyzed.

6.1 Programming environment

The algorithm used in this thesis is based on the Nearest Neighbor Algorithm and the Clarke and Wright Algorithm. Both the static and dynamic model, as well as the simulation is coded in Matlab version 2014A. Our supervisor Mehdi Sharifyazdi helped in the development of the simulation algorithm. The algorithm code for Matlab is found on the CD that follows this thesis.

“MATLAB® is a high-level language and interactive environment for numerical computation, visualization, and programming” ((MATLAB 2014).

Matlab is a tool that can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions provides the opportunity to explore multiple approaches and find a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java™ (MATLAB 2014).

6.2 Modeling Background

In the simulation model daily amount of waste is produced. The simulation is then run in both the static and dynamic method, independently but at the same time. Afterwards the results are compared. The simulation is based on some constants that are described in chapter 5.2.2. The daily amount of waste is produced through random number generation and these are based on the average daily filled level of each container and the standard deviation. The random numbers are generated with Matlabs Standard Random Number Generator Engine.

The daily levels of the containers that are generated in the simulation are as mentioned based on calculations of average demand per day (per container) and

standard deviation per container. Using the received historical data about capacity utilization from 2013 and 2014 these averages and standard deviations have been calculated. The historical data is provided on a monthly basis and some of the months includes a four week period, while others includes a five week period as presented in table 6.

The number of weeks per month has been taken into account when calculating the average and standard deviation. The frequency of emptying per month has also been taken into consideration. To calculate the average daily demand the monthly demand is divided on

Month	Number of Weeks
January-13	5
February-13	4
March-13	4
April-13	5
May-13	4
June-13	4
July-13	5
August-13	4
September-13	5
October-13	4
November-13	4
December-13	4
January-14	5
February-14	4
March-14	4
April-14	5
May-14	4
June-14	4

every day in the respective month. This is because the data only presents an average

capacity utilization per month. In the cases where utilization does not exist it is assumed that the chauffeur have driven to container and not emptied it because it was below a filled level of 10%. The total average is then calculated by adding every day together and divided by number of days. The standard deviation is also calculated based on the monthly historical data. First the monthly variance for the months that include four weeks is calculated. This is then divided by 28 days to get the daily variance. The standard deviation per day is then calculated by taking the square root of the daily variance and dividing it by the square root of 28. The same method is used with the months that include five weeks. The number divided by is then 35. To calculate the daily standard deviation in total for each container the following formula has been used:

$$S = ((28 \times Sx4) + (35 \times Sx5)) / (28+35),$$

where Sx4 is the daily standard deviation for the four-week months, while Sx5 is the daily standard deviation for the five-week months.

Table 6: Number of Weeks Each Month

6.2.1 The Evaluation Measures in the Simulation

In order to compare the two different methods some indices needs to be measured in the simulation. They are presented below.

- What is total driving distance in the static method?
- What is total driving distance in the dynamic method?
- What is the service level in the static method?
- What is the service level in the dynamic method?
- What is the difference in total driving distance between the static and the dynamic method?
- How many containers are above 80% full when they are emptied?
- What is the average capacity utilization of the containers in the static method?
- What is the average capacity utilization of the containers in the dynamic method?
- What is the average capacity utilization of the vehicle in the dynamic method?

6.2.2 The Constants

In order to achieve the objectives described above, the following constants from table 7 are provided as input to the model. The constants are further explained below.

#	Constant	Parameter
1	Number of Simulations	1
2	Warm up Period (weeks)	4
3	Number of Weeks	56
4	Number of Weekdays	6
5	Working Hours per Day	8
6	Number of Container Locations	851
7	Vehicles's Capacity (Litres)	35000
8	Container Minimum Level to Be Emptied in Static Method	10%
9	Container Minimum Level to Be Emptied in Dynamic Method	80%
10	Vehicle's Speed (km/h)	17
11	Container Emptying Time (min)	5
12	Container Checking Time Below 10% (min)	1,5
13	Service Level Base	80%
14	Coefficient for Rectangular Distances According to Coordinates	100000
15	Coefficient for Estimation of Urban Distance Based on Rectangular Distances	2

Table 7: Input to Simulation Model

-
1. One simulation is performed.
 2. The warm up period is set to 4 weeks. This is because the first week the simulation is performed gives long-term effects on the service level and distance. The warm up period is therefore set to four weeks so that all the containers are at least emptied ones.
 3. The whole simulation consists of 56 weeks, although the result is only based on 52 weeks (because of warm up weeks).
 4. The number of weekdays to use for emptying is set to six. This is Monday until Saturday given from the data collected.
 5. A chauffeur can work eight hours per day. This is based on the Norwegian Working Environment Act.
 6. Number of container locations is 851, however the number of containers are different due to two containers in the same location some places.
 7. The vehicles capacity is 35m^3 .
 8. The containers in the static method are not emptied if the level is lower than 10%.
 9. In the initial simulation the minimum level to be emptied in the dynamic method is set to 80%.
 10. The vehicle drives with an average speed of 17 km/h. This is actual data recorded in the trucks.
 11. It takes approximately five minutes to empty one container; this includes checking if the container is above a 10% level and the actual emptying.
 12. If the container is not above a 10% level it is not emptied and the time set to check the level of the container is 1,5 minutes based on real-life experience from the route we observed.
 13. Service Level Base is set to 80% because REN does not want the utilization of the containers to exceed 80%.
 14. If there does not exist any shortest path between two containers (from the Floyd Warshall Algorithm) the distance between these containers are calculated as the absolute value of the difference between the x-coordinates plus the absolute value of the difference between the y-coordinates. These absolute values are then multiplied by 100 000 to give a distance in meters.
 15. To be able to not use the rectangular distance function the number retrieved from the calculations in point 14 is multiplied with 2 to get a higher distance.

6.3 Results

The result from the simulation is presented in table 8.

Output	Results
Total Driving Distance in Static Method (km)	66876
Total Driving Distance in Dynamic Method (km)	58924
Difference Between Driving Distance	-8,2%
Capacity Utilization of Containers in Static Method	31,0 %
Capacity Utilization of Containers in Dynamic Method	39,4 %
Average Vehicle Capacity Utilization in Dynamic Method	84,5 %
Overcapacity in Static Method	1,7 %
Overcapacity in Dynamic Method	0,0 %
Service Level in Static Method	97,1 %
Service Level in Dynamic Method	99,1 %

Table 8: Result from simulation

The result shows that total driving distance in the static method is 66 876 km compared to a total driving distance in the dynamic method, which is 58 924 km. This gives a difference of minus 8.2%, which is a significant decline in driving distance. This is illustrated in figure 9.

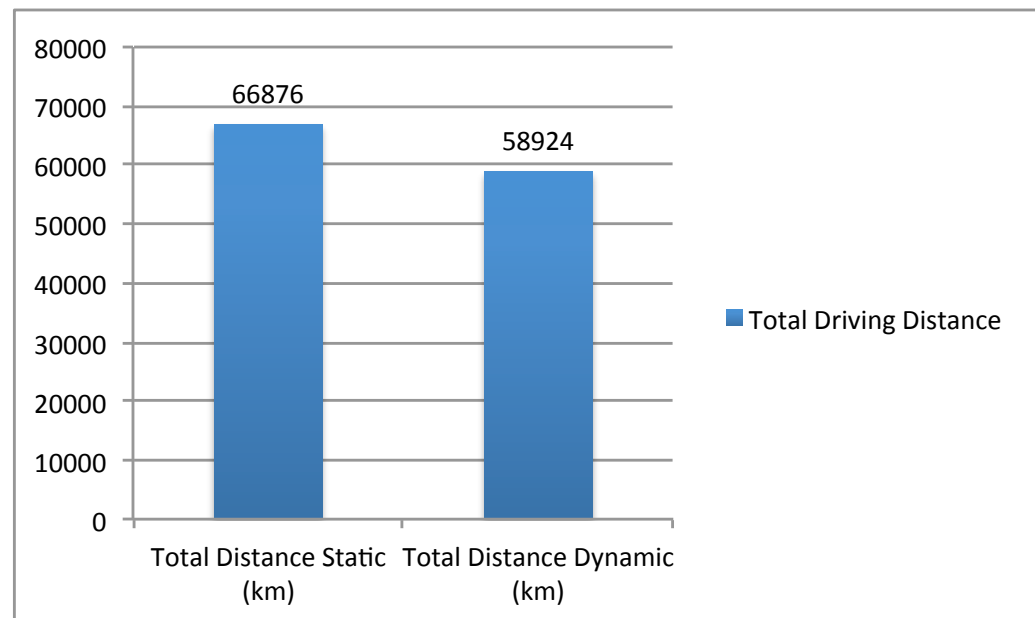


Figure 9: Comparison of Total Driving Distance

The service level is based on how many days out of total the containers are below an 80% level when they are emptied. Figure 10 illustrates the results on service level from both the static and dynamic method. In the static model the service

level is 97.1% while it in the dynamic model is 99.1%. The difference here is not immense, but again the dynamic method provides a slightly better result. This is expected and probably due to the fact that all containers at a minimum of 80% level appear on the daily lists of emptying and are prioritized.

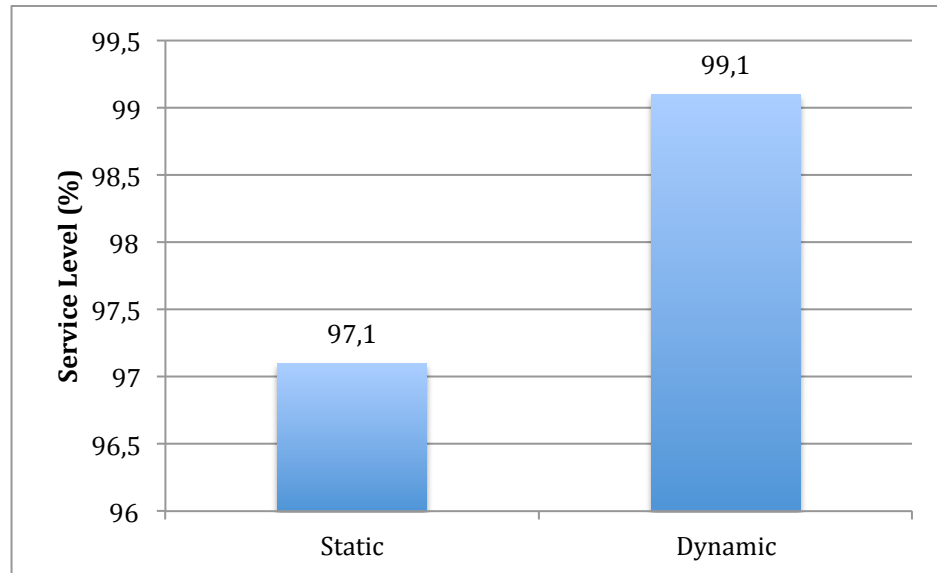


Figure 10: Comparison of Service Level

A better parameter and result for calculating and analyzing service level is the output “overcapacity”. This result shows us how often the containers exceeds a 100% level, meaning how often the containers are full and REN most probably receives complaints. In 1.7% of the cases there is overcapacity in the static method, while this never happens in the dynamic method (results shows 0%). This was also expected beforehand because the containers are emptied at an 80% level, and there is still a buffer of 20% that gives time to empty before the container gets full. In the dynamic method there is a 100% customer service level meaning that there are no days where the containers are fuller than 100%, while in the static method the customer service level is 98,3%. This is shown in figure 11.

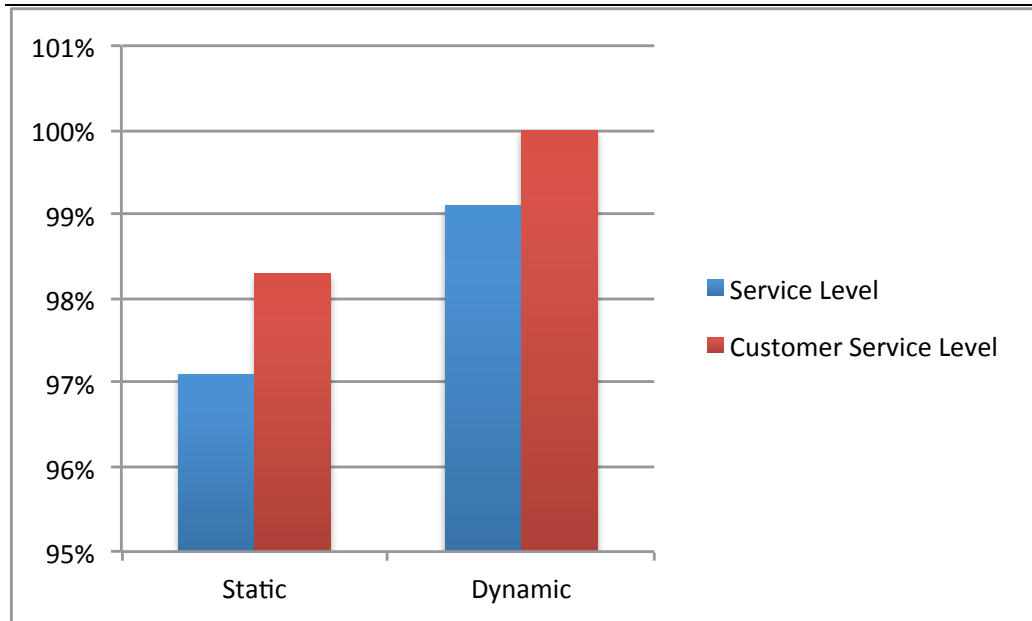


Figure 11: Comparison of Service Level and Customer Service Level

Looking at average capacity utilization of the containers (shown in figure 12) one can see that the difference is not that big with 31% in the static case and 39.4% in the dynamic. This result illustrates how full the containers are on average at the end of each day.

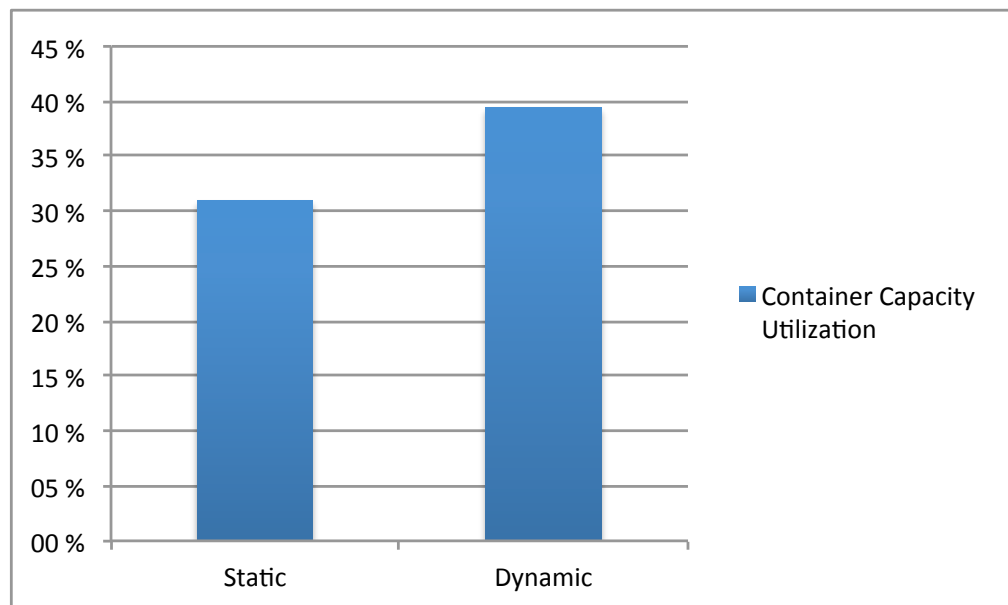


Figure 12: Comparison of Container Capacity Utilization

The average capacity utilization of the vehicle in the dynamic method is 84.5%. This was expected to be a bit lower due to the limitation in the Clarke and Wright algorithm mentioned before. In the static method we assume that capacity

utilization of the vehicle is approximately 100% (this is because the chauffeur continues on his route until the vehicle container is full).

The results show that the dynamic method is the best solution for the collection process of glass and metal waste with both shorter driving distance and higher service level. The only aspect where the static method is slightly better than the dynamic method is in the concern of vehicle capacity utilization.

6.4 Sensitivity Analysis

The parameter for how full the containers must be in order to be emptied in the dynamic method must be determined in advance before the simulation start. The parameter will be referred to as container percentage. The container percentage impacts the result significantly. A sensitivity analysis has been conducted in order to observe if total driving distance and service level are sensitive to changes in the container percentage of the containers. The sensitivity analysis consist of nine different scenarios, changed only by the minimum level of how full the containers have to be in the dynamic method in order to be emptied. The static results are therefore almost equal in each scenario. The container percentage is changed from 60% until 100% with a five percent interval. The result from the sensitivity analysis is given in table 9.

Container Percentage	60%	65%	70%	75%	80%	85%	90%	95%	100%
Total Driving Distance in Static Method (km)	66968	66702	66782	66607	66876	66841	66783	66872	66730
Total Driving Distance in Dynamic Method (km)	63993	62593	61714	59967	58924	58023	56510	55687	54628
Difference Between Driving Distance	-4,4 %	-5,6 %	-6,5 %	-7,4 %	-8,2 %	-9,1 %	-9,9 %	-10,8 %	-11,6 %
Capacity Utilization of Containers in Static Method	30,7 %	31,0 %	30,6 %	30,7 %	31,0 %	30,8 %	30,5 %	30,9 %	31,6 %
Capacity Utilization of Containers in Dynamic Method	29,7 %	32,0 %	34,4 %	36,8 %	39,4 %	41,9 %	44,4 %	46,9 %	49,5 %
Average Vehicle Capacity Utilization in Dynamic Method	84,8 %	85,1 %	84,9 %	85,3 %	84,5 %	84,6 %	84,7 %	84,0 %	84,3 %
Overcapacity in Static Method	1,5 %	1,6 %	1,6 %	1,6 %	1,7 %	1,7 %	1,5 %	1,7 %	1,7 %
Overcapacity in Dynamic Method	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,1 %	0,2 %	0,7 %
Service Level in Static Method	97,3 %	97,2 %	97,2 %	97,2 %	97,1 %	97,2 %	97,3 %	97,1 %	97,1 %
Service Level in Dynamic Method	100,0 %	100,0 %	99,9 %	99,8 %	99,1 %	93,4 %	88,4 %	84,0 %	79,6 %

Table 9: Sensitivity Analysis

As shown in the table the dynamic method has a higher service level than the static method in all of the cases where the container percentage is set lower than 80%. When the container percentage is set above 80% the service level in the dynamic method declines fast from 99,1% when the container percentage is set to

80%, to 79.6% when the container percentage is set to 100%. This is illustrated in figure 13.

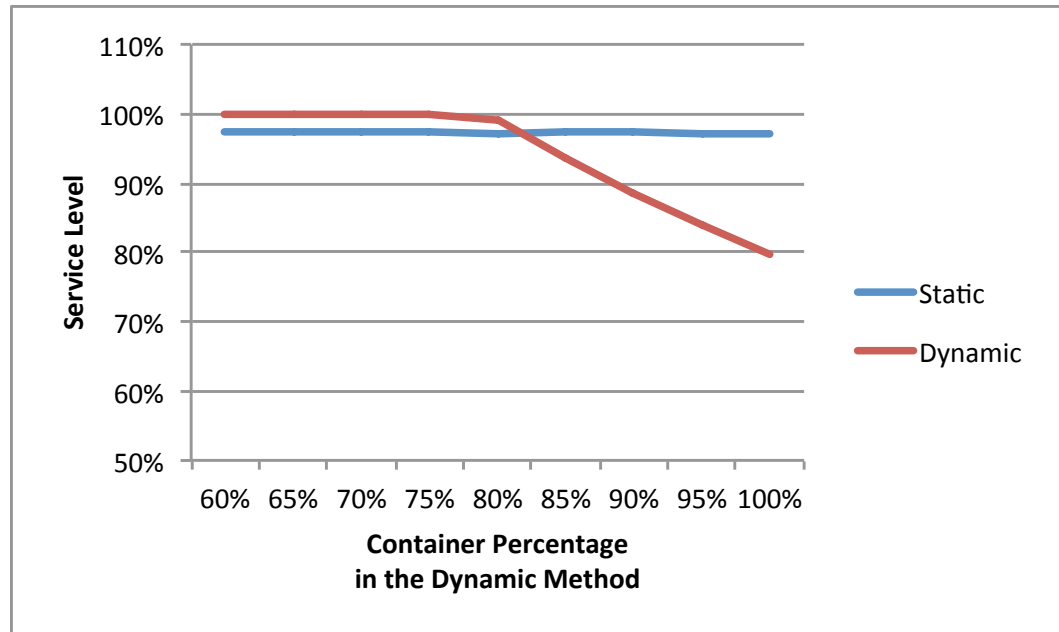


Figure 13: Sensitivity Analysis on Service Level

When the container percentage is set between 60% and 80% the best results concerning service level in the dynamic method is given, a higher percentage provides an even poorer result than the static method. This was expected because the service level for each container is defined as the proportion of time where the capacity of the container is utilized below 80%.

Looking into the customer service level shown in figure 14 we see that overcapacity increases in the dynamic method the higher the container percentage is set. This is expected because the containers are emptied at a much fuller level the higher the parameter is set. A container percentage is set between 60% and 85% provides almost the same result in this analysis, while above 85% the result decline. However, when looking at the customer service level the dynamic method has a better service level then the static method in all of different container percentages.

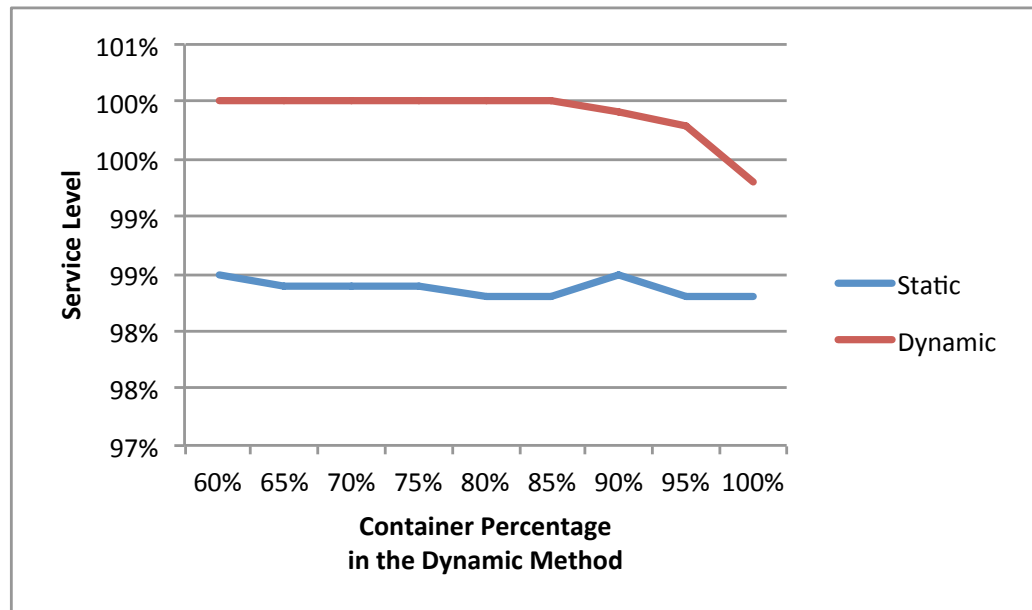


Figure 14: Sensitivity Analysis on Customer Service Level

The total driving distance is on average 8% higher in the static method compared to the dynamic method. The difference varies from 4,4% till 11,6%. Figure 15 shows that the total driving distance decreases significantly with the different container percentages. The higher the container percentage is sat, the lower the total driving distance get. When the container percentage is set to 100% the best result concerning driving distance for the dynamic method is given.

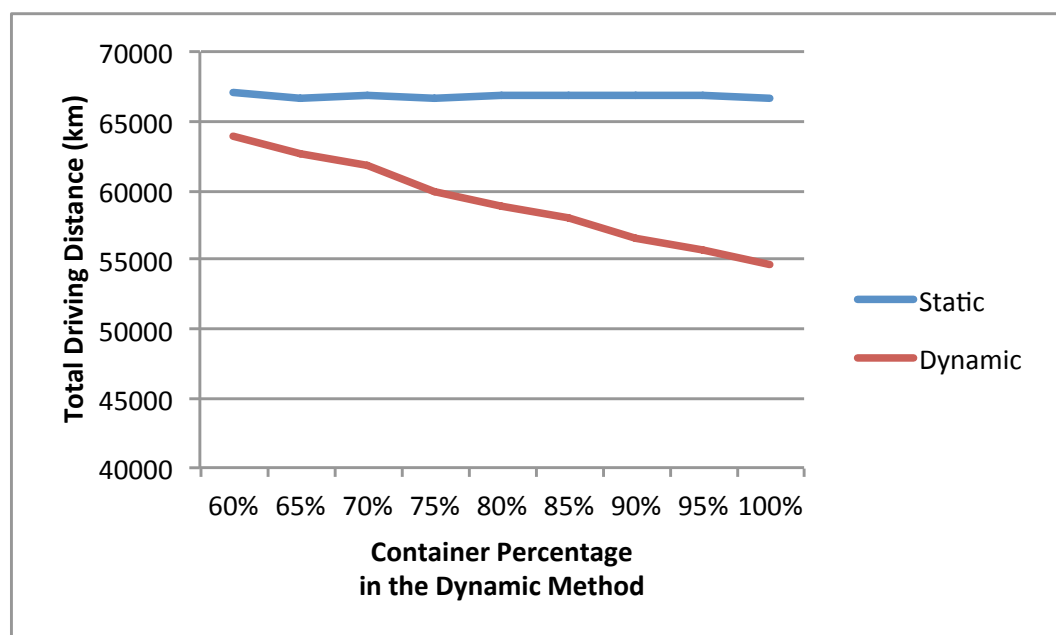


Figure 15: Sensitivity Analysis on Total Driving Distance

Capacity utilization of the containers increases in the dynamic method the higher the container percentage is sat. This is expected due to the fact the containers have a higher level before it is emptied. When the container percentage is set to 100% the dynamic method results in approximately 50% utilization on average, which is a 60% improvement from the static method (figure 16).

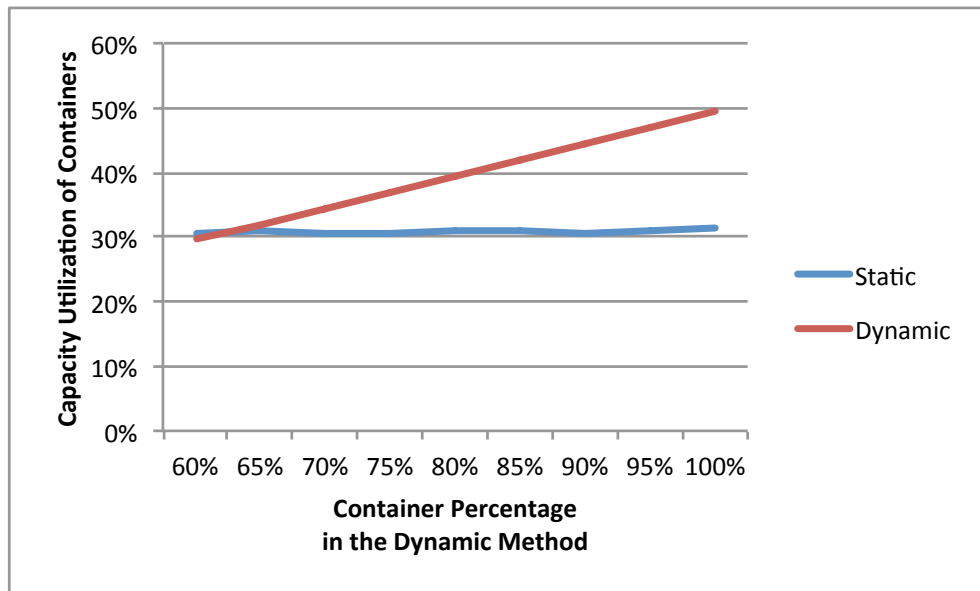


Figure 16: Sensitivity Analysis on Container Capacity Utilization

Looking at the tradeoff between service level and total distance in the dynamic method figure 17 shows that an 80% container percentage provides the best solution when combining service level and total driving distance.

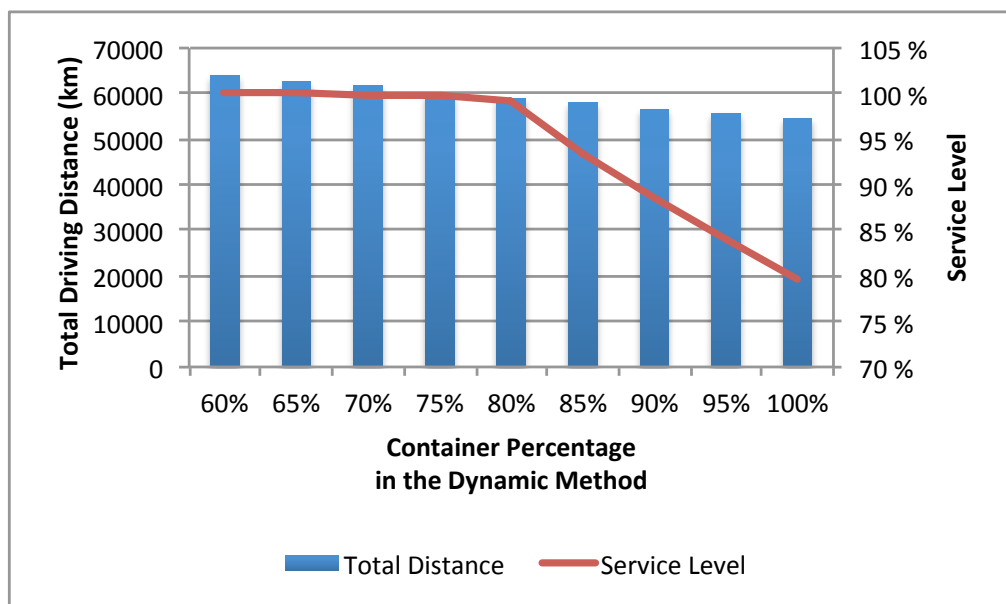


Figure 17: Trade Off Between Service Level and Distance

Nonetheless, looking at the customer service level parameter (shown in figure 18), the same trend is there but it does not make a significant notice until the container percentage is set to 95%. This implies that the best result could be when the container percentage is set to 90%.

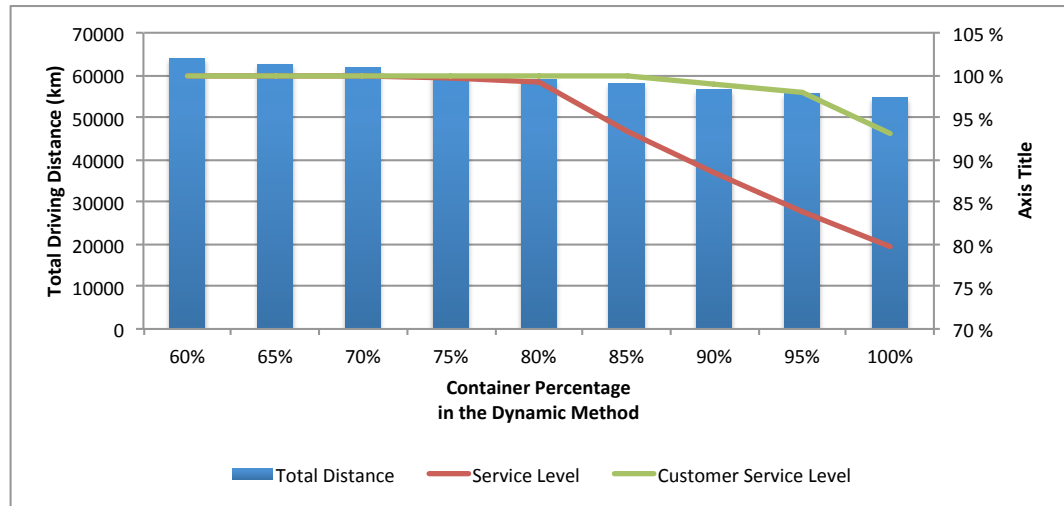
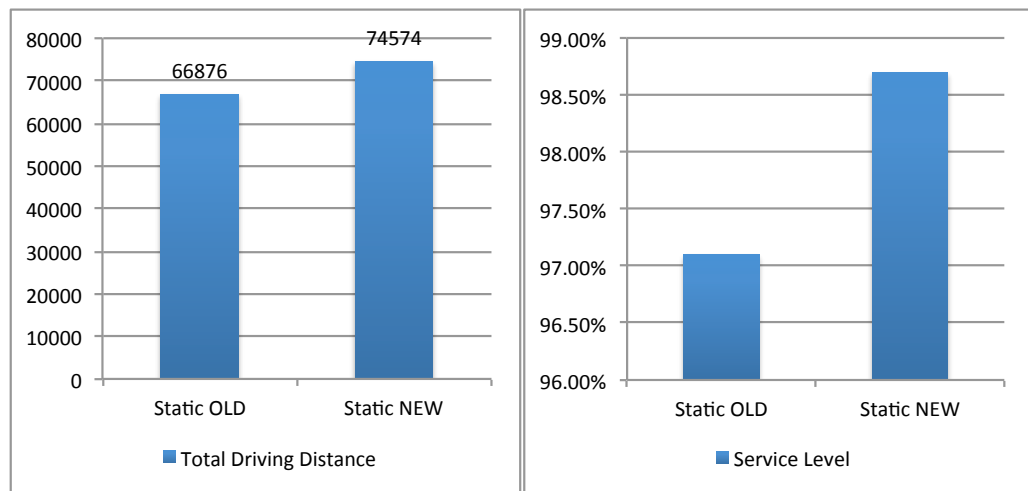


Figure 18: Trade Off Between Service Level and Distance (2)

However, based on REN's wish to measure the service level at 80% we believe that a container percentage of 80% is the best option for the dynamic method. At this level the results shows higher service level than the static method and shorter driving distance. A container percentage of 80% is therefore chosen when continuing the analysis and comparison of the static and dynamic methods.

Looking into a deeper analysis on container level shows us that there are some flaws in the static method. Eleven containers are never emptied because they are the very last on the weekly list, and the time available for collecting is out (i.e. the chauffeurs cannot work any more that week due to the eight hour time limit per day). This influences the service level in the static method. In the "real world" this would never have been the case, and all containers must be emptied. Hence, it is necessary to rewrite the algorithm for the static method so that the chauffeurs can collect all containers even though it goes beyond the time limit. This provides new results for the static case, shown in table 10.

Output	Value
New Total Distance Static	74574
Old Total Distance Static	66876
New Service Level Static	98,70%
Old Service Level Static	97,10%
New Over Capacity Static	0,20%
Old Over Capacity Static	1,70%
New Container Utilization	26%
Old Container Utilization	31,00%

Table 10: New Static Results**Figure 19: New Static Results vs. Old Results – Total Driving Distance and Service Level**

As shown in figure 19, the total driving distance increases with approximately 10%, while the service level increases with almost two percent. Additionally, overcapacity decreases from 1,7% to 0,3% implying that there are less instances where the containers are a 100%. The capacity utilization of the containers however decreases from approximately 30% to 26%, which provides a much poorer utilization of the containers. The new static results do not affect the already mentioned improvements of the dynamic method. The dynamic method still provides the best alternative.

6.5 Container Level Analysis

Continuing on the container level analysis the most important variable that it is necessary to look into is the average levels of the containers when they are emptied.

6.5.1 Too Frequent Emptying

One of the main problems for today's situation is that containers are emptied too often and as the routes are fixed and predetermined independent of filling rate of containers, the chauffeurs must stop at collection points that are under 10%, which is not to be emptied, and check, which is time-consuming.

When looking at the more detailed data from each method it is clearly that on average in the static method the containers are only around 60% full when they are emptied, while level is above 80% in the dynamic method, this is illustrated in figure 20.

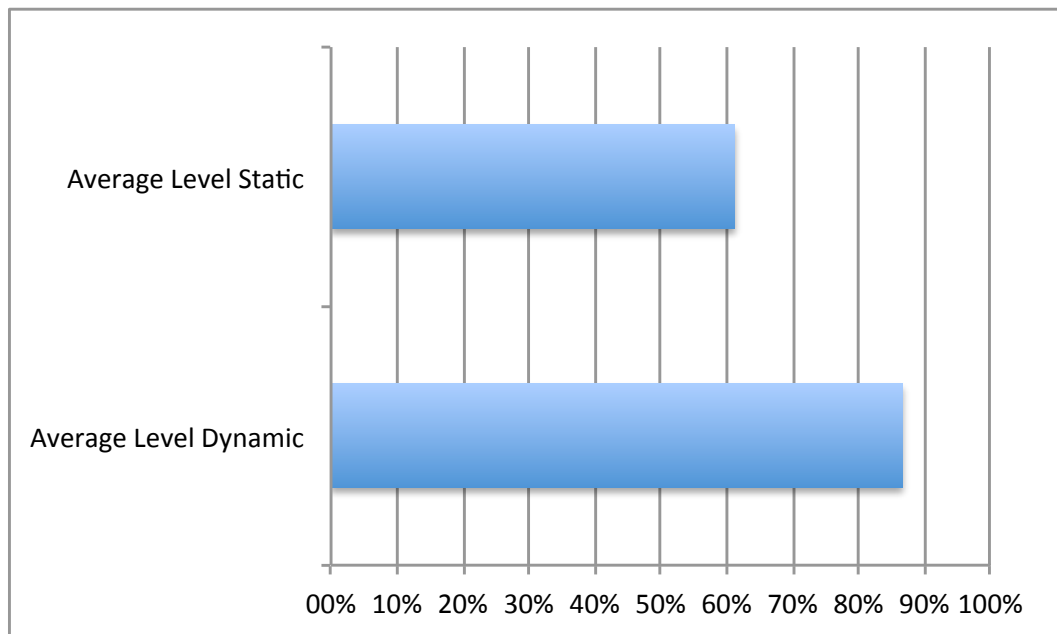


Figure 20: Average Level of Containers When Emptied in Both the Static and Dynamic Method

The averages are calculated as average level of the containers the evening before they were emptied. Because of the possibility of growth in the utilization of the container during the emptying day approximately 10% have been added to both the static and the dynamic average. Both the average level in the static method and the dynamic method is based on a sample from all days in the simulation model.

During observation of a static route it was experienced that some of the containers were below 10% and consequently not emptied. The chauffeurs have to leave the vehicle to check how full the containers are. This is very time consuming and

provides a lot of extra driving when the containers are not full enough to be emptied. By switching to a dynamic routing this type of problem could be avoided. Both driving distance and time could be reduced.

6.5.2 Number of Containers Emptied Every Day

In the static method the number of containers that are emptied in a four-week period are 1395 in total (table 11).

Driver/Week	Number of Containers
D1W1	190
D1W2	182
D1W3	174
D1W4	160
D2W1	190
D2W2	164
D2W3	170
D2W4	165
Total	1395

Table 11: Total Number of Containers Emptied in the Static Method

This gives an average of 349 containers per week, and implies that each chauffeur has to empty 175 containers per week. Dividing this on a daily basis it means that each chauffeur has to empty approximately 30 containers each day.

In the dynamic method the average number of containers that are emptied every day is also approximately 30 per chauffeur. All containers above 75% are counted every day. The assumption is that they are rising above 80% the next day putting them on the list of emptying. The containers with the acquired level on Saturday are not included in this calculation due to no emptying on Sunday. This gives an average of 60 containers each day and as mentioned an average of 30 containers per chauffeur. However, the standard deviation is calculated to be 16 per day. Looking more specific on the numbers one can see that they vary from 29 to 113 containers to be emptied. This is shown in figure 21.

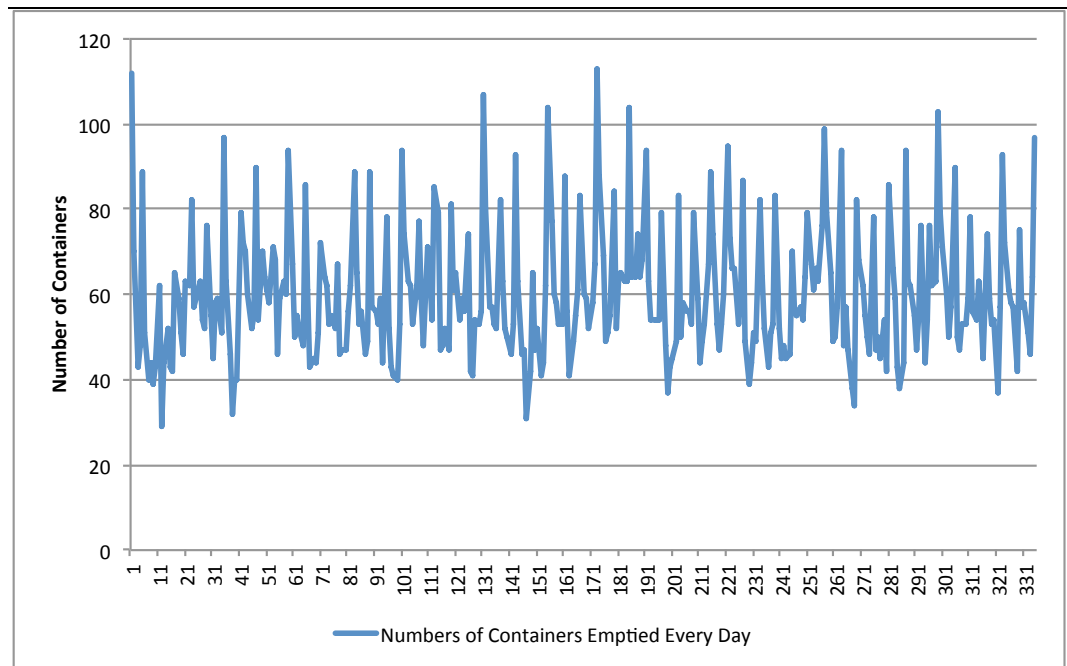


Figure 21: Number of Containers Emptied Every Day in the Dynamic Method

Comparing these two results show that by switching from static to dynamic routes there will be no decrease in the number of containers emptied every day. However the variance in the dynamic models provides some complications. Some days the chauffeurs have to empty over 100 containers, this will not be possible within the time limit. The service level is however a 100% in the dynamic method, which implies that all containers that must be emptied are emptied before they level rise above 100%. The reason for this could be how the routes are prioritized. As mentioned earlier the routes are provided priority based on the average waste level of the filled containers, the highest average level gets highest priority. This gives the opportunity of not emptying the least critical containers (even though they are above 80%), and assigning them to a route on the next day with a higher priority. Because of this possibility the service level is not affected as much as one should have thought.

6.6 Other Improvements

Switching from fixed to dynamic routes also provides some non-numerical improvements that could be solutions to the main challenges in the industry.

6.6.1 Too Late Emptying/Littering

If both REN and the carrier have an overview of the service level at all times, overflowing containers and bottles outside the containers might be eliminated by a

large extent. REN's effects of the challenges have been explained above. The carrier on the other hand, will be able to save a lot of time by not having the need to tidy up bottles outside when emptying the containers. This is time consuming, as every bottle must be placed in the container

6.6.2 Resource Use on Complaint Supervision

By installing sensors in the collection containers, the customer group gets an overview of the collection points service level at all times. Consequently, REN immediately see if the situation is due to fully return points or not. By this, they are able to prescribe complaint execution from correct instance without REN having to devote resources to site visit the collection point. Both carriers and REN's cleaning patrol can then be without hit and miss, and unnecessary use of resources/costs. In addition, the customer that contact will get a good impression of the agency by having systems in which shows that REN has a great overview and control of this service.

6.6.3 Contract Supervision

REN will have a good overview of service level and previous emptying's. The carrier knowing that REN has this overview will alone contribute to a better quality of the service. Simplified control, almost all of the control activities can be done from the office. Less reporting for carrier, in which reports the service level at every emptying today.

6.6.4 Environmental- and Cost Effective Services

Installing sensor and using dynamic routing will probably optimize the routes. The sensors functions as a tool for both REN and Sørum to achieve more control and overview. This implies an environmentally and cost-related gains for carrier and REN. Level measurement will contribute to less littering outside the collection containers and fleet management will contribute to less motoring and pollution in residential areas. REN might gain less cost through cheaper and better services from the carrier and through less administration of complaints handling and contractual supervision. In addition, REN will be able to assess various pricing models, e.g. per each emptying instead of tonnage or a combination. Consequently, the carrier uses fewer resources on reporting and manual routines for registration of service level and more. Moreover, the carrier and REN avoid time spent on tidying outside the collection containers.

6.7 Conclusion

Switching from fixed to dynamic routes provides many great improvements to the current situation. Both total driving distance and service level will be better if changing to sensors in the containers. However the question is where to set the minimum level of emptying in the dynamic model. To be able to utilize the containers and reduce driving distance as much as possible the level should be set as high as it is possible, given the constraint of maintaining the service level of a 100%.

The sensitivity analysis shows that setting the container percentage to 80% provides the best result for the dynamic model. By setting it higher there is a decrease in service level. The total distance does also decrease the higher the container percentage is set to, however because of the decreasing service level this is not an option.

The average level of containers every day is higher in the dynamic model than in the static model. Vehicle utilization on the other hand is better in the static method than in the dynamic method. Both of these results were expected beforehand.

One of the main problems REN faced was that some containers were emptied too often. By changing to a dynamic routing this could be improved greatly and will improve the service level regarding less littering outside the containers. The utilization of containers when they are emptied is above 80% in the dynamic method compared to 60% in the static method. On the other side we see that the average number of containers that must be emptied every day is the same in both the static and the dynamic model. The variance in the dynamic model however is extremely high. This can as mentioned provides some problems for the chauffeurs if they have to collect 50 containers each one day.

If REN chooses to change to dynamic routes the problem of driving to containers that are below a 10% level is eliminated and is also contributing to less unnecessary driving distance.

Based on the result of this thesis it is clear that by eliminating the driving to both empty and half full waste containers, and prioritizing the containers that are filled

above 80% of their capacity it is possible to reduce driving distance and improve service level in the collection process of glass and metal waste.

CHAPTER 7:

FINAL CONCLUSION

7.0 Final Conclusion and Remarks

In this final chapter concluding remarks will be presented. Limitations in the model and suggestions for further research are also elaborated. Lastly, a final conclusion to the thesis is presented.

7.1 Concluding remarks

The main objective of this thesis was to look into the possible improvements of switching from fixed to dynamic routes in the collection process of glass and metal waste in the municipality of Oslo, not to decide whether the sensors shall be implemented or not in practice. Based on previous theories and articles, two methods have been developed in order to minimize the travelling distance in both the static and dynamic case. This objective was chosen because it was provided as a wish from REN together with a comparison of the service level. After the modeling a simulation of the two models were performed. This simulation was based on 52 weeks of collecting to be able to compare both models and observe if the dynamic case had any positive effects on the service level and travelling distance. As a consequence of the results in travelling distance and service level, we noticed early that there were opportunities for improvements in other fields as well, such as container capacity utilization and the utilization of containers when they were emptied.

The different inputs that were necessary to solve the developed models have been defined in the thesis. However, some of the inputs is more fitted for the perfect world and is not exact with the present situation. We have not taken any reservation for queue, diversions or pollution. These variables might not necessary change the concluding/final results, but they certain might have an impact also on the formulation/design of the developed model.

Altogether, the results in this thesis show support from the variables analyzed. Consequently, the results in this thesis show that there is a possibility for improvements by switching from static to dynamic routes, both in total travelling distance and service level, as well as the utilization of the containers capacity. In addition, other existing challenges (e.g. littering and complaints) can be improved if switching to dynamic routes.

Looking back at the methodology foundation of the thesis, three of the four steps in the model by Mitroff, Betz et al. (1974), presented in chapter 3.4, is completed. The implementation phase has not been carried out, as the project does not start before 2016. Even though we have achieved results from the two methods, some of the inputs are not accurate enough to make it fit “real life”. It is necessary to make some changes in the inputs for the static method before REN/Sørum optionally adopts the model in practice. However, the models and results achieved could be useful when looking into the problem of actually switching from static to dynamic routes.

7.2 Limitations and Suggestions for Further Research

Pidd (1999) states that a model never fully can reflect the reality it wants to represent, and that a model is only intended to present a certain aspect of the real world. One of the main limitations of this research was the fact that we did not access the original routes as they are today. This provides a problem when comparing current situation with the situation where sensors are installed. The data used in the static model may not be accurate. By investigating the problem at hand with the correct routes might simplify the distribution of the geographical sections and thereby increase the reliability and validity. Also some of the data that were received and used as input were not complete, and the researcher had to take some assumptions. This also influences the result.

Additionally, another limitation is that this thesis has assumed that congestion does not have any effect on travel time. For further research it might be of interest to examine how queue, diversions and pollution might affect the results.

The Clarke and Wright Algorithm used in the dynamic method might not provide the best possible results due to its limitation in accuracy and flexibility. The dynamic method also includes the mentioned limitation of not fully utilizing the capacity of the vehicle. This is something further research can look into, by rewriting the algorithm and carrying out new simulations. However, developing a heuristic is beyond the scope of this thesis and expertise is necessary to construct a model in which REN/Sørum can use in the planning of implementing sensors. Another limitation of this research concerns seasonality. The methods do not take seasonality into account, but through discussion with one of Sørum’s chauffeurs it

is clearly that this is happening in real life, especially during holidays. The problem with too full containers appears at festive seasons such as Christmas, Easter and summer vacation.

By doing a quick cost estimation it is possible to see what can be saved in cost when switching from a fixed to a demand controlled routing. As this is not a part of the thesis it is just mentioned to inspire for further research. If choosing 80% as the minimum level to empty the containers in the dynamic method it is possible to reduce the total driving distance by 15 650 km per year. This implies a cost saving of 131 460 NOK if the vehicle uses approximately 0,6 liters of fuel (Diesel) per km (this is an estimate given by the chauffeur) (based on a km price set to 8,4 NOK). Also other costs such as maintenance on the vehicles and other related costs associated with the vehicle would be lower if the total driving distance is reduced. The savings given by reduced driving distance has to be measured against investment cost and monthly cost of using the sensor.

The driving distance and time spent on travelling to Syklus in Onsøy have been omitted from this thesis. This is something that might be taking into consideration in further research in order to achieve an even more realistic result of the whole collection process.

7.3 Final Remarks

The results given in this thesis might not have direct influence on how REN and Sørsum choose to carry out the collection process of glass and metal waste in practice. Nor will it affect whom or how REN choose their contractor to perform the collection activities. However, the works that have been put down in this thesis have addressed issues and challenges that are necessary to solve in order to conduct the measures for improvements.

From our modeling and based on the input used we have come to the conclusion that improvements are possible to achieve by switching from fixed to dynamic routes.

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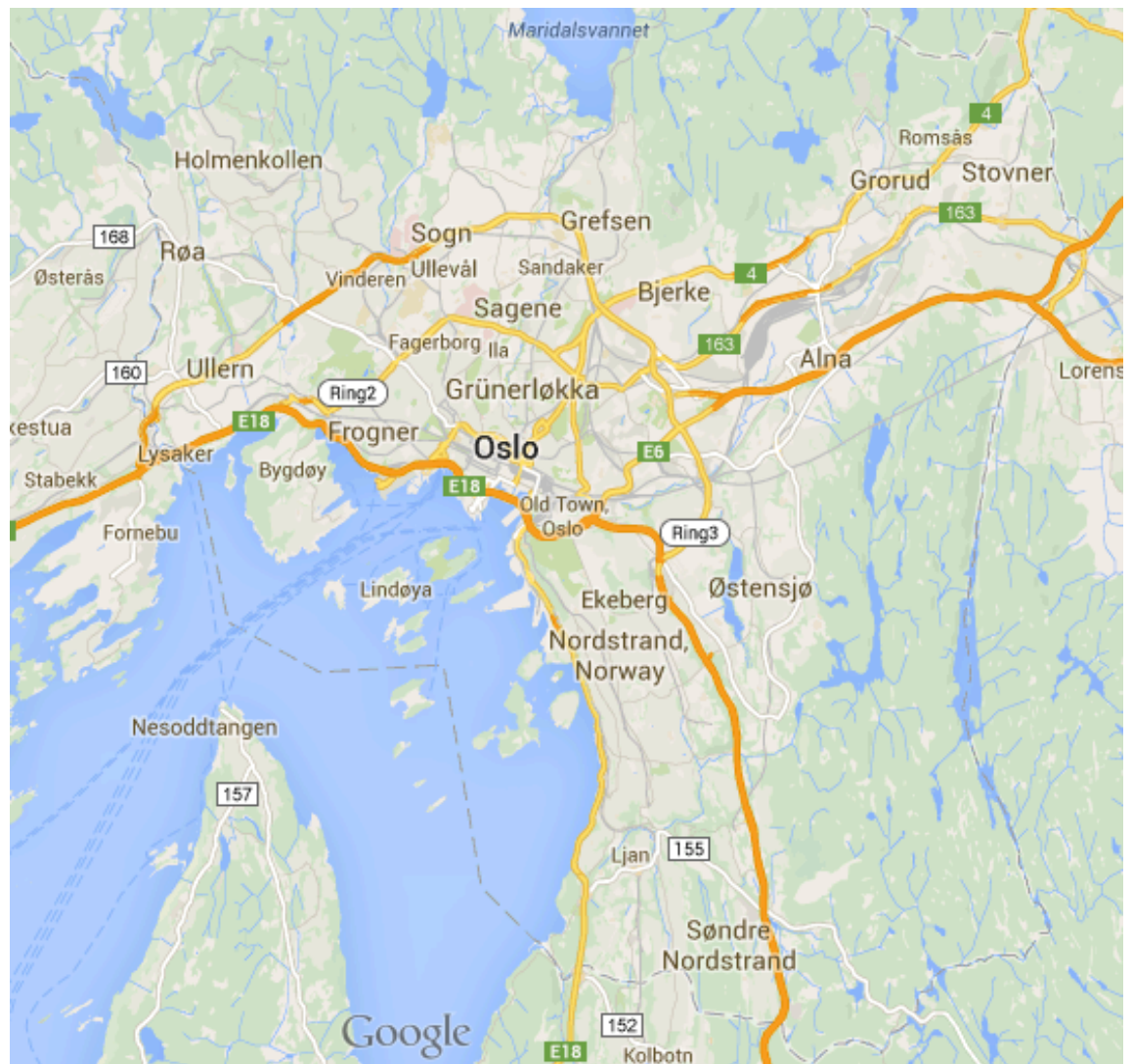
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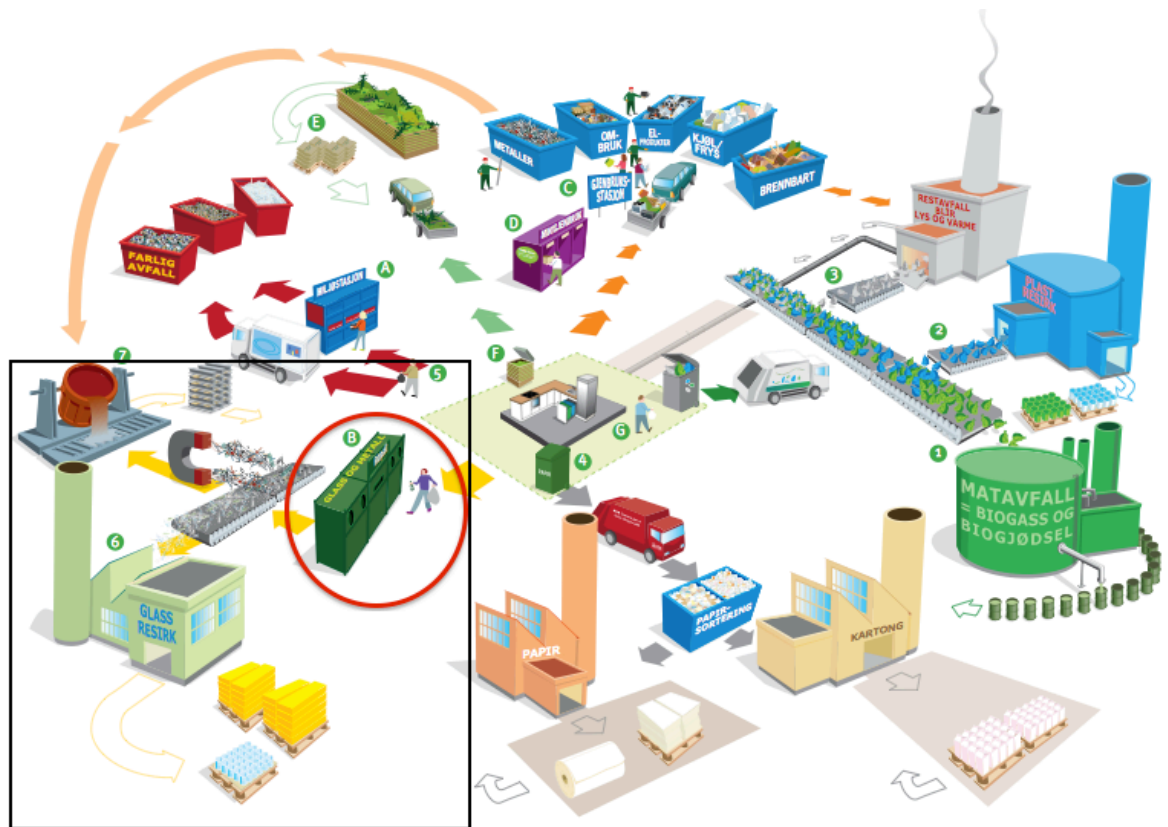
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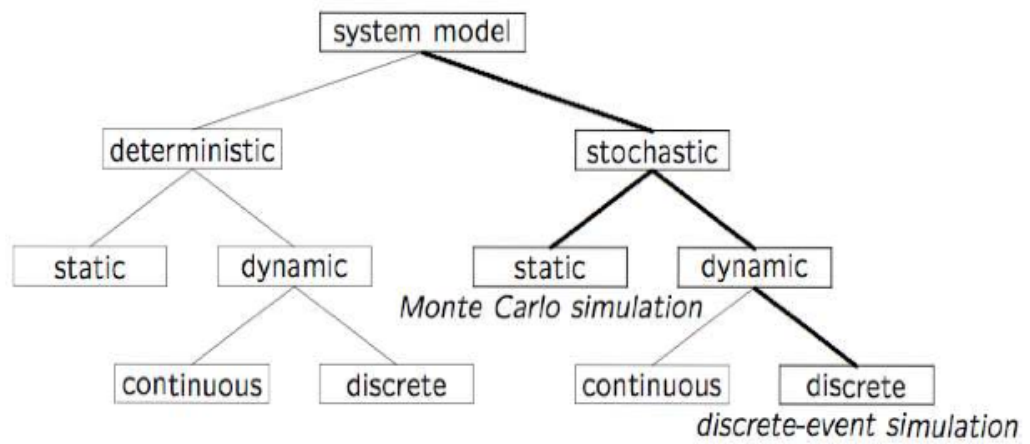
Appendices

Appendix 1 – Oslo Area

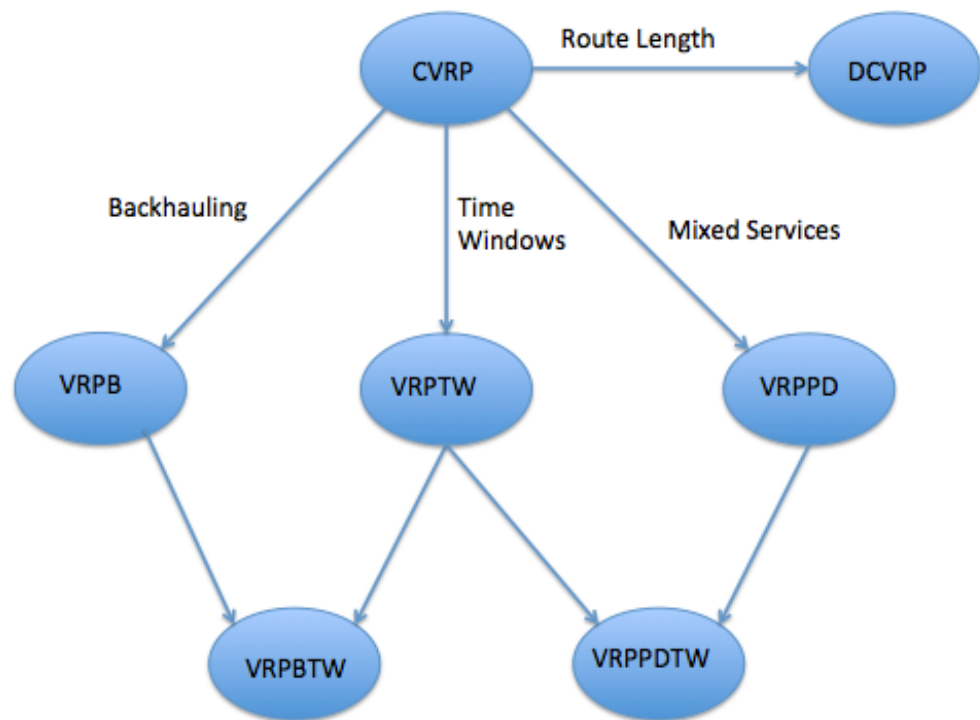


Appendix 2 – The current collection process in Oslo



Appendix 3 – Hierarchical classification of a simulation process

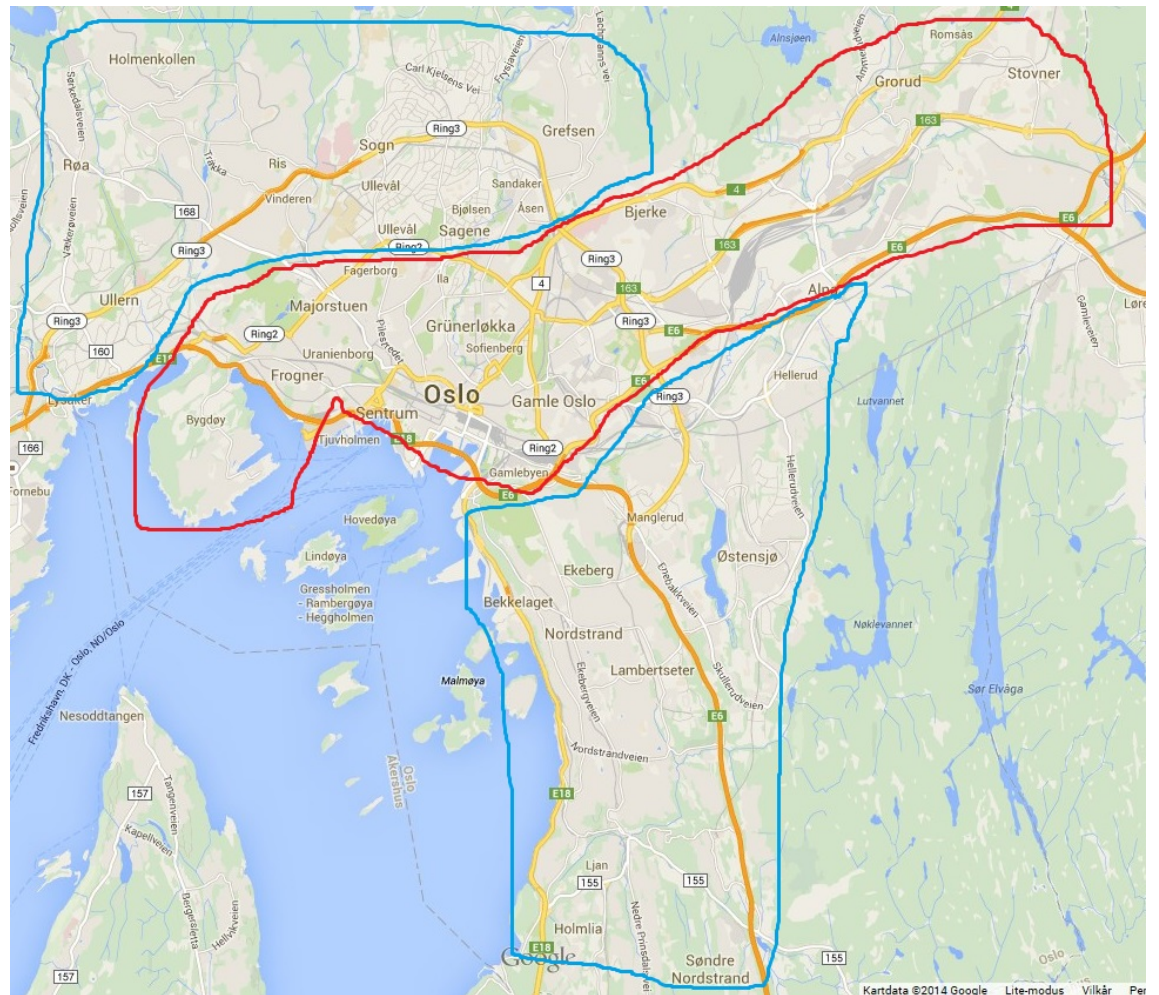
Appendix 4 – The basics problems of the VRP class and their interconnections



Appendix 5 – Geographical sections

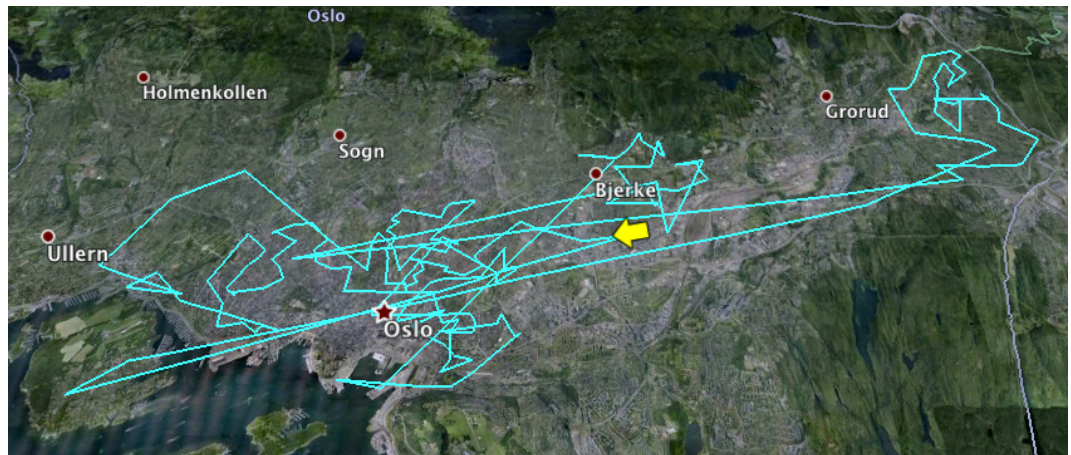
Red area = Chauffeur one

Blue area = Chauffeur two

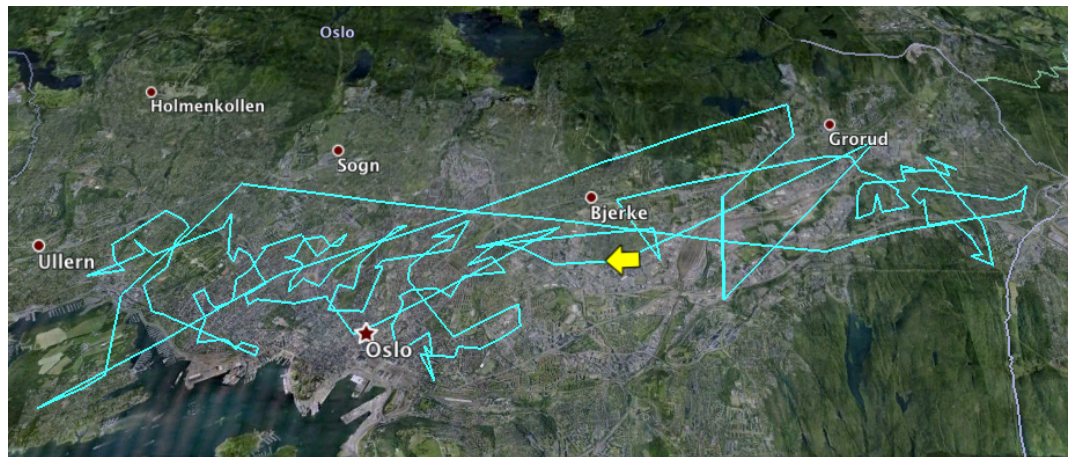


Appendix 6 – Static Routes – Driver 1, Week 1

Order	Address	Order	Address	Order	Address	Order	Address
1	Risikøkkveien 11 (ny uke 21)	49	Schultz gate 7	97	Professors Dahls gate 16	145	Sinsenveien 64 / Aker sykehus personal boliger
2	Risikøkkveien 10 (ny uke 23)	50	Sunnsgt 1 / Hertzbergs gt	98	Briskebyveien / Eliert sundts gate 18-26	146	Ribstonveien 35
3	Brokkveien 52 (Wien)	51	Fagerborggt 40B / Gørdtztgt2	99	Briskebyveien 7 / Harelabveien.	147	Liljeveien 25a
4	Haraldsrud Glenbruksstasjon (Brobekkn 87)	52	Ullevalisveien 97B / Stengt	100	Skovveien 37-39 v/Urianborg Kirke	148	Reitstad Allé 24
5	Ulvenvn.100	53	Ullevalisveien 82 / Theresesgt	101	Oscars gate 20/ Hegdehaugsveien31	149	Lørenveien 2 / Sinsen Samfunshus
6	Ulvenveien19 / Ulven Terrasse btl.	54	Ullevalisveien 79 / General Birchsgt	102	Pilestredet 58 / Homnabakken	150	Dyneklippt 20/Tt.vn 101
7	Karl Staaffs vei 67	55	General Birchs gate 16 nr1	103	Underhaugsveien 15	151	Spirreaveien 19 a
8	Karl Staaffs vei 69	56	Armuer Hansesgt. 10	104	Bjerregaardsgt 21/ Hans Ross Gt	152	Reitstadvn 6
9	OBS Lørenvn 63 (Inne på Parkeringssplss)	57	Stengst 1/ Theresesgt.	105	Akersveien 30	153	Ole deivskvei 20 / Fretex
10	Lørenvengen 20	58	Stengst 1/ Theresesgt. - 2.tømning	106	Herman Ross gate 10	154	Teisen (Teisenvn 18 / Regnbuenvn)
11	Vesterveien 3 /Løren minigjenbruksstasjon	59	Kirkeveien 106 / Wilhelm Færdensvei	107	Truumannsgate	155	Regnbuaveien 11
12	Peter Møllersvei 15	60	Kirkeveien 92/ Schunsgt ved Shiel	108	Mardalsveien 131	156	Regnbuaveien 2
13	Lørenveien 35	61	Harald Hårfagrevei / Trudvangveien 2.tømning	109	Geitmyrsveien 35	157	Regnbuaveien 28
14	Sinsenveien 15 / Fjellhaug skole	62	Harald Hårfagrevei / Trudvangveien 2.tømning	110	Youngstorgt 6	158	klosterheimveien 24
15	Sinsenveien 12	63	Majorsruveien 29	111	Motrefldstgt 33 /Jens Bjelkesgt	159	Agmund Boltsv 51
16	Trondheimsveien 139/ Sinsenveien 4	64	Neuberggata 11	112	Smalangen 31-49 / Gørnland torg	160	Agmund Boltsv 2
17	Carl Berner (Tromsøgt 42)	65	Tidemandsgt 46 v/Amaldus Nielsens plass	113	Borggata 2	161	Kalbakkken Senter (kalbakkvn 2)
18	Jørgen Løvlandsgate 5	66	Gyldenløves gate 20c	114	Sørilgata / Eriehauggata	162	Veitvetveien 29
19	Sars gt. 44	67	Frognerveien 33 / Løvenskjoldsgate	115	Schweigaardsgate 63-67	163	Veitvet Senter (Veitvetvn 9)
20	Verks gt 2 / Karlstadgata Rodes plass	68	Frognerveien 25 / Vestheimgt	116	Åkebergveien 3 / Jordal,gt	164	Grevlingveien 7
21	Sofienberg Parken/Toftesgt-Gruners,gt	69	Frognerveien 48 / Odinsgate	117	Jens Bjelkes gate 88	165	Veitveitsvingen 1
22	Olaf Fyves Plass 2 (Sofienberggt. /Markvn.)	70	Frognerveien 48 / Odinsgate	118	Hagegt 36 / Sigurds,gt./Tøyen senter	166	Grevlingveien 22
23	Schous plass	71	Søhneimgt 2c	119	Kampen Skole (Normansgt/skedsomt 17)	167	Grevlingveien 56
24	Selduksgt. 17 / Thorvald Meyersgt	72	Bygdøy alle 77	120	Sigurd Hoels vei 96/ Joh H Andresensvei	168	Strømsveien 266 /Alnbru/Industrivei/ v/Rimi
25	Thorvald Meyersgt 18-20 / Sannegt	73	Drammensvn. 100	121	Enfjøsveien 17	169	Smalvollveien 65 - Smart Club
26	Vogts gate 21	74	Olav Kyrresgate 7	122	Rolf Hofnoss gate 24 (ny uke 23)	170	Grorud Torg v/Rema 1000 (rosenborgvn 2)
27	Presidentgt 5 / Bunnpris	75	Gustav Vigelandsvet 1 / Pnhsessaillen 3	123	Leismann Hiorths allé	171	Ammerudveien 105
28	Torshov (Hegerngt / Johan Svendsgt 1)	76	Gustav Vigelandsvet 54	124	Gladsengveien 15	172	Ammerudvn 21 P-plass (Rema 1000)
29	Torshov gata / vogts gate	77	Øvre silkestrå (Skøyenveien 51)	125	St. Jørgens vei 1	173	Bygdøy Allé / Fredrikstangesgt 24
30	Bentsebrugata Minigjenbruksstasjon	78	Skøyenveien 1	126	St. Jørgens vei 56	174	Drammensveien 62-64
31	Åsengata 42	79	Srnestad Statoil (Veggo Hansteensv. 1)	127	St. Jørgens vei 65	175	Skillebekk (Drammensv/Munkedamsvei 97)
32	Nordkappgt/Jolly K Johansensngt (Torshovparken)	80	Sørbyhaugen 2 (ny uke 23)	128	Grenseveien 48	176	Thomies gate 5
33	Tverrbakken 4	81	Hoffsvien 63	129	Økernveien 47	177	Lassons gate 10
34	Tverrbakken 5/ Fagerheimgt	82	Hoffsvien 50	130	Dronning Ingrid's pl.	178	Ruseløkka (Observatoriegt 5 / Parkv.)
35	Kingosgt 9	83	Hofftunet bse Hofftunet / Jarlsbogeveien 4	131	Hovinveien 41	179	Ruseløkkn 50 / Cort Adlersgt
36	Bjerregaardsgt 70 / Uelandsgt	84	Engelbretsvet 3-5 tidl. Hoffsvn. 17	132	Hovinveien 39	180	Munkedamsveien 45/Ruseløkkeveien 53b
37	Darres gate 2	85	Skøyen Terrasse (Nedre Skøyenvei)	133	Liliebergsvingen 14	181	Frognerstranda 4
38	Rosteds gt 10 / Deichmannsgt	86	Hoffsvien 2	134	Gørnvoll (Grensevn 66)	182	Skarpsnoparken
39	Langsgt 11 / Wesselsgt.	87	Harbitzalleen 14/ sigurd Iversensvei	135	Gørnvoll Allé	183	Bygdøveien 20
40	Pilestredet 36	88	St. Edmundsvei 39	136	Fyrstikktorget, Karoline Kristiansensvei 3	184	Killingen / Holsts vei 1
41	Hegdehaugsveien 20	89	Gråbrødreveien 10	137	Malernhaugsveien 108	185	Folkemusset (Museumnsveien 7)
42	Stensbergt 19 / Hallingst	90	Gråbrødreveien 2	138	Ringgt nr 1 / Tøyen / Tøyen T-bane	186	Huk Aveny 35 Vikingskipshuset
43	Pilestredet park 7 / stensbergt 23.-pil,park minigljrk.	91	Vestikroken 2	139	Fridtjofsborgveien 39	187	Fredr.ksborgv 45 v/Spar
44	Waldemar Thranesgate 3 / Bjerregaards gt 2 A	92	Nedre Silkestrå 13	140	Sukkertoppveien 3	188	Strømsborgveien / Huk grenda
45	Lille Bislett (Sofies Plass 2)	93	Gullikroken 7	141	Sinsenentrasen / Båhusvn / Olaf Schousvei	189	Bygdøyneisveien 36 - Kon Tiki Museet
46	Colletsgt / Ullevålsveien	94	Sørkedalsveien 10 v/lens Evensen	142	Båhusveien 10	190	Vinderen (Borgenvn. 66)
47	Pilestredet 72	95	Bogstadvveien 74. Majorstuen Skole	143	Knut Avssoensvei 1		
48	Pilestredet 77 / Fagerborggt	96	Industrgt 33/ Dunkersgt.	144	Trondheimsveien 197		

Appendix 7 – Static Routes – Chauffeur 1, Week 2

Order	Address	Order	Address	Order	Address	Order	Address
1	Økernveien 145 / Økern senter	47	Motzfeldtsgt 33 / Jens Bjelkesgt	93	Gustav Viglandsv. 1 / Prinsessealleen 3	139	Martin Borrebekken vei 15
2	Lørenveien 35	48	Olafagangen / Smalagangen / Grønland T-Bane	94	Wessenspromenaden 10, Sjølyst	140	Statstråd Mathesensvei 16
3	Lørenveien 11	49	Olafagangen 31-49 / Grønland torg	95	Karenslyst alle 38	141	Lunderudn. 8s (Lunderudn 7)
4	Carl Berner (Tromsøgt 42)	50	Grønlandsleir et 40 / Schweigaardsgt	96	Harbitzaalleen 14/ sigurd Iversensvei	142	Erich Mogenssens vei 20
5	Sars gt/80/Trondheimsveien 107	51	Schweigaardsgate 63-67	97	Smedstad Stetoll (Viggo Hansteensv. 1)	143	Lunderdsettla 1
6	Ola Narr 2/ Finnmarksgt 53 / Nordre Tøyen btl.	52	Schweigaardsgate 86 / Østfoldgate	98	Vinderen (Borgvnn. 66)	144	Rødbergveien 76
7	Sars gt. 44	53	St. Halvardsgate 1	99	Akerbakken 30	145	Sletteålkka bs (Sletteålkka 5A)
8	Helgesensgt. 56 miljøstasjon	54	Egdesgate 3 / Arupgate	100	Herman Foss gate 10	146	Haraldstrud Gjenbruktstasjon (Broekken 87)
9	Veiks gt 2 / Karlstadgata Rodes plass	55	Borggata 2	101	Dikkgate 7 / Colletsgate	147	Lunden 13A
10	Johan Thore Holts plass 1, Freia	56	Jens Bjelkes gate 60	102	Darres gate 2	148	Grorud Torg v/Rena 1000 (Rosenborgvn 2)
11	Seiduksgt. 17 / Thorvald Meyersgt	57	Sørligata / Enehauggata	103	Marselsgt 24 / Grunersgt	149	Skansveien 16
12	Sorlienbergt Parken/Toftesgt-Gruners gt	58	Jens Bjelkesgate 9	104	Marselsgate 9	150	Høybråtenveien 40
13	Olaf Ryes Plass 2 (Sofienberggt. /Markn.)	59	Lakksgt 75-79 /Slebesgt.- gatetun	105	Marselsgate 24	151	Høybråtenv. / Bikuben
14	Schnous plass	60	Rosteds gt 10 / Deichmannsgt	106	Thorvald Meyersgt 18-20 / Sannergt	152	Starvn 6 v/Ica
15	Korsgata 14	61	Langsgt 11 / Wesselsgt.	107	Kjøbenhavngt 8, Malmøgt (Dællenga)	153	Idas vei 54
16	Torvakkagata 9	62	Waldemar Thranesgate 3 / Bjerregaards gt 2 A	108	Dællenggata 38	154	Stovnern 54 v/Spær
17	Nordregate 9	63	Lille Bislett (Sofies Plass 2)	109	Kjøbenhavngt 23 / Chr.Michelsens gt	155	Vesthellinga btl (Johann Svorkmosv 92)
18	Maridalsveien 10/ Fredensborg minigjenbruktstasjon	64	Pilestredet 58 / Homnabakken	110	Einar Tanbarakjelves Pl. / Christiesgt 23	156	Fossumberget btl (Fossumberget 54)
19	Maridalsveien / Fredensborgveien 70 (Maridalvein 13)	65	Pilestredet 72	111	Youngstorgt 6	157	Stoverlia btl (Stoverlia 19)
20	Maridalsveien 31 / Uelandsgt - parkeringsplass	66	Stengst 1/ Theresesgt.	112	Ringgt nr 1 / Tøyen / Tøyen T-bane	158	Tante Ulrikkesv 42 (P-plass)
21	Bjerregaardsgt 70 / Uelandsgt	67	Stengst 1/ Theresesgt. -2.tømning	113	Hagsgt 36 / Sigurds gt/Tøyen senter	159	Fossumveien 60
22	Kirngosgt 9	68	Fagerborggt 40b / Gørbitzgt2	114	Jens Bjelkes gate 88	160	Stovner senter V/arenottak
23	Kirngosgt 17 liadalen	69	Kirkeveien 92/ Schunnsgt ved Snell	115	Akebergveien 3 / Jordal gt	161	Jornesvei 10
24	Uelandsgt. 57 / Claus Riis gt	70	Harald Hårfagresvei / Trudvangveien	116	Kampen Skole (Normanngt/Skedsnøgt 17)	162	Tante Ulrikkesv 1
25	Søren Jaabæksgt 6 ved liadalen kirke	71	Harald Hårfagresvei / Trudvangveien 2.tømning	117	Sons gate 28/ Kampen nærmiljøstasjon	163	Jacobines Ryes vei
26	Griffenfeldts gate / Uelandsgate	72	Schulitz gate 7	118	Odalsgata 25	164	Ellen Gleditschv 2
27	Thurmannsgate	73	Industrigt 33/ Dunkersgt.	119	Jordal Terrasse	165	Martha Tynesvei 2
28	Torshov gata / vogts gate	74	Professor Dahls gate 16	120	Konowsgt. 9 / Ekebergveien 7 / Alnaregata	166	Vestlikosken (Vestlisingen / Tokerrudberget)
29	Vogts gate 64	75	Uranienborgveien 22	121	Ustikker 3, vippetangen	167	Tokenud bse (Tokerrudberget 9)
30	Vogts gate 68	76	Briskabveien 7/ Harelabveien.	122	Sørenskaia 81	168	Inga Bjørnsensvei 76
31	Nordkappgt./Jolly K. Johansensgt (Torshovparken)	77	Frogroveien 33 / Løvenskjoldsgate	123	Årvollveien / Loftshusveien	169	Vestlikollen bse (Nico Hambrosv 37)
32	Sunnmørsgata 10 - Ny uke 15	78	Frogroveien 25 / Vestheingt	124	Årvollveien 24	170	Vesti Senter (Vestlisingen 184)
33	Nordmøregata 1	79	Frogroveien 48 / Odinsgate	125	Årvoll gård	171	Vestlisingen 196
34	Einars vei 25	80	Tidemannsgt 46 v/Amaldus Nilsens plass	126	Selvbyggervn. 1	172	Ragnhild Scibys vei 4
35	Einars vei 35	81	Neuberggata 11	127	Selvbyggervn 13-23	173	Bankallstubbvn 1
36	Eindrides vei 2	82	Majorsstveien 29	128	Selvbyggervn 38	174	Karen Platous vei 31
37	Bergljotsvei 2	83	Sørkedalsveien 10 v/Jens Evensen	129	Selvbyggervn 135	175	Margrethe Parmsvet 1
38	Bergljotsvei 13	84	Solheimsgt 2c	130	Anna Rogstadsvet 1	176	Fossumveien 4
39	Fougner's vei 16 / Hekkeveien	85	Bygdøy Alle / Fredrikstangesgt 24	131	Kristine Bonnevesv 5 / Anna Rogstadv.	177	Haugenstua (Sigurd Astrupsv / Garver Ytte b.v)
40	Helgesensgt. 84 mot Tøyenbadet	86	Drammensveien 62-64	132	Selvbyggervn 193	178	Ruthsv 27 / Sienga 1
41	Rathkes Gt 16b (Sleidertrups gate.)	87	Skillebekk (Drammensv/Munkedamsvei 97)	133	Årvoll Senter v/ Stjerneat (Bård Skolemst.v.1)	179	Ruths vei 4/ v Stovner sykehljem
42	Rathkes Gt 8 v/park	88	Laassons gate 10	134	Bjerke btl (Refsdvingen 5)	180	Jerkovn 28 v/Rimi
43	Trondheimsveien 2D	89	Ruseløkka (Observatoriet 5 / Parkv.)	135	Krokveien 39	181	Folkemuseet (Museumsveien 7)
44	Ankeretorget 7 / Ykesskolens hybelhus	90	Ruseløkkn 50 / Cort Adlersgt	136	Lundlveien 12	182	Fredriksborgv45 v/Spær
45	Brugata 14	91	Drammensvn. 100	137	Brobekkeveien 52 (Meny)		
46	Norbvgata 1	92	Ingar Nilsens vei 1	138	Brobekken / Midtv. (Se Brobekkn 51-57)		

Appendix 8 – Static Routes – Chauffeur 1, Week 3

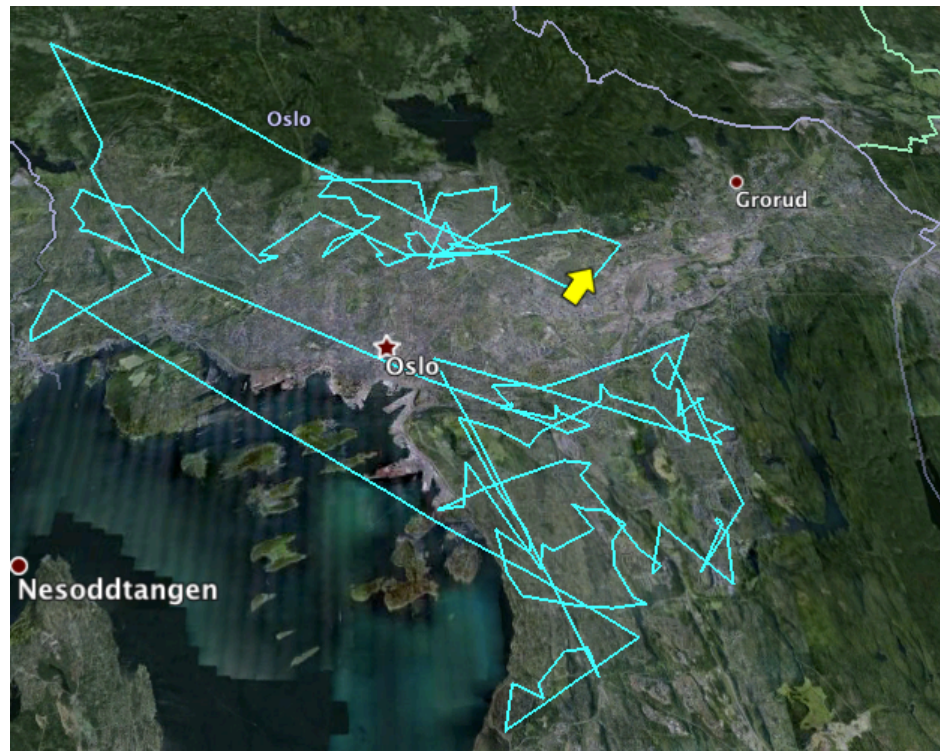
Order	Address	Order	Address	Order	Address	Order	Address
1	OBS Lørenv 63 (Inne på Parkeringsplass)	45	Herman Foss gate 10	89	Skøyenveien 18	133	Michèleveien 12 B
2	Lørenveien 35	46	Thurmannsgate	90	Skøyenveien 1	134	Grondun 93
3	Sinsenerrasen / Båhusvn / Olaf Schousvei	47	Maridalsveien 131	91	Heggelbakkken 2	135	Vestre Haugen 1
4	Båhusveien 10	48	Colletsøgt / Ulevålsveien	92	Smeistad Straioll (Viggo Hansteensv. 1)	136	Maria Dehlisvei 43 v/Haugen mat
5	Jørgen Løvlandsgate 5	49	Lille Blislett (Sofies Plass 2)	93	Hofturnet bse Hofturnet / Jarlsbogveien 4	137	Maria Dehlisvei 57
6	Trondheimsveien 139/ Sinsenveien 4	50	Pilestredet 58 / Homnabakken	94	Engelbreitsvei 3-5 tdl. Hoffsvn. 17	138	Maria Dehlisvei 37
7	Sinsenveien 12	51	Oscars gate 20/ Hegdehaugsveien31	95	Skøyen Terrasse (Nedre Skøyenvei)	139	Ole Brummsvei 2
8	Frydenbergveien 39	52	Underhaugsveien 15	96	Harbitzalleen 14/ sigurd Iversenvei	140	Ole Brummsvei 30
9	Carl Berner (Tromsøgt 42)	53	Pilestredet 72	97	Nedre Silkestrå 13	141	Garver Yteborgsvei 111
10	Sars Gt. 44	54	Pilestredet 77 / Fagerborggt	98	Gulkrøken 7	142	Garver Yteborgsvei 129
11	Verks gt 2 / karlsstadgata Rodes plass	55	Schultz gate 7	99	Øvre silkestrå (Skøyenveien 51)	143	Kristoffer Robinsvei 2
12	Sofienberg Parken/Tofteest-Gruner.s.gt	56	Suhmg. 1 / Hertzbergs gt	100	Borgenveien 3	144	Henrik Sørensenvei 39
13	Olaf Ryes Plass 2 (Sofienberggt. /Markvn.)	57	Fagerborggt 40b / Gørbitzgt2	101	Hartvig Halvorsenvei 4 / Diakonhjemmet	145	Ludvig Karstens vei 14
14	Schous plass	58	Ulevålsveien 97b / Stengt	102	Middelthunsgt.29	146	Munkebakken 11
15	Storgt.55 Anker Hotell	59	Ulevålsveien 79 / General Birchsøgt	103	Frogner Stadion / Middelthunsgt v / 21c	147	Munkebakken brt (Munkebakken 296)
16	Storgt.55 A	60	General Bricks gate 16 nr1	104	Sørkedalsveien 10 v/Jens Evensen	148	Munkebakken 169
17	Smalgangen 31-49 / Grønland torg	61	Armauer Hansensgt. 10	105	Bogstadvæien 14, Majorstuen Skole	149	Ellingsrudåsen T-bane (Edv. Munchsv 51)
18	Motzfeldtsgt 33/Jens Bljkesgt	62	Stensgt 1/Theresesgt.	106	Industrikt 33/ Dunkersgt.	150	Ellingsrud bs. (Edv. Munchsv 99)
19	Borggata 2	63	Stensgt 1/Theresesgt. - 2.tømning	107	Professor Dahls gate 16	151	Edv Munchsv 27
20	Sørilgata / Enehauggata	64	Kirkeveien 106 / Wilhelm Færdensvei	108	Briskøbveien / Eliert sundts gate 18-26	152	Nordre Fjeldstad Brt (Erl. Michelsen 21)
21	Schweigaardsgate 63-67	65	Kirkeveien 92/ Schumsgt ved Snell	109	Briskøbveien 7/ Haraldabveien.	153	Høybråteveien 17A
22	Akberveien 3 / Jordal.gt	66	Harald Hårfagrevei / Trudvangveien	110	Skoweien 37-39 v/Urbanborg Kirke	154	Høybråteveien 29A
23	Jens Bljkes gate 88	67	Harald Hårfagrevei / Trudvangveien 2.tømning	111	Hegdehaugsveien 20	155	Høybråteveien 35A
24	Hagegt 36 / Sigurds.gt./Tøyen senter	68	Majorstuveien 29	112	Stensberggt 19 / Hallingsgt	156	Høybråten (Høystakkn 14)
25	Kampen Skole (Normansgt/Skedsmsgt. 17)	69	Neuberggata 11	113	Pilestredet 19 / Hallingsgt	157	Høybråtenveien 79
26	Ensjøveien 17	70	Tidemandsgt 46 v/Arnaldus Nielsens plass	114	Youngstorgst 6	158	Høybråtenveien 91
27	Gladenveien 15	71	Gyldenløves gate 20c	115	Ribstonveien 35	159	Nybrottveien 1
28	Hovinveien 41	72	Frognerveien 33 / Løvenskioldsgate	116	Dyneliøgt 20/Tr.vn 101	160	Bredes vei 15
29	Ringgt nr 1 / Tøyen / Tøyen T-bane	73	Frognerveien 25 / Vestheimgt	117	Broekkveien 52 (Meny)	161	Lerkvnn 25-27
30	Seidalsgt. 17 / Thorvald Meyersgt	74	Frognerveien 48 / Odinsgate	118	Haraldsrud Gjenbrukstasjon (Broekkvn. 87)	162	Lerkvnn 67
31	Thorvald Meyersgt 18-20 / Sanneggt	75	Frognerisplass - rundkjøring v/Frognerparken	119	Reistadvn 6	163	Hockeyveien 17 - Ny uke 10
32	Presidentgt 5 / Bunnpris	76	Solheimsgt 2c	120	Kalbakkken Senter (Kalbakkvn 2)	164	Vindren (Borgenvn. 66)
33	Torshov (Hegerngt / Johan Svendsøgt 1)	77	Bygdøy Alle / Fredrikstangsgt 24	121	Sagstukroken / Grondveien	165	Karenslyst alle 11 / Messeveien - Flyttet midlertidig
34	Torshov gate / vogts gate	78	Drammensveien 62-64	122	Vestbyveien 16 / Sagstuveien	166	Folkemuseet (Museumsveien 7)
35	Nordkappgt/Idolv K Johansensgt (Torshovparken)	79	Skillebekk (Drammensv/Munkedamsvei 97)	123	Sjernerblokken 5 v/Grond Mat	167	Huk Aveny 35. Vikingskipshuset
36	Tverrbakken 5/ Fagerheimgt	80	Thomles gate 5	124	Grandsdalen 1 - Ny uke 15	168	Fredriksborgv.45 v/Spar
37	Kingosgt 9	81	Lassons gate 10	125	Grandsdalen 29 v/kiwi	169	Grond Torg v/Rema 1000 (Rosenborgvn 2)
38	Bjerregårdsgt 70 / Uelandsgt	82	Ruseløkka (Observatoriet 5 / Park.)	126	Grandsdalen 23D	170	Ammerudveien 105
39	Darres gate 2	83	Ruseløkkvn 50 / Cort Adlersgt	127	Furuset senter/Granstangen 23 - Søren Bullsv.	171	Ammerudvn 21 P-plass (Rema 1000)
40	Rosteds gt 10 / Deichmannsgt	84	Munkedamsveien 45/Ruseløkkeveien 53b	128	Lerkvnn 99	172	Veitvet Senter (Veitvetvn 9)
41	Langesgt 11 / Wesselsgt.	85	Drammensveien 100	129	Lerkvnn 97	173	Smalvollveien 65 - Smart Club
42	Waldemar Thanesgate 3 / Bjerregaards gt 2 A	86	Olav Kyrresgate 7	130	Uslottveien 15	174	Ringnesveien 50
43	Akersbakken 30	87	Gustav Vigelandsvet 1 / Prinsessealleen 3	131	Furusetveien 11		
44	Bjerregårdsgt 21/ Hans Ross Gt	88	Gustav Vigelandsvet 54	132	Østausa brt (Micheletsv 38)		

Appendix 9 – Static Routes – Chauffeur 1, Week 4

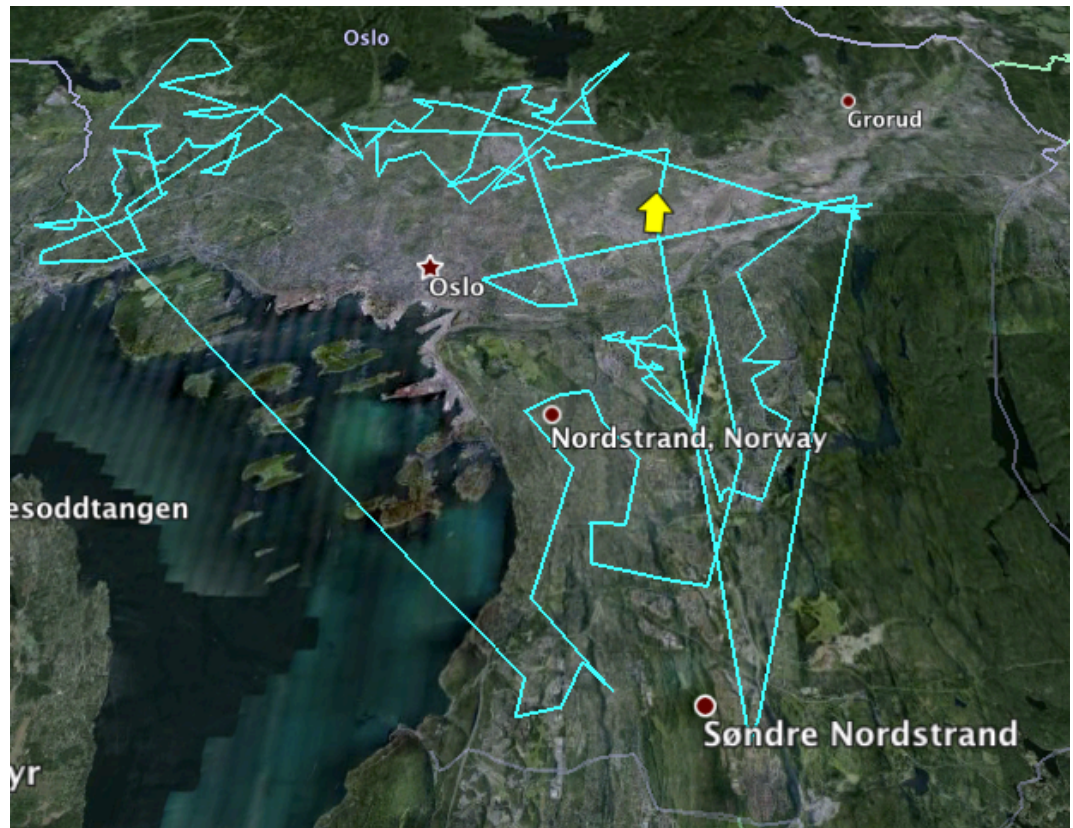
Order	Address	Order	Address	Order	Address	Order	Address
1	Økernveien 145 / Økern senter	41	Kampen Skole (Normannsgt./Skedsmogt. 17)	81	Majorstuveien 29	121	Nordtvedtn 7 (iCA Sparrmat)
2	Lørenveien 35	42	Sons gate 28/ Kampen nærmiljøstasjon	82	Sørkedalsveien 10 v/Jens Evensen	122	Chr. Heilsums 18 /Engsletta brl/Gårdsyn.
3	Fougner's vei 16 / Hekkeveien	43	Ringgt nr 1 / Tøyen / Tøyen T-bane	83	Solheimsgt 2c	123	Akerlia 20-28
4	Carl Berner (Tromsøgt 42)	44	Lakkegt 75-79 /Slebesgt - gatetun	84	Erling Skjalgssonsgate 19	124	Akerlia brl (Kalbaksllyngen 5)
5	Sars gt.80/Tromheimsveien 107	45	Rosteds gt. 10 / Deichmannsgt	85	Bygdøy Alle / Fredrikstangsgt 24	125	Akerlia 1
6	Sars gt. 44	46	Maridalsveien 10 / Fredensborg minigjenbrukstasjon	86	Drammensveien 62-64	126	Apalløkkeveien
7	Tromheimsveien 63, Tøyenhus BL (63-83)	47	Maridalsveien 31 / Uelandsgt - parkeringsplass	87	Skillebekk (Drammensv/Munkedamsvei 97)	127	Grorud Torg v/Rena 1000 (Rosenborgvn 2)
8	Tromheimsveien 77, Tøyenhus BL (63-83)	48	Bjerregårdsgt 70 / Uelandsgt	88	Lassons gate 10	128	Bergensveien 37
9	Helgesensgt. 56 miljøstasjon	49	Kingosgt 9	89	Ruseløkke (Observatorieg. 5 / Parkv.)	129	Ammerudveien 126
10	Verts gt 2 / Karlstadgata Rodes plass	50	Kingosgt 17 laddelen	90	Ruseløkken 50 / Cort Adlersgt	130	Ammerud brl (Ammerudhellinga 33-43)
11	Københavnsgt 8./ Malmøgt (Dællenga)	51	Thurmannsgate	91	Drammensvn. 100	131	Ammerudhellinga 56-66
12	Dællengagata 38	52	Torshov gata / vogts gate	92	Ingar Nilsens vei 1	132	Ammerudhellinga 70-80
13	Nordmøregata 1	53	Nordkappgt/only k. Johanssensgt (Torshovparken)	93	Gustav Vigelandsgt 1 / Prinsessealleen 3	133	Ammerudlia brl (Ammerudgrenda 166-176)
14	Bergljotsvei 2	54	Dirksgate 7 / Collets gate	94	Messapromenaden 10, Sjølyst	134	Ravnkollbakken 1
15	Helgesensgt 84 mot Tøyenbadet	55	Herman Foss gate 10	95	Karenslyst alle 3B	135	Romsås Senter 1
16	Rathkes gt. 16b (Skjeldrups gate.)	56	Akersbakken 30	96	Harbitzalleen 14/ Sigurd Iversensvei	136	Ravnkollbakken 36
17	Rathkes Gt 8 v/park	57	Waldemar Thranesgate 3 / Bjerregårds gt 2 A	97	Smedstad Statoil (Viggo Hansteensv. 1)	137	Ravnkollbakken 54
18	Schous plass	58	Ullevalsveien 51	98	Holmenveien 20	138	Ravnkollbakken 64 v/Kivi
19	Korsgata 14	59	Lille Bislett (Sofies Plass 2)	99	Vinderen (Borgenvn. 66)	139	Svarttjern brl (Odvar Solbergsgt 186-224)
20	Nordregate 9	60	Pilestrødet 58 / Homansbakken	100	Kirkeveien 167	140	Odvar Solbergsgt 170
21	Olaf Ryes plass 2 (Sofienberggt./Markvn.)	61	Pilestrødet 72	101	Lovisenberggata 11	141	Odvar Solbergsgt 118/218
22	Sofienberg Parken/Toftegt-Gruners.gt	62	Stensgt 1/ Theresesgt.	102	Lovisenberggata 23	142	Odvar Solbergsgt 120
23	Seilbuksgt. 17 / Thorvald Meyersgt	63	Stensgt 1/ Theresesgt. - 2.tømming	103	Holbergsgt 4	143	Odvar Solbergsgt 158 kiwi
24	Thorvald Meyersgt 18-20 / Sannergt	64	Fagerborggt 40b / Gørbtztgt2	104	Langesgt 11 / Wesselsgt.	144	Emmaellifjell brl (Odvar Solbergsv 66-114)
25	Marselsgate 9	65	Kirkeveien 98 / Wilhelm Færdenvei	105	Darres gate 2	145	Odvar Solbergsgt 2
26	Marselsgt 24 / Grunersgt	66	Kirkeveien 92/ Schumsgt ved Sneil	106	Youngstorgt 6	146	Sverre Iversens vei 17
27	Tromheimsveien 2D	67	Hammerstads gt. 23	107	Egedesgate 3 / Anupgate	147	Haugenstua (Sigurd Astrupsv / Garver Ytte.b.v)
28	Ankertorget 7 / Yrkeskolens hybelhus	68	Harald Hårfagrevei / Trudvangveien	108	Konowsgt 9 / Ekebergveien 7 / Alnaftegata	148	Høybråtenveien 40
29	Chr Krohgs gate 35-51	69	Harald Hårfagrevei / Trudvangveien 2.tømming	109	Oddsagata 25	149	Skansveien 16
30	Motfeldtsgt 33 / Jens Bjelkesgt	70	Schultz gate 7	110	Lundiveien 12	150	Høybråtenvn. / Blikuben
31	Smaålgangen 31-49 / Grønland torg	71	Industrigata 71	111	Broekkveien 52 (Meny)	151	Starvn 6 v/Ica
32	Olafagangen / Smaålgangen / Grønland T-Bane	72	Industrigt 33/ Dunkersgt.	112	Martin Borrebekken vei 15	152	Stovnervn 54 v/Spar
33	Borgata 2	73	Professor Dahls gate 16	113	Haraldrud Gjenbruksstasjon (Broekkvn 87)	153	Olaus Fjortoftsvei 2
34	Sørilgata / Enerhaugata	74	Urbanenborveien 22	114	Haraldrudveien 20	154	Fossumberget brl (Fossumberget 54)
35	Grønlandsleiret 40 / Schweigaardsgt	75	Briskebyveien 7/ Harelabveien.	115	Haraldrudveien 24	155	Stovner senter V/arenottk
36	Schweigaardsgate 63-67	76	Frognerveien 33 / Løvenskjoldsgate	116	Årvoll Senter v/ Stjernevat (Bård Skolemst.v.1)	156	Ragnhild Scibbys vei 4
37	Schweigaardsgate 86 / Østfoldgate	77	Frognerveien 25 / Vestheimgt	117	Sletteløkka 36	157	Lerkvvn 28 v/Rimi
38	Åkerbergveien 3 / Jorlat gt	78	Frognerveien 48 / Odinsgate	118	Rødvedt brl (Rødvetvn 7-9)	158	Sørengkaia 81
39	Jens Bjelkes gate 88	79	Tidemannsgt 46 v/Arnaldus Nielsens plass	119	Rødvedt Skole (Sandåsyn 1)	159	Folkemuseet (Museumsveien 7)
40	Hægegt. 36 / Sigurds.gt / Tøyen senter	80	Neuberggata 11	120	Rødvetveien 40	160	Fredrikshovgt 45 v/Spar

Appendix 10 – Static Routes – Chauffeur 2, Week 1

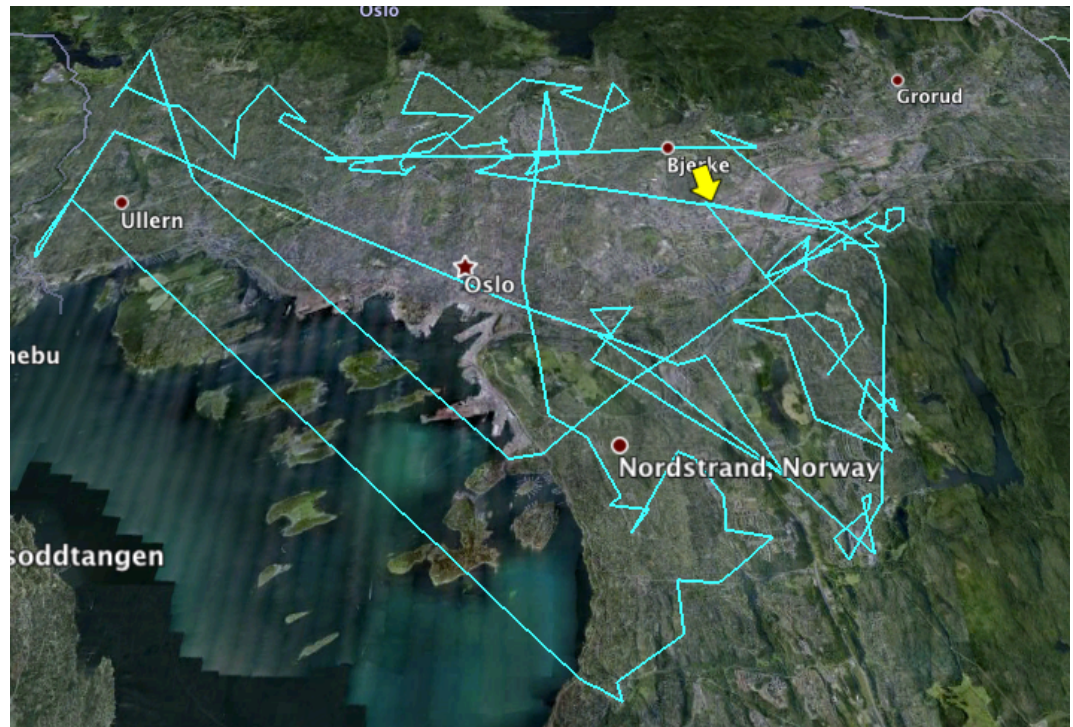
Order	Address	Order	Address	Order	Address	Order	Address
1	Økern Torveg 5	49	Bølerlia 31	97	Landingsvei 84 (Ørebakken brl)	145	Gamle Bygdevei 163
2	Stig (Rødbergvn 16)(Tonsenhagen Torv)	50	Bølerlia 8	98	Arnebråfveien 118 (Tidl.Arnebråfveien 157 / Jarbakken)	146	Sveavegen 79 Lerdalsgrenda brl
3	Kjelsåsn 7 v/Rema 1000	51	Bølerlia 10	99	Ankeveien 58	147	Lerdalsfaret 14
4	Kjelsåsn 7 v/Rema 1000 - 2. tømning	52	Bølerlia 67	100	Nils Collett Vogts vei 6	148	Sponstuveien 18A
5	Grefsentunet Disen Stasjon	53	Bølerlia 12	101	Sørkedalsveien 258 /Peder Ankers plass	149	Sponstuveien 26
6	Kapelivn / Morelivs v/Grefsen Skole	54	Bølerskogen 35	102	Ekraveien 35	150	Nedre Prinsdalsvei 72 / ICA Prinsdal park plass
7	Hans Nielsen hauges gate 12	55	Bølerlia 52- Ica Butikk	103	Makrellbekken (Morgedalsveien 1)(Njårdhallen)	151	Øvre Prinsdalsvei 47A
8	Sandaker plass (Sandakerveien 62)	56	Urnmarksvæien 15 / Bølerskogen 2	104	Holmenkoliveien 15	152	Nebbeljordet 5 / Rugdeberget / Nebbeljordet brl
9	Sandaker Senter (V.v.Asengata 1)	57	Harleikka 24 / Bøler	105	Jensmessveien 1	153	Olaves Hvervns vei 10
10	Kyrre Greppes gt 13	58	General Ruges vei 97 / Bogerud T-bane	106	Holmenkoliveien 43	154	Asperudtuppen brl (asperudtuppen 1)
11	Kyrre Greppes gt 11	59	Skulterudveien 59 / Rimi Skulterudv.br	107	Gaupefaret 4	155	Lerdalstuppen brl (asperudv 52)
12	Lillogata 5K	60	Enebakkveien 208/Plogveien / Rimi	108	Frogneretenevnen 27 / Stasjonsveien	156	Asperudveien 1b / Liakoliveien
13	Mardalsveien 175 / Gjølvikgata	61	Manglerud Senter (Plogvn 31)	109	Slendalst. / Gulleåsvn.	157	Holmlia senter vei 3
14	Adv Dehls plass (Bjørsegt 1)	62	Enebakkveien 154B	110	Gullesåveien 9A v/Hemningbanen/Slendal	158	Holmlia senter vei 26
15	Sagene Torv (Kristiansandsgata 1)	63	Dovervingen 1	111	Slendavingen 53	159	Holmlaveien 100 / Rema / Esso
16	Sandakerveien 22A - Borettslag v/ restavfall	64	Sandstuveien 41 / Brattikollen T Bane	112	Halkor Torgersensvei 14	160	Nordåsv. 72 v/Kivi
17	Sandakerveien 22 B	65	Ractsvei 38 / Steingrimsvei	113	Ternisveien 31B/ Jegerveien 32 - Jegerkollen sameiet	161	Lusefjernveien 3
18	Nils Lantssønsvei 34	66	Langbølgen 2 / Lambergseter senter	114	Frogneretenevnen 63 v/Parkplass	162	Nordassjøfå 1
19	Bergsællen 1 / Damplassen	67	Nordstrandveien 62 kivi	115	Bessevud (Ankern. 23) Holmenkoliveien 99	163	Åstråten 1 v/Busstopp
20	Sognsveien 61 / Trollsvingen	68	Nordstrandveien 40 / Sæter v/Esso	116	Stasjonsveien 64	164	Bjørn Bondesvei 149
21	Sognsveien 70 Shell Uleval stadion	69	Ljåbrubakken 1 / Ekebergveien	117	Låveveien 70 / Håkon Tveters vei / Statoll Østensjø	165	Ravnåsv. 38 / Ravntrøken
22	John Collets alle 1 / John Collets Plass	70	Nedre Prinsdalsvei 1 / Busstopp	118	Haakon Tvetersvei 17 - Skøyenåsen T-bane	166	Gamlelinda 45
23	Sogn Studentby - Rolf E.Stenersens alle 26-28	71	Nedre Prinsdalsvei 1 / Haukesto stasjon	119	Haakon Tvetersvei 50-52	167	Hallagerbakken 108
24	Carl kjelsensv.23 v/Nordberghjemmet	72	Møllefaret 46 / Elvefaret BL	120	Vetlandveien 82	168	Hallagerbakken 32-48 / Hallagerbakken brl.
25	Langmyrgrenda 25	73	Møllefaret 10-34 / Sømningens BL	121	Oppsalstubben 3 - Rimi	169	Liakoliveien 1a/ Høgåsveien
26	Peder Ankervei / Øvre langås	74	Lysjordet nat (vakerørven 114-132)	122	Vetlandveien v/Rimi (Nytt punkt ved Oppsal T-bane)	170	Høgåsveien 50-70 (100)
27	Langmyrveien 1 / Åmotveien	75	Lysjordet 46 v/Rimi	123	Oppsal Terrasse 2	171	Liakoliveien 26A
28	Mardalsveien 328	76	Bjørnsletta Shell (Bærumsvn 20b)	124	Tveita Senter (Tveitenvn 150)	172	Tirilunga 1
29	Mardalsveien 350	77	Ullern alle 41 Åsjordet v/Spar	125	Nils Hansens vei 4	173	Trygve Strømbergsvet 6 / Nedre Prinsdal brl.
30	Mardalsveien/Kjelsåsveien 188 - Brekkekrusset	78	Solterudveien 37D	126	Etterstad (Etterstadsletta 3)	174	Storeåsen 35A / I rundkjørningen
31	Sagadammen / Frysåveien	79	Bestumveien 58	127	Biskop Jens Nilsensgt. 5 - Rema 1000	175	Hverdenbukt P-plass/Ljansbrukveien 2
32	Asbjørnsensvei 3	80	Sørangen 21 (ny uke 21)	128	Etterstad Øst brl (Etterstadsletta 47)	176	Gladvollveien / Herregårdveien 1
33	Kjelsås st (Midtoddvn 12)	81	Våkerøveien 5	129	Etterstadtrøken 5G	177	Lambertsseterveien 7 / Pearl Engensvei 2 A
34	Grefsenvn / Midtoddvn 2	82	Bestumveien 30	130	Etterstadsletta 41A	178	Marlenlundveien 2 / Hollet satson
35	Gamle Kjelsåsveien / Marsveien	83	Sigurd Iversensvei 42	131	Enebakkveien 34 / Småensgt	179	Drammensveien 198
36	Kapeliveien 118 v/ Miljøstasjon	84	Skogbyrnet 39 (ny uke 22)	132	Grønno Miljøstasjon / Gjenbrukstasjon / Søriveien 1	180	Betzy kjelsberg 9 v/Coop
37	Grefsenveien / Lysgåsvn 2	85	Ulleakervn. 16d / CC vest	133	Brennaveien 131	181	kasaveien 1/Mardalsveien
38	Grefsenkollvn 14 / Akebakkeskogen	86	Ulleaker st. (Ulleakervn. 30)	134	Helga Vaneks vei 1	182	Sørbråtveien 27
39	Myrrefjordet (Myskogn / Kurvn 1)	87	Kristian Aubertvei 20	135	Gamle Bygdevei 43	183	Sørbråtveien 86-88
40	Stilla hf (Solligrenda 70)	88	Våkerøveien 205A v/Raa Apotek	136	Lofsrudveien 68 (Mortensrud senter)	184	Nyjordveien 54 / Nyjordstuben 1
41	Frysåveien 9 Brekke brl.	89	Raa bse (Porfryn 1)	137	Lofsrudveien 6 / Lofsrudhøgda	185	Granbergstubben 24 / Bjørndalen senter
42	Minister Ditlefvei 21 v/Nordberg Mat(Weny)	90	Ostadsveien 69	138	Lofsrudhøgda 209	186	Meklenborgåsen 10
43	Folke Bernadottes vei 43	91	Myrhaugen 25	139	Blakkenvei 123	187	Åslandtrøken 18
44	Østmarkveien 25 REMA1000	92	Stasjonsveien 71/Landingsvei v/Hovseter T-Bane	140	Mortensrudveien 142	188	Åslandhellinga 389
45	Ustrudveien 20 / Østbyveien	93	Hovseter Senter (Hovsetervn 68-82)	141	Mortensrudveien 185	189	Klemetsrud Postkontor (Enebakkvn 403)
46	Utrnarksvæien 1 / Bøler senter	94	Hovseterveien 52	142	Mortensrudveien 200	190	Landingsvei 84 (Ørebakken brl)
47	Bølerlia 1 / General Ruges vei	95	Hovseterveien 36	143	Jordstlemveien 48		
48	Bølerlia 6	96	Landingsvei 52 (Jarbakken brl)	144	Marta Steinvikvei		

Appendix 11 – Static Routes – Chauffeur 2, Week 2

Order	Address	Order	Address	Order	Address	Order	Address
1	Linderud Senter (Erik Mogenssønnsvei 38)	42	Gunnar Schjelderups vei 13	83	Ettaåsen 62 / Hellerudveien / Bjartkollen brt.	124	Ormsundveien / Grønnsundvn 20
2	Stig (Rødbergvn 156/Tonsenhagen Torg)	43	Kapelveien 118 v/ Miljøstasjon	84	Hellerudveien 130	125	Lilbakkveien 6a
3	Kjelsås v/ Skedbanen	44	Greisenvn / Midtoddvn 2	85	Oppsalstribben 3- Rimi	126	Høgda veien / Trygve Ryensvei 2
4	Kjelsås v/ Rema 1000	45	Kvireforset (Myrskogvn / kurvn 1)	86	Vetlandsribben 64 v/ Rema	127	Østeriveien 10
5	Kjelsås v/ Rema 1000 - 2. tømning	46	Kjelsåsveien 69 v/ Gm Brannstasjon	87	Vetlandsfaret 5	128	Feltspatveien 29
6	Greisenvn 47	47	Greisenvn 14 / Akabakkoskogen	88	Solbergveien 98 / Skøyenåsen	129	Steinspranget 34 / Steinspranget brt.
7	Birch Reichenwalds gate 34	48	Hans Nordhils gate 98	89	Skøyenkrøken 11	130	Mellombølgen 62 / Bergkrystallen T. bane
8	Birch Reichenwalds gate 18	49	Gunnar Schjelderups vei 11 R	90	Mekantikerveien 8	131	Enebakkveien 289 v/ Prik / Lille Langerud torg
9	Sandaker plass (Sandakerveien 62)	50	Gunnar Schjelderups vei 33	91	Vetlandsveien v/ Rimi (Nytt punkt ved Oppsal T. bane)	132	General Ruges Vei 97 / Bogerud T. bane
10	Sandaker Senter (V v/ Åsengata 1)	51	Treschowgate 2A	92	Låveveien 70 / Håkon Tveiters vei / Statoll Østensjø	133	Stallerudveien 5 / Stallerud brt.
11	Kyrre Greppes gt 13	52	Disenvn 31 v/ Nærmat	93	Østensjøvn 79 / Bryn senter	134	Stallerudveien 89
12	Sandakerveien 98	53	Kongsberget 12 / Bergsengt	94	Østensjøveien 67	135	Stallerudveien 93
13	Sandakerveien 74	54	Sogn Studentby - Rolf E. Stenersens alle 26-28	95	Manglerudveien 116	136	Stallerudveien 119
14	Fernanda Nissens gate 1	55	Rasmus Winderensvei 46	96	Symveien 2	137	Stallerudveien 121
15	Nydalsveien 17	56	Rasmus Winderensvei 6	97	Vardeveien 45	138	Skullerudveien 59 / Rimi Skullerudvn brt
16	Maridalsvn 262 / Bishop Heuchsv v/ Shell	57	Vinderveien 1	98	Stamhusveien 84 / Ekeberg. Skole	139	Bølerfla 52- Ica Butikk
17	Maridalsv brt (Maridalsveien 229) Badebakken	58	Frognerseierveien 27 / Stasjonsveien	99	Ekebergveien 65 (for det er Ekeberg camping)	140	Tveita Senter (Tvetervn 150)
18	Moldegata 1C	59	Slendelst / Gulleråsvn.	100	Marielundveien 2 / Holtet satstjon	141	Rappveien 1
19	Moldegata 9	60	Frognerseierveien 63 V/ Parkplass	101	Ekebergveien 175	142	Damfaret 25 / Godella T. bane
20	Moldegata 1	61	Gaupefaret 4	102	Ekebergveien 174 / Kastellet Brannstasjon	143	Solbergveien 44
21	Mor go hietas vei 3	62	Holmekollveien 15	103	Kastellveien 2	144	Hellerudstribben 2 / Tveterveien 170 v/ ICA
22	Adv Dehlis plass (Bjørsegt 1)	63	Olav Aukrusts vei 22	104	Cappelens vei 12	145	Arnliot Gellines vei 29
23	Sageve Torg (Kristiansandsgata 1)	64	Arnebråthveien 118 (Tidl Arnebråthveien 157/ Jarbakken)	105	Solveien 47	146	Grønmo Miljøstasjon / Gjenbruksstasjon / Sørliveien 1
24	Leilandgt. 78 / Jutulveien	65	Sørkedalsveien 258 / Peder Ankersplass	106	Mosseveien 186	147	Låbruvveien 90
25	Kongvingergetta 1a	66	Ekraveien 35	107	Nordstrandveien 78	148	Låbrubakken 1 / Ekebergveien
26	Tåsenveien 28	67	Sørkedalsveien 193 / Buss holdeplass	108	Nordstrandveien 40 / Sæter v/ Esso	149	Midtåsen 51 / Nøttekneika / Øvre Jan vei
27	Pastor Fangens vei 26	68	Vakerdveien 205A v/ Røa Apotek	109	Nordstrandveien 62 kiwi	150	Åsdalsveien 55
28	Nils Laurtssønnsvei 34	69	Røhagan 1B	110	Nordstrandveien 86	151	Gladvollveien / Herregårdsveien 1
29	Bergsallén 1 / Damplassen	70	Enebakkveien 158 (v/ Spar)	111	Langbølgen 56	152	Herregårdsveien 8/ Kruterveien 1
30	John Collets alle 1 / John Collets Plass	71	Manglerud Senter (Plogvn 31)	112	Langbølgen 39 v/ Kiwi	153	Gladvoll Terrasse 3
31	Kai Mundts vei 41 / Tåsen senter	72	Manglerudveien 1C	113	Langbølgen 2 / Lambergseter senter	154	Herregårdsveien 37
32	Nils Bays vei 26 / Lensolveien	73	Steinbergveien 38	114	Lambergseterveien 59 / Nyånde	155	Brattvollveien 35 / Munkrudstjetta brt.
33	Nordbergveien 64/ Borgestadveien	74	Enebakkveien 154B	115	Gina Krogsvell 1	156	Vækerdveien 75 / Lyseveien
34	Nordbergveien 105	75	Vahlåveien nr 9 / Ryenbergveien	116	Cecilie Thorstensvei V/ Rema 1000	157	Lilleaker st. (Lilleakervn. 30)
35	Sognsveien 165 (ny uke 21)	76	Konowsgt 74 / Vahlavn. / v/ Shell	117	Rachsvell 38 / Steingrimsvell	158	Lilleakervn. 16d / CC vest
36	Sognsveien 218/ Ringsjå Studentby	77	Ryenbergveien 73 B	118	Radarveien 64	159	Husebybakken 16
37	Olav M Trosskvei 8	78	Tubroveien 2	119	Lambergseterveien 7 / Pearl Engensvei 2 A	160	Olaf Bull's vei nr. 28
38	Olav M Trosskvei 32	79	Enebakkveien 34 / Smållens gt	120	Nydalsveien 28	161	Olaf Bull's vei nr. 30-82
39	Minister Ditlevsvei 21 v/ Nordberg Mat(Weny)	80	Biskop Jens Nilsønsgt. 5- Rema 1000	121	Ekebergveien 195 / Ica / Bråthen T- Bane	162	Grindbakken 3
40	Maridalsveien 350	81	Østmarkveien 25 NEMA1000	122	Frierveien 18	163	Arnulf Øverlands vei 81
41	Sandakerveien 131	82	Ettaåsen 10	123	Bekkeilaget Texaco (Mosseveien 147)	164	Sørkedalen 963 v/ Samvitkeilaget

Appendix 12 – Static Routes – Chauffeur 2, Week 3

Order	Address	Order	Address	Order	Address	Order	Address
1	Stig / Rødbergvn 16/(Tonsenhagen Torg)	44	Konvalveien 29	87	Emil Korsmo vei 10	130	Tråkka 34
2	Kjelsåvn 7 v/Rema 1000	45	Carl Kjelsensv.23 v/Norderghjemmet	88	Lille Langervud vei/f. brl (Langervudhagen)	131	Tråkka 10
3	Kjelsåvn 7 v/Rema 1000 - 2. tømning	46	Minister Ditlevs vei 21 v/Nordberg Mat(Meny)	89	Låveveien 70 / Håkon Tveters vei / Statoli Østensjø	132	Holmenkoliveien 15
4	Grefsenveien / Kapeilvn	47	Langmyrveien 1 / Amotveien	90	Låveveien 1 / Tvetenveien	133	lensmessveien 1
5	Grefsenveien Disen Stasjon	48	Reistad brl (Lindebergåsen 27)	91	Paal Bergsvei 31	134	Frognerstetereien 27 / Stasjonsveien
6	Kapeilvn / Morelsv v/Grefsen Skole	49	Lindebergåsen 10 (P-plass) v/Prix	92	Gamle Bygdevei 43	135	Slømdal st / Gulteråsn.
7	Sandaker plass (Sandakerveien 62)	50	Lindebergåsen 45-49	93	Ljabrubakken 1 / Ekebergveien	136	Gulleråsveien 9A v/Hemmingbanen/Slømdal
8	Sandaker Senter (V.v Åsengata 1)	51	Øie Reistadsvei 7	94	Nordstrandveien 40 / Sæter v/Esso	137	Frognerstetereien 74
9	Kyrre Greppes gt 13	52	Øie Reistadsvei 27	95	Nordstrandveien 62 kwi	138	Frognersteternv.63 v/Parkeplass
10	Kyrre Greppes gt 11	53	Øie Reistadsvei 37	96	Langbølgen 2 / lambeigseter senter	139	Besserud (Ankervn.23) Holmenkoliveien 99
11	Lilligata 5K	54	Lutvansskolen brl (Øie reistadv 5)	97	Rachsv 38 / Steingrimsvei	140	Setra vei 16 c
12	Mardalsveien 175 / Gjølvingata	55	Heggestien 71/Lindebergvn.1 garasjelek	98	Sandstuveien 41 / Brattikollen T Bane	141	Midtstugrenda 15
13	Adv Dehlis plass (Bjølsengt 1)	56	Lindebergveien 10 / Lindeberg Omorgssenter	99	Dovervingen 1	142	Svartrosveien 25
14	Sagene Torg (Kristiansand sgata 1)	57	Lindebergåsen 64b	100	Martenslundveien 2 / Holtet satjon	143	Voksenkoliveien 7
15	Bjølsengata 15-17 / Sarpstorggata	58	Furuset Statoli (Tevlingvn 19)	101	Lambertstetereien 7 / Pearl Engensvei 2 A	144	Voksenkoliveien / Holmenkoliveien 160
16	Holmestrandsgt 22b	59	Lindebergåsen 5	102	Gladvollveien / Herregårdsveien 1	145	Voksenkoliveien 57G / Tryansveien
17	Mardalsveien 286 / Nedre stabursvei	60	Tveita Senter (Tvetenvn 150)	103	Nedre Prinsdalsvei 72 / TCA Prinsdal park plass	146	Lillevansveien 81
18	Mardalsveien 350	61	Opsalsluben 3- Rimi	104	Asperudtoppen brl (asperudtoppen 1)	147	Sørkedalsveien 258 /Peder Ankersplass
19	Mardalsveien/Kjelsåsveien 188- Brekkekrusset	62	Vetlandsveien v/Rimi	105	Holmlåveien 100 / Rema / Esso	148	Ekraveien 35
20	Sagaåmmen / Frysjaveien	63	Østmarkveien 25 REMA1000	106	Nordåsv. 72 v/Kivi	149	Arnebråveien 118 (Tidl.Arnebråveien 157/ Jarbakken)
21	Stilla hf (Solilgrenda 70)	64	Ulsrudveien 20 / Østbyveien	107	Ravnåsv. 38 / Ravnkroken	150	Landingsvei 84 (Orrebakken brl)
22	Grefsenvn / Midtdovn 2	65	Utmærksveien 1 / Bøler senter	108	Lvsjordet nat (Vækerøvn 114-132)	151	Makrellbakken (Morgedalsveien 1)(Njårdhallen)
23	Kjelsås st (Midtdovn 12)	66	Bøleria 52- Ica Butikk	109	Hofsfjel Løvenskioldsvet 23	152	Sondrevegen 9
24	Gamle Kjelsåsveien / Marsveien	67	General Ruges Vei 97 / Bogerud T-bane	110	Hofsfjel Løvenskioldsvet 25	153	Silurnv / Ulendhausseen 82
25	Kapeilveien 118 v/ Miljøstasjon	68	Skullerudveien 59 / Rimi Skullerudvn. brl	111	Ullern alle 6	154	Lilleaker st. (Lilleakervn. 30)
26	Grefsenveien / L yngåsn 2	69	Gamle Enebakkvei 51	112	Bjørnsletta Shal (Bærumsvn 20b)	155	Lilleakervn. 16d / CC vest
27	Kjelsåsn 87/ L yngåsn v/ Jokerbutikk	70	Gamle Enebakkvei 121	113	Lvsheggen 46 v/Rimi	156	Vækerøveien 5
28	Grefsenkollvn 14 / Åkebakskogen	71	Løvsedalvn 2	114	Skogfaret 7	157	Sigurd Iversensvei 42
29	Myrforjordet (Myrskogvn / Kunn 1)	72	Enebakkveien 264, Abildsø Skole	115	Ullern alle 41. Åsjordet v/Spar	158	Silurveien 45
30	Grefsen Terr brl (Grefsen Terr / Kurv 1)	73	Enebakkveien 208/Plogveien / Rimi	116	Åsstubben 1	159	Huldrveien 28
31	Myrerskogveien 52 c	74	Treskeveien 95	117	Ullernkollen 13	160	Trimveien 8
32	Lachmannsvein 54	75	Treskeveien 47	118	Ullernkollen 1	161	Sognsvamsveien 51D
33	Kallandvn 2 / Solemskogvn	76	Treskeveien 31	119	Ostadsalsveien 69	162	Gaustadveien 8 Gaustadveien brl
34	Sandakerveien 22 A - Borettslag v/ restaurall	77	Skuruvveien 41	120	Roa bse (Portrynn 1)	163	Gaustadveien 35 ved garasjehus
35	Sandakerveien 22 B	78	Vektoreveien 35	121	Vækerøveien 205A v/Roa Apotek	164	Betsy Kjelsberg 9 v/Coop
36	Nils Lauritsønsvet 34	79	Manglerud Senter (Plogvn 31)	122	Sørkedalsveien 148/ Huseby Gardelær	165	Biskop Jens Nilssønsgt. 5- Rema 1000
37	Bergsællen 1 / Damplassen	80	Plogveien 29	123	Sørkedalsveien 148/ Huseby Gardelær	166	Enebakkveien 34 / Smållens gt
38	Sognsveien 61 / Trolsvingen	81	Rugveien 44	124	Perabråtan	167	Grønmo Miljøstasjon / Glenbruksstasjon / Sørilveien 1
39	John Collets alle 1 / John Collets Plass	82	Otto Sognsvei 5	125	Stasjonsveien 64	168	Lindeberg Senter (Jerkovvn 17)
40	Sognsveien 84	83	Wetlesensvei 2	126	Lybekkeveien 17	169	Nyjordveien 54 / Nyjordstubben 1
41	Sogn Studentby - Rolf E.Stenersens alle 26-28	84	Manglerud idr.anlegg (Plogvn 22)	127	Arnebråveien 40	170	Grenbergstubben 24 / Bjørndalen senter
42	Klaus Torårdsvet 6-16	85	Enebakkveien 154B	128	Holmenkoliveien 43		
43	Sognsveien 102	86	Johan Hirsch vei	129	Gauperfaret 4		

Appendix 13 – Static Routes – Chauffeur 2, Week 4

Order	Address	Order	Address	Order	Address	Order	Address
1	Olav Nygårdsv. 34	43	Haugrudveien 84	85	Nils Bays vei 26 / Lersøveien	127	Enebakkveien 158 (v/ Spar)
2	Olav Nygårdsv. 59	44	Haugrudveien 86	86	Sogn Studentby - Rolf E. Stenensens alle 26-28	128	Manglerud Senter (Plogvn 31)
3	Olav Nygårdsv. 23	45	Haugrudveien 88	87	Sognsveien 218/Kringsjå Studentby	129	Enebakkveien 289 v/Prix / Lille Langerud torg
4	Olav Nygårdsv. 216	46	Hauksdalen btl (Johan Castb. v. / Dr.Dedichensv 31)	88	Minister Ditlevsvei 21 v/Nordberg Mat(Weny)	130	Valhallveien nr 9 / Ryenbergveien
5	Olav Nygårdsv. 194	47	Dr. Dedichensvei 20	89	Tåsenveien 77	131	Ryenbergveien 73 B
6	Østmarkveien 25 REMA1000	48	Dr. Dedichensvei 28	90	Mardalsveien 350	132	Turbinveien 2
7	Ulsrud T-bane (Ulsrudn 35)	49	Fagerholt btl (Dr.Dedichensv 54)	91	Grefsen v/ Midtdovn 2	133	Enebakkveien 34 / Smålensgt
8	Bølerbakken 2	50	Fagerholt btl (Dr.Dedichensv 90)	92	Kapellveien 118 v/ Miljøstasjon	134	Biskop Jens Nilssønsgt. 5- Rema 1000
9	Bøleria 52- Ica Butikk	51	Dr. Dedichensvei 100	93	Kjelsåsveien 69b v/Gml Brannstasjon	135	Stamhusveien 84 / Ekeberg. Skole
10	Eterveien 1 / Østensjøveien btl.	52	Lutvanskrøken	94	Grefsenkollv 14 / Åkebakkeskogen	136	Enebakkveien 289 v/Prix / Lille Langerud torg
11	Østensjøveien 208	53	Ole Messetkvei 10 i rundkjøringen	95	Myerjordet (Myrskogvn / Kuvn 1)	137	General Ruges Vei 97 / Bogerud T-bane
12	Låveveien 70	54	Johan Castbergsv. 54	96	Kjelsås v/ Skelbanen	138	Rustadgrenda 12
13	Østensjøvn. 79 / Bryn senter	55	Johan Castbergsv. 30 / V park.plass	97	Kjelsåsvn 7 v/Rema 1000	139	Rustadgrenda 47
14	Mekamikerveien 8	56	Stubberudlia btl (Tvetenvn 259)	98	Kjelsåsvn 7 v/Rema 1000 - 2. tømning	140	Weiding Olsensvei 5
15	Vetlandsveien 64 v/Rema	57	Trøsterud Senter (Tvetenvn 233)	99	Sandakerveien 74	141	Skullerudveien 59 / Rimi Skullerudvn. btl
16	Oppsaskrubben 3- Rimi	58	Haugrudsentret 1	100	Sandaker plass (Sandakerveien 62)	142	Johan Scharffensvei 99
17	Vetlandsveien v/Rimi	59	Haugrudshagan 80	101	Sandaker Senter (V.v. Åsengata 1)	143	General Ruges Vei 92
18	Hellerudshagen 22	60	Haugrudshagan 82	102	Kyrre Grepes gt 13	144	Rundtjernveien 72
19	Hellerudfaret 28	61	Haugrudshagan 125	103	Gunnar Schjelderups vei 11 R	145	Larsbråten 32 (l enden)
20	Hellerudfaret bs (Hellerudfaret / Hellerudvn 61)	62	Sagene Torg (Kristiansandsvegata 1)	104	Gunnar Schjelderups vei 13	146	Stig (Rødbergvn 16)(Tonsenhagen Torg)
21	Hellerudveien 53	63	Adv Dehls plass (Bølsergt 1)	105	Grømo Miljøstasjon	147	Linderud Senter (Erik Mogenssønsvei 38)
22	Stordamveien 34	64	Kongsberggt 12 / Bergensgt	106	Kongsveien 50	148	Rasmus Winderensvei 46
23	Tvæita Senter (Tvetenvn 150)	65	Mor go hertas vei 3	107	Martenlundveien 2 / Holtet satsjon	149	Rasmus Winderensvei 6
24	Nåkkves vei 3	66	Moldegata 9	108	Ekebergveien 174 / Kastellet Brannstasjon	150	Frognersteterveien 27 / Stasjonsveien
25	Smalvollskogen btl (Gunnulvsv. 10)	67	Moldegata 1	109	Cappelens vei 12	151	Stemdalst / Gulleråsvn.
26	Smalvollskogen btl (Lavransv.)	68	Moldegata 1C	110	Lambertsteterveien 7 / Pearl Engensvei 2 A	152	Heyerdahl vei 3
27	Ragnfridsvei 68	69	Mardalsvn 262 / Biskop Heuchsv v/Shell	111	Ekebergveien 195 / Ica / Bråthen T-Bane	153	Frognerstetervn.63 V/Parkplass
28	Kristins vei 2	70	Mardalsv btl (Mardalsveien 229) Badebakken	112	Rachsv. 38 / Steingrimsv. 1	154	Gaupefaret 4
29	Sørteillinga btl (Simon Darrsv 29)	71	Tåsenveien 28	113	Cecilie Thoresensvei v/Rema 1000	155	Holmenkollveien 15
30	Hellerudstubbene 2 /Tvetenveien 170 v/ ICA	72	Nils Lauritssønsvei 34	114	Langbølgen 2 / Lambertseter senter	156	Olav Aukrusts vei 22
31	Haugrudshagan 10	73	Bergsallien 1 / Damplassen	115	Langbølgen 39 v/Kiwi	157	Arnebråteveien 118
32	Haugrudtunet 1 / Hugerudveien 36	74	John Collets alle 1 / John Collets Plass	116	Mellomhølgen 62 / Bergkrystallen T-bane	158	Sørredalsveien 258 / Peder Ankersplass
33	Haugrudveien 20	75	Ullevålsallien 2G	117	Nordstrandveien 62 Kiwi	159	Ekraveien 35
34	Haugrudveien 44	76	Nedre Ullevål 2B	118	Nordstrandveien 40 / Sæter v/Esso	160	Olaf Bulls vei nr. 30-82
35	Haugrud btl (Haugrudvn 18)	77	Nedre Ullevål 9	119	Ljårbakken 1 / Ekebergveien	161	Grindbakken 3
36	Sjernermyrveien 24	78	Nedre Ullevål 7	120	Gladvollveien / Herregårdsv. 1	162	Husebybakken 16
37	Haugrudveien 72	79	Kirkeveien 166B	121	Herregårdsv. 8 / Kruttkveien 1	163	Ormsundveien / Grønsvundvn 20
38	Haugrudveien 74	80	Apalveien 42	122	Gladvoll Terrasse 3	164	Bekkelaget Texaco (Mosseveien 147)
39	Haugrudveien 76	81	Blindernvn /Apalveien 60	123	Vækerøyveien 75 / Lyseveien	165	Inger Hagerups plass
40	Haugrudveien 85	82	Blindernveien 41	124	Lilleaker st. (Lilleakervn. 30)		
41	Haugrudveien 78	83	Juvveien 12 / Ullevålsallien	125	Lilleakervn. 16d / CC vest		
42	Haugrudveien 82	84	Kal Munchs vei 41 / Tåsen senter	126	Vækerøyveien 205A v/Røa Apotek		

Preliminary Thesis Report

ID number: **0816762**
0943657

Preliminary Thesis Report
BI Norwegian Business School

**How can the Agency of Waste
Management solve the Vehicle
Routing Problem in the collection of
glass and metal in order to acquire
higher customer service and
minimize total costs?**

Hand-in date:
15.01.2014

Campus:
BI Oslo

Examination code and name:

GRA 19002 – **Preliminary Thesis Report**

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Programme:
Master of Science in Business and Economics, Logistics – Supply Chains
and Networks

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Summary

The paper is a preliminary report for our master thesis. The topic in question is the recycling process of glass and metal where the focus is on the collection part of the recycling process.

Being aware of environmental consequences is today of growing interest and has become more or less a trend and competitive advantage. The Agency of Waste Management in the municipality in Oslo outsourced the collection of waste for the first time in 1992 and shall now negotiate on new 5th generation contracts. In this context, we have got the challenge of writing a paper enabling them with the knowledge necessary in order to choose the best contractor to perform the collection of glass and metal.

The objective of the thesis is to develop a model for a vehicle routing problem and solve it using a heuristic technique. It is supposed to examine whether it is possible to enhance the efficiency of the collection of glass and metal concerning total costs and increase the service level/fill rate. The research question is as follows:

“How can the Agency of Waste Management solve the vehicle routing problem in the collection of glass and metal in order to acquire higher customer service and minimize total cost?”

By refining previous literature we see that this question in particular has been in a lot of research earlier and based on this we develop a model to solve our problem.

Since we are performing an operations research the strategy will be quantitative modelling, but there will also be some qualitative research present. The research design is an experimental study in accordance to the type of research we are doing.

1. Introduction

1.1 Background

In today's society it has become of increasing importance to be environmental conscious in business and industry as well as for the private homes. One can say that being a green business has often become a competitive advantage in today's economical world. Accordingly, it has been of importance to address the issues related to reverse logistics in many companies and how to manage the reverse logistics in a cost effective and efficient manner. Additionally, it has been an increasing concern towards the designing of the physical reversed logistics channel. This involves scheduling traffic routes the vehicles shall drive and where to best locate the different collection facilities. Further the capacity of both vehicles and collection facilities is of importance in order to design a vehicle route. Moreover, it has to satisfy the requirements from an economic, social and environmental standpoint. The focus in this paper is the waste collection process controlled by the Agency of Waste Management for the municipality of Oslo with emphasis on glass and metal.

Further the paper is organized as follow. The next sections will give an introduction of the Agency of Waste Management and how it currently collect glass and metal followed by a description of the problem statement. Section 2 provide some important definitions and explanations in which are relevant to answer the research question, and relevant literature and models. Further, section 3 illustrates our own research model and the assumptions applied to develop this. Section 4 gives an insight into the methodology to be used before section 5 finish off by giving a picture of the expected progress plan.

1.2 The Agency of Waste Management

The municipalities in Norway are required by law to solve the collection of household waste on a local level. Consequently the municipalities must organize own collection systems, which results in various ways of performing according to the municipalities needs regarding (types of) households, the municipality itself and sanitation companies (Bø, Flygansvær et al. 2012). Today the collection process regarding collecting devices has been more complex and there exist three diverse systems of collecting household waste in Norway today: collection by

containers/devices, deep collectors and waste disposals. When deciding how to collect the waste it is important to consider three main drivers: effective transport capacity, number of containers/devices and delivery frequency (service level) (Bø, Flygansvør et al. 2012). It is essential to streamline these three main drivers in accordance to minimize the environmental consequences (lowest possible CO₂ emissions) and costs that may appear regarding waste collection.

The Agency of Waste Management (AWM) governs the City of Oslo's waste disposal. However, private waste disposal companies perform the emptying and transport of household waste on tenders from AWM. The agency is headquartered in Nydalen, and manages recycling stations, mini-recycling stations and garden centres in Oslo (Renovasjonsetaten 2013). The residents in Oslo generate approximately 230.000 tons of household waste in total each year. The AWM provides for the collection of paper-, food-, plastic- and residual waste, in which together constitutes approximately 70% of household waste. This requires more than 7 million emptying's of collection devices per year. The households collect these four types of waste in three different coloured bags, which are disposed in a common bin. There is a blue bag for plastic, a green bag for food waste and a third bag, preferable white, for residual waste. In addition there is a separate bin for the collection of paper and cardboards. On the other side, the residents themselves provide for bringing approximately 30% of generated waste volume, such as glass- and metal packaging, from the households to different recycling points/devices and facilities for glass and metal (Renovasjonsetaten 2013).

1.3 Problem Statement

The collection of waste in Oslo was outsourced for the first time in 1992 and has been outsourced four times since. In this way the knowledge and control has been transferred from AWM to the contractors such as RENAS. AWM is currently working on a project to conduct the "5th generation contracts" for collection of waste. The main goal for the new contracts is to help ensuring best possible quality on collected, sorted waste and highest possible recycling rate on materials. From the experiences of the new source separation system, the current refuse collection contracts is considered to not be sufficient enough regarding incentive schemes and solutions securing best possible waste quality and material recycling rate. Nor do the contracts secure lowest possible climate- and environmental

impact through optimal route planning. In addition, the current renovation contracts' cost effectiveness is affected because the composition of the collection equipment is significantly different from what was assumed. Moreover, the area of focus of the project is: waste quality, recycling rate of materials, climate and environment, cost effectiveness, customer satisfaction and innovation.

Keeping this in mind, the main focus of the paper will be to perform an analysis of the collection of glass and metal disposals regarding level gauges (how full the collection points are at all times and how often the collecting devices has to be emptied) and the fleet management of transportation and distribution points/devices based on this. The aim is to develop a model such that the AWM obtains the knowledge necessary to accept and develop the best contract for its purpose regarding the collection process. Accordingly, the research question can be formulated as follows:

“How can the Agency of Waste Management solve the vehicle routing problem in the collection of glass and metal in order to acquire higher customer service and minimize total cost?”

To answer the research question we will model a vehicle routing problem and solve it using a heuristic technique to retrieve the optimal solution.

1.4 Limitations

In order to answer the research question some limitations has to be made due to time and scope. Reversed logistics is a broad topic and according to the research question and problem statement many aspects is interesting for further research. This research will focus on the collection process, and not the reprocessing, of only glass and metal, in which involves only the part of the recycling process where the contractors pick up glass and metal from the collection points (appendix 1). This is due to limit the scope of data in which will make it easier to access and collect data. If we were to consider the entire collection of waste disposal we could meet problems with to much data and bad quality of the data. The thesis is therefore limit to only solely focusing on the collection of glass and metal and not of paper, food, plastic and residual waste.

1.5 Theoretical Relevance

From a theoretical point of view, the thesis will most likely contribute with noteworthy results. There already exist research on this field, but non-are conducted in Norway and therefore we hope this thesis could participate with relevant constraints and optimal solutions from a Norwegian perspective. It will be a combination of literature within the field of optimization models, distribution, supply chain and reverse logistics.

1.6 Practical Relevance

As the main goal of this thesis is to develop a model for the AWM, in order to provide them with more knowledge about vehicle route planning in their negotiation of new contract, a practical relevance of our study is present. The thesis will contribute the AWM to pick the right contractor to perform the collection of glass and metal. Further, the thesis is expected to contribute both the AWM and also a general model for other companies facing issues in how to collect (all kind of) waste as efficient as possible in order to deliver high customer service. By this we will develop a model concerning how to best schedule an efficient traffic route and where to locate the different collection devices in order to increase the response time.

2. Theory

Although the field of reverse logistics is relative new and has a short history so far, there exist a lot of previous research regarding how to manage the process of reverse logistics in an efficient manner. In addition, it will be important to find theory and literature associated with optimization. Accordingly, in this part there will be a presentation of relevant theory and literature that are considered to be most relevant according to the subject in question. A challenge to be met is the difficulties to find all the relevant literature that is relevant to answer the research question. There are many different fields within logistics literature that will be important for us to conduct to develop a new model.

2.1 Relevant Definitions and Explanations

2.1.1 Reverse Logistics

Reverse logistics is often seen in many different settings and meanings. For instance, reverse logistic is defined by Rogers and Tibben-Lembke (2001) (p.130)

as “*The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal*”. On the other hand, Fleischmann, Bloemhof-Ruwaard et al. (1997) (p.2) states that reverse logistics is considered as the “logistic activities all the way from used products no longer required by the user to products again usable in a market (...) involves the physical transportation of used products from the end user back to a producer, thus distribution planning aspects. The Next step is the transformation by the producer of the returned products into usable products again”. This indicates that reverse logistics mainly consist of two aspects: collection process and reprocessing (Jahre 1995). Figure 1 gives an illustration of how a reversed logistics channel may look like.

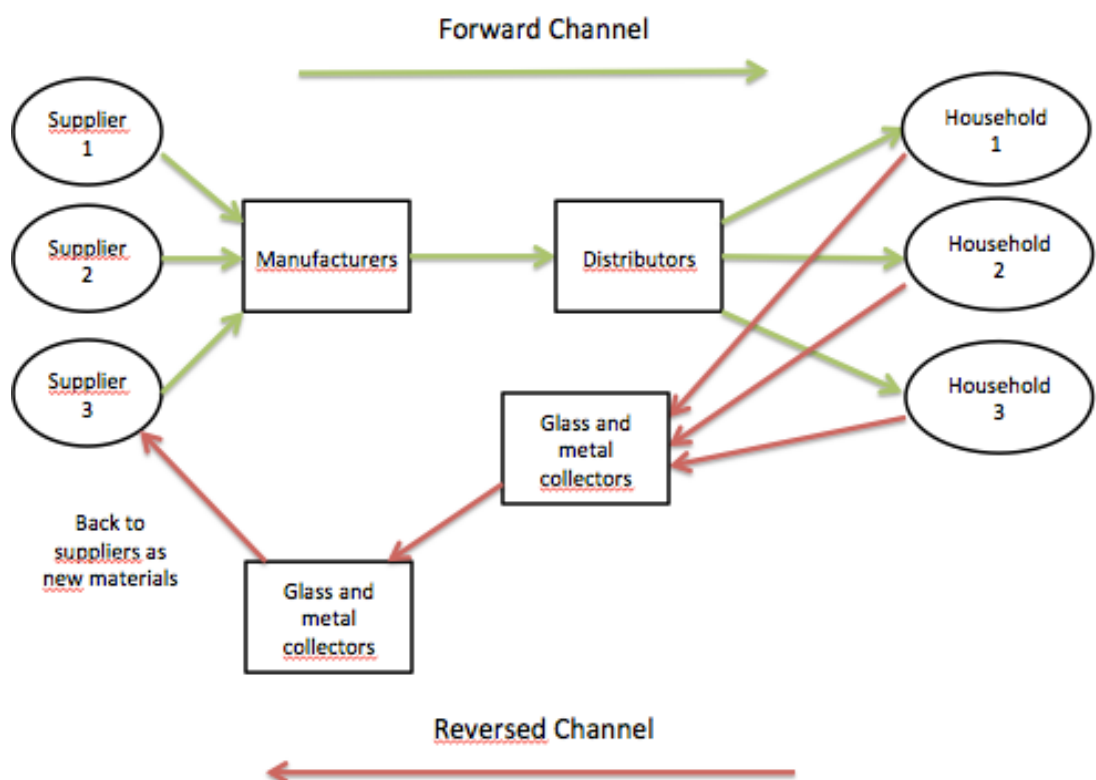


Figure 1: A reversed logistics channel

2.1.2 Optimization

Biegler (2010) defines optimization in a mathematical context as maximizing or minimizing a function, where the function has a set of variables that are subject to a set of constraints. In other words, it is to find the best possible solution to a function describing system behaviour, within the systems constraints. This task requires the following elements:

- 4) An objective function that provides a scalar quantification performance measure that needs to be minimized or maximized.
- 5) A predictive model to describe the behaviour of the system, and also to express the limitations or constraints of the system.
- 6) A set of defined variables that appear in the predictive model.

The idea of optimization is to find the combination of values for the defined variables that satisfies the constraints given by the predictive model and at the same time maximizes or minimizes the objective function.

2.1.3 The Vehicle Routing Problem (VRP)

The vehicle routing problem (VRP) concerns “the transport between depots and customers by means of a fleet of vehicles” (Rizzoli, Montemanni et al. 2007) Elements that could define and constrain each model of the VRP are the *road network*, *the vehicles* and *the customers*. According to Teixeira, Antunes et al. (2004) a VRP consist of the creation of sequence of routes for multiple days of a fixed planning period (e.g. a week) and are usually modelled in the literature as the PVRP. Rizzoli, Montemanni et al. (2007) states VRP can be formulated as to find optimal routes for a fleet of vehicles that perform an assigned task on a number of spatially distributed customers. To solve the problem one must find the best route serving all customers using the fleet of vehicles and fulfilling all operational constraints and minimize total travelling distance.

2.1.4 Arc Routing Problem (ARP)

Lancaster University Management School (2013) defines arc routing problems as “a special kind of vehicle routing problem in which the vehicles are constrained to traverse certain arcs, rather than visit certain nodes as in the standard Vehicle Routing Problem.” The arcs typically represent streets that require some kind of

treatment or service. Nuortio, Kytöjoki et al. (2006) states that ARP is commonly used in situations where all the bins along the route has to be collected at the same time, and most of the street segments must be collected

2.1.5 Heuristic Technique

A heuristic approach is used to develop an acceptable, but not necessarily an optimal solution, to a problem by applying human intelligence, experience, common sense and certain rules of thumb (Shuster and Schur 1974). To determine what constitutes an acceptable solution is part of the task of deciding which approach to use. We can roughly define that an acceptable solution is both reasonably good (i.e. close to optimum) and derived within reasonable effort, time and cost constraints. The procedure is often a full-fledged iterative algorithm, where each iteration involves performing a search for a new and better solution than the best solution already found (Hillier and Lieberman 2010).

One way to solve the vehicle routing problem is to use a heuristic technique. An example of a heuristic solution process is included in appendix 2. Classic heuristic methods was mostly developed between 1960 and 1990 (Toth and Vigo 2002) and these methods perform limited exploration of the search space and produce good quality solutions within modest computing times. Furthermore heuristics can be classified into three categories:

- 1) Constructive heuristics
- 2) Two-phase heuristics
- 3) Improvement methods

The two-phase heuristic can again be divided into cluster-first, route-second methods and route-first, cluster-second methods.

2.1.6 Metaheuristic Technique

A metaheuristic is a general solution method that involves both a general structure and strategy guidelines for developing a certain heuristic method to fit a particular kind of problem (Hillier and Liberman 2010). Toth and Vigo (2002) that metaheuristics allow deteriorating and infeasible intermediary solutions in the course of the search process. Ant Colony Optimization (ACO) is a metaheuristic technique, and according to Rizzoli, Montemanni et al. (2007) it is an optimization framework inspired by observation of ants, and how they use pheromone trails to communicate information regarding the shortest path to food.

To explain it further, picture a moving ant lays some pheromone on the ground, thus marking a path with a trail of this substance. Afterwards an isolated ant moves randomly and detects a previously laid pheromone trail. The ant can now decide to follow it. The collective behaviour that results is a form of autocatalytic behaviour where the more ants follow a trail, the more attractive it becomes. The probability of an ant choosing the path increases with the number of ants that previously chose the same path (Rizzoli, Montemanni et al. 2007).

2.2 Literature Review

All over the world case studies concerning this particular subject has been conducted. The collection of refuse waste is one of the most difficult operational problems faced by local authorities in any large city. Nuortio, Kytöjoki et al. (2006) performed a study about optimizing vehicle routes and schedules for collecting municipal solid waste in Eastern Finland. They describe what might be regarded as a Stochastic Periodic Vehicle Routing Problem with Time Window and limited number of vehicles (SPVRPTW). Further they propose an optimization model of how to design vehicles routes and schedules for collecting municipal solid waste in Finland by using a neighbourhood thresholding metaheuristic variable. Hence, the objective of the study was to minimize the travelling distance and plan the collection activities for each of the vehicles. The findings of the study demonstrate that there is possible to gain a cost reduction compared with the current practice.

Rizzoli, Montemanni et al. (2007) describes in their paper how the ant colony optimization can be successfully used to solve a number of variants of the basic VRP. They conclude their research with this allegation: "... after more than ten years of research, ACO has been shown to be one of the most successful metaheuristics for the VRP and its application to real-world problems demonstrates that it has now become a fundamental tool in applied operations research" (Rizzoli, Montemanni et al. 2007) (p.149))

In Italy Ghiani, Guerriero et al. (2005) performed a study about waste collection in a small town. Their objective function was to minimize total distance travelled by vehicles, The main difficulties they had to tackle included small and narrow streets where only small vehicles could drive, a time window constraint to avoid traffic congestion and difficulties with some vehicles not being able to unload some containers. They modelled the problem as an arc routing problem

and using a heuristic technique they came up with a computerized system which allowed one to avoid overtime and to accomplish a reduction in total cost of about 8%.

According to Baptista, Oliveira et al. (2002) (p.220) “a period vehicle routing problem (PVRP) is a multilevel problem assembling two classical problems: the assignment problem and the vehicle routing problem”. They states that each customer has to now the collection days and there is a need to design vehicle routes for each day of the time horizon in order to minimize distribution costs. This is illustrated through a real period vehicle routing system with focus on collection paper containers in Portugal and solved by using a heuristic algorithm proposed by Christofides and Beasley (1984). It presents a modification of the classical PVRP.

Also Teixeira, Antunes et al. (2004) studied the route planning of vehicles for the collection of urban recyclable waste in Portugal. The objective of problem in their research is a PVRP. Generally, this concerns minimization of the total travelling distance for each of the collection vehicles routes in the planning period, based on the constraints of vehicle capacity and duration of work shift as an extension of vehicle routing problems. In order to solve the problem Teixeira, Antunes et al. (2004) employs a heuristic method involving three phases: definition of the geographic zones served by the vehicles, definition of the waste type to collect on each day of the month, and definition of the collection routes.

Álvarez-Valdés, Benavent et al. (1993) Álvarez-Valdés, Benavent et al. (1993) presents a computerized system for urban and suburban garbage collection, an ARC model, as a solution of a specific routing problem. The model has the intention to function as a decision system and assist organizers when designing efficient collection routes. Furthermore, the challenge they meet is to construct the traffic routes for the vehicles while considering several constraints such as traffic regulations and personnel's working time due to minimize total travelling distance. They further developed two procedures to construct the route automatically: an adaptation of classical methods used in Arc Routing Problems and modified methods for the Traveling Salesman problem (TSP).

Mourão and Almeida (2000) presents two lower-bounding methods and a heuristic method to solve a capacitated arc routing problem concerning refuse collection in Lisbon. The lower-bound methods are both based on the transportation model, while the heuristic method is three-phased heuristic with a

route-first, cluster-second method and is based on the transformation of solution obtained with the lower-bounding method.

Bommisetty (1998) addresses the issue of collecting recyclable material in a large university campus with many buildings. The problem is modelled as a VRP with additional constraint and uses a two-phased algorithm to provide a heuristic solution. The objective in this study is to minimize collection time.

Based on the previous literature presented above we have drawn out those variables we believe have a greatest impact on the model we have as purpose to develop. As already mentioned, the literature above shows that there have been conducted many researches in other countries, but no one in Norway and its particular system. Therefore, our model does contain many of the same variables in addition to some others we have learned about during our courses and believe are important too.

3. Research Model

3.1 Research Model

In this section we will present the fitted model for our research. The model consists of the variables we believe have the greatest influence on the total cost.



Figure 2: Research Model

3.1.1 Fill rate

The fill rate measure how full the collection devices are when emptied. The goal in this thesis is to always assure that the collection devices never are completely filled so that the households never has to place the glass or metal in bags around the collection facilities. It is impossible to achieve a 100% fill rate and the goal for the fill rate in this case is the collection devices to never exceed 80% of their capacities.

3.1.2 Filling rate

The filling rate is related to the fill rate, but they must not be confused with each other. Filling rate concerns how fast the collection devices are filled up and this will affect how often the devices must be emptied. The filling rate is therefore an important factor that influences total cost.

3.1.3 Traffic and roads

Traffic in this context has an impact on total costs to the extent that queues, stops at traffic lights, roadwork, and the “quality” of the roads itself might increase the total costs due to fuel for the vehicles. Additionally, traffic is connected to working time, routes and the environment (which will be further explained below).

3.1.4. Working time

There does not exist a law for when recyclables can be picked up, but it is usually carried out early in the morning to prevent traffic congestion. This will work as a constraint on the problem because of the time-window open to finish the work. Also a regular Norwegian workday is 8 hours long including lunchtime, this also has to be taken into consideration.

3.1.5 Routes

The routes will affect how fast and effective the work is carried out and will therefore also affect the total cost. This is one of the main goals of the research, to analyse which route gives the best result

3.1.6 Uncertainty

In a reverse logistics network there are high chances for uncertainty when it comes to how much is returned, the quality of the returned products, and when

products is returned. It is difficult to predict exactly the amount of glass and metal the household's throw at all time and if the waste is thrown in accordance to restrictions given by AWM.

3.1.7 Capacity

We need to take into account the capacity of both the vehicles and the collection devices. These will affect total costs due to the emptying rate and which route the truck has to drive in order to obtain the most efficient collection.

3.1.8 Season

According to Chopra and Meindl (2013) a seasonal factor measure the extent to which the averages demand in a season is above or below the average in the year. Glass and metal does not have a specific seasonal factor but one can argue that around the 17th of May and after New Years Eve the demand will be higher than the rest of the year, even though this is not scientifically proved.

3.1.9 Environment

One of the main issues AWM wants to improve is how the recycling affects the environment. The current contracts does not secure lowest possible climate- and environmental impact, and this has to be taken into account by identifying the optimal route to be used. This can be to reduce the length of the route and minimize use of fuel. Environmental impact will be one of the output variables, depending on input variables.

3.2 Mathematical Model

Due to the model presented above we have developed a vehicle routing problem and considered different constraints based on the different variables influencing total cost (appendix 3). All of the variables mentioned above have not been included in the mathematical model due to complexity but it has to be kept in mind while solving the problem. The mathematical model is still a work in progress and works only as a draft for now.

4. Research Methodology

In this section we will first reflected on the research strategies and designs that are best suited for our research area. Afterwards we will present how we collect data and how we plan to ensure quality.

4.1 Research Strategy

According to Bryman and Bell (2011), the meaning of a research strategy is to generalize and orientate the business research. The research strategy can be divided into quantitative and qualitative research. It may be argued that a distinction between those are superficial, although necessary to get a clearer picture and help to better organize the research methods and approaches to observe, collect, analyse and deducing the data. Quantitative research is often a wider examination and may be understood as data collection consisting of quantification and measurements, while qualitative research entail words and emphasis non-quantifying methods were it might be easier to observe a real situation rather than evaluating theory (Bryman and Bell, 2011).

Our study is mainly a quantitative research. Quantitative modelling has usually been the basis of solving real-life problems in operations management. We will in this study develop a quantitative model, and use it to simulate different solutions for the research problem in question. The study will be based on quantitative data related to the collection of glass and metal, such as capacity, distance between collection facilities and so on. Even though the main strategic approach is quantitative we will also conduct some qualitative research to complement the collected quantitative data. Qualitative research could be helpful as a source to understand how one can use the quantitative data (Bryman and Bell, 2011) or apply the data in proper ways.

4.2 Research Design

Adoption of the research strategy cannot alone generalize the business research. Along with the business research there are important decisions regarding research design and methodology. “A research design provides a framework for the collection and analysis of data” (Bryman and Bell, 2011) (p.40.) There are five various kinds of design to choose from: experimental design, cross-sectional or social survey design, longitudinal design, case study design and comparative design.

We are performing an operations research and normally this type of research has an experimental design. We will develop a model and solve it using a heuristic technique to help AWM in the choosing of their next contractor. It is the focus and objective of the research, and not the application of a set of methods or the use of one design over another that distinguishes operations research from

other forms of research. The objective of operations research is to improve delivery of services, and this is the case in our study as well: to improve the routing problem.

4.3 Data collection

In this part of the paper we will present how we are going to collect data, and at the same time try to justify for the choices we have taken.

Total cost, driving time and environmental impact is the output variables/ performance measures generated by problem we are simulating. In order to obtain these values different input variables must be identified and collected. It is crucial that all relevant variables or factors are identified to provide the best possible model. To be able to identify the right input variables we need to collect both secondary and primary data. Primary data is data collected by the researcher, while secondary data is described as exploring any already existing materials (Bryman and Bell 2011).

4.3.1 Secondary data

The purpose of collecting secondary data is to identify which input variables that already exists and what input variables that needs to be collected as primarily data in order to run the simulation models. We believe that the following input variables can be gathered by using secondary data sources:

1. Traffic (lights etc.)
2. Routes (distance between collection facilities)
3. Working time (when they usually work, and how long)
4. Capacity of vehicles
5. Capacity of collection facilities

Even though study is heavily quantitative driven it is necessary to conduct interviews with both the AWM and the current contractors in order to get access to the quantitative data, to understand how and why things are done the way they are today and also to be aware of constraints that are not already mentioned.

The format of the interview will be semi-structured, which means we will use a list of questions as a leader for the interview. This is usually called an interview guide. It is important for us to prepare properly for the interview and

make the interview guide as good as possible to be able to retrieve the information we need. Bryman and Bell (2011) offers some guidelines to make the preparation better. We firstly need to construct a certain amount of order on the topic areas. This is to make the interview flow well, but we must also be prepared to alter the order of the questions during the interview. Other important things is to formulate the questions so it will help us answer our research question, and use a language that is comprehensible and relevant to the people we are interviewing. We must therefore prepare to be able to explain different words if it is needed. During the interview we will use a tape recorder (if we are allowed) to be sure that we retrieve all the information we want. This is important both to remember what they say and also the way they say it. Using a recorder will help us get a more thorough and correct examination of what the interviewee says, and it could help us correct the natural limitations of our memories.

4.3.2 Primary data

The main primary data we are collecting are filling rate and fill rate, which are variables that do not exist already. To be able to access this information we have to observe the collection of glass and metal for a period of time (e.g. a month), and make assumptions based on this. After this information is gathered it is possible to calculate the total cost and environmental impact for each different route using a computer program.

4.3.3 Data analysis

The variables that will be collected from secondary- and primarily sources are pure numbers and can be directly put into the developed model. The outcome of the interviews is mainly quantitative data and they do not require additional analysis in order to be used in the developed model. The main task with regards to data analysis will be to compare different routes that are an option in order to identify the most efficient and effective.

4.4 Quality of the Research

Reliability and validity are important aspects to remember when ensuring the quality of the research. Reliability refers to whether the results of a study are consistent, if it is possible to do the same study one more time and get the same results, while validity is concerned with how precisely you measure what you actually intend to measure (Bryman and Bell, 2011). The reliability criteria are

most important in a quantitative issue, but we will take it into account in regards to our qualitative part of our study as well. Validity is important in all research studies. Two alternative criteria for evaluating a qualitative research are trustworthiness and relevance.

4.4.1 Reliability

We divide reliability into different aspects. In quantitative studies they are called stability, internal reliability and inter-observer consistency, while in qualitative they are known as external and internal reliability. Stability and external reliability is concerned with the degree to which a study can be replicated (Bryman and Bell, 2011). It can be measured through the test- retest method or in alternative form (using different questions to measure the same). In our case, since we are using a model with inputs, it would be possible to retest the solution by using the same input variables.

Inter-observer consistency and internal reliability refers to different people observing the same thing during an observation. I.e. do they agree about what they see and hear? Bryman and Bell defines it as: “When a great deal of subjective judgment is involved in such activities as the recording or observations or the translation of the data into categories, and where more than one observer is involved in such activities, there is the possibility that there is a lack of consistency in their decisions.” To avoid this, we will as previously mentioned use a tape recorder during interviews.

4.4.2 Validity

In a quantitative research you are concerned with measurement validity. “The issue of measurement validity has to do with whether or not a measure of a concept really measure that concept” (Bryman and Bell, 2011). To be able to be sure that we are measuring the right thing and are taking all constraints into account in our study we will use the interviews to gather the correct information. By applying mathematical models that can provide results for a simple version of the system, validity can be assured. Additionally, by verifying and validating the results generated by the developed model with experienced personnel, is it possible that validity can be increased (Hillier and Lieberman 2010).

5. Progress Plan

The following table shows the activities that are to be conducted through the process of working on the Mater Thesis. However, there might be some deviations from this timetable as it is tentative and some changes during time are to be expected.

Actions	Deadline	Finished/ Started
Deliver preliminary thesis report	January 16 th 2014	Finished
Gain access to information/data from REN	February 1 st 2014	-
Complete theory and literature review	March 1 st 2014	-
Finalize and test conceptual model	March 20 th 2014	-
Improve model based on feedback	April 1 st 2014	-
Sampling and data analysis	May 1 st 2014	-
Interpreting and discuss results	May 20 th 2014	-
Finalize thesis	June 20 th 2014	-
Rework the thesis based on supervisor's recommendations	August 1 st 2014	-
Deliver final thesis	September 1 st 2014	-

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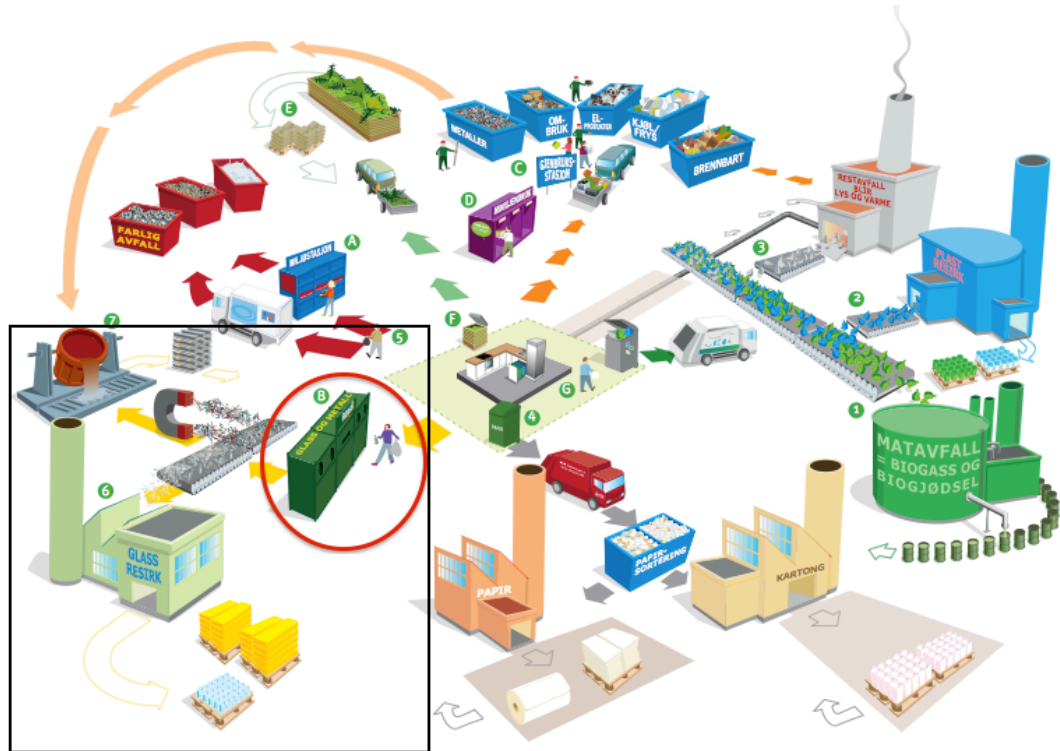
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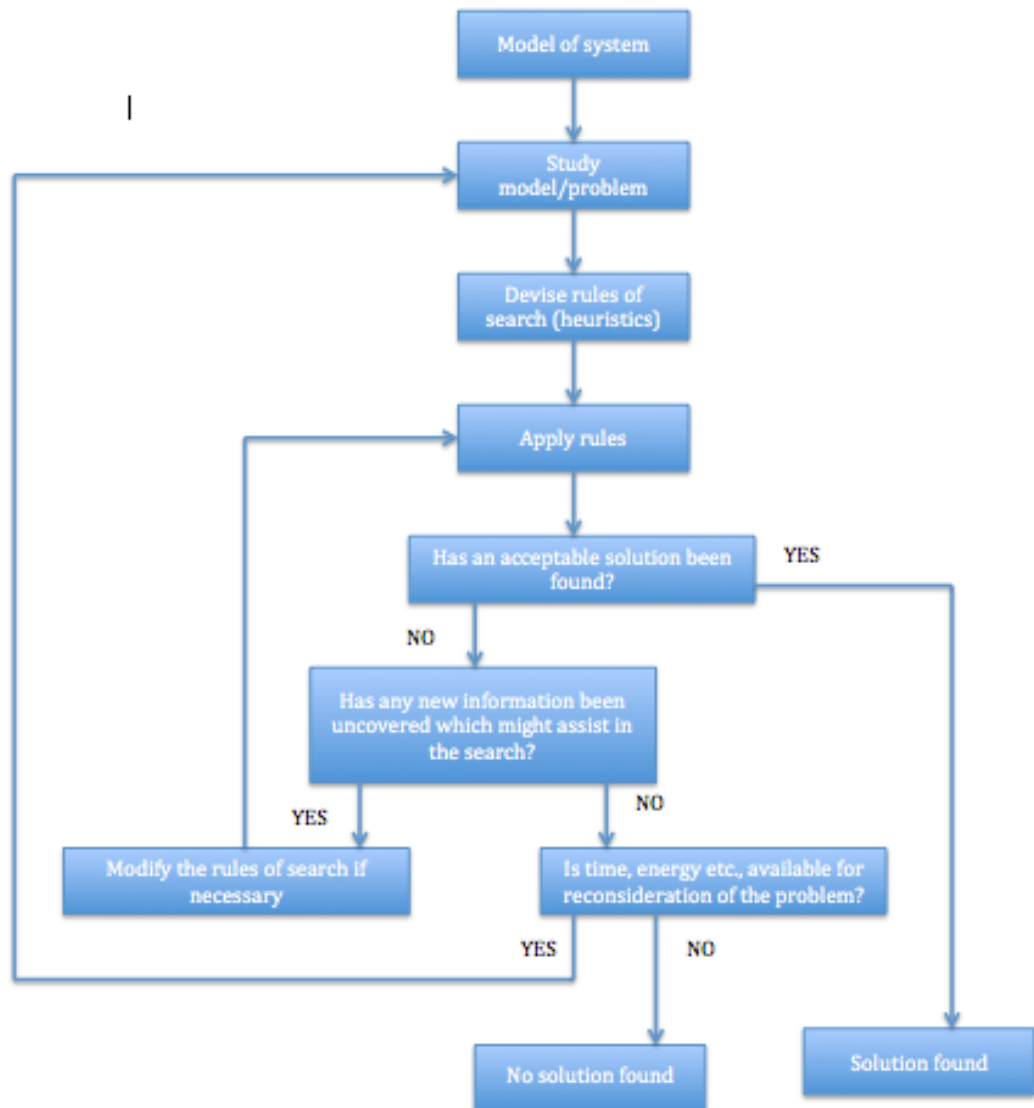
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7. Appendices

Appendix 1 – The current collection process in Oslo



Appendix 2 – A possible heuristic solution process

Appendix 3 – Mathematical Model

Indexes:

$$r = 1, \dots, R$$

$$i = 1, \dots, N$$

$$j = 1, \dots, N$$

Parameters

C	Capacity of each vehicle
a_i	Filling rate of container at node i
b_i	Total capacity of container at node i
$d_{i,j}$	Distance between node i and j
$T_{i,j}$	Direct driving time between nodes
L_i	Service Level
$K_{i,j}$	Variable cost of driving
K'	Fixed cost for every route every time

Variables:

$X_{r,i,j}$	Binary variable indicating whether node j is visited after node i in route r
F_r	Frequency that route r are visited
E_r	Binary variable indicating whether there exist a route namely r
$Y_{i,r}$	Binary variable indicating whether node i is visited in route r

Minimize:

$$f = \sum_{r=1}^R K' \times F_r + \sum_{i=1}^N \sum_{j=1}^N \sum_{r=1}^R F_r \times K_{i,j} \times X_{r,i,j} \quad (1)$$

Subject to:

$$\sum_{j=1}^N X_{r,i,j} = \sum_{j'=1}^N X_{r,i,j'} \quad \forall r \quad (2)$$

$$\sum_{j=1}^N X_{r,i,j} \leq 1 \quad (3)$$

$$F_r \geq 0 \quad \forall r \quad (4)$$

$$X_{r,i,j} \in \{0,1\} \quad (5)$$

$$\sum_{r=1}^R F_r \times Y_{i,r} \quad (6)$$

$$b_i \times \sum_{r=1}^R F_r \times Y_{i,r} \geq a_i \quad \forall i \quad (7)$$

$$Y_{i,r} = \sum_{j=1}^N X_{r,i,j} \quad \forall i, r \quad (8)$$

$$\sum_{i=1}^N \frac{a_i \times Y_{i,r}}{\sum_{r'=1}^R F_{r'} \times Y_{i,r'}} \leq C \quad \forall r \quad (9)$$

Verbal explanation of the model

- 1) The objective function, minimizing total cost
- 2) Route-making constraint
- 3) Route-making constraint
- 4) Sign/type elimination
- 5) Sign/type constraint
- 6) Demand constraint
- 7) Demand constraint
- 8) Demand constraint
- 9) Demand constraint