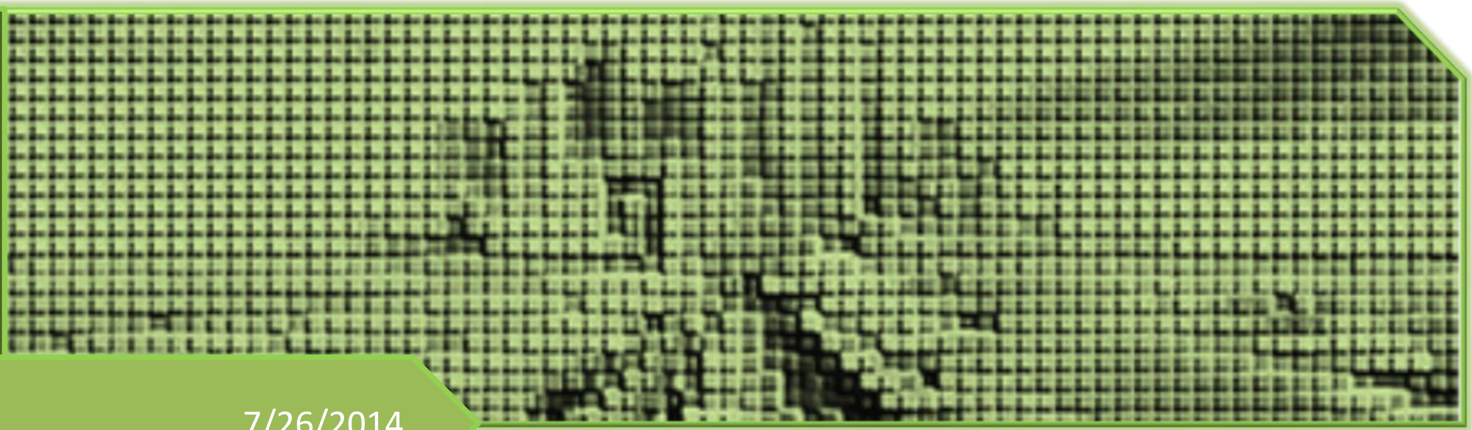
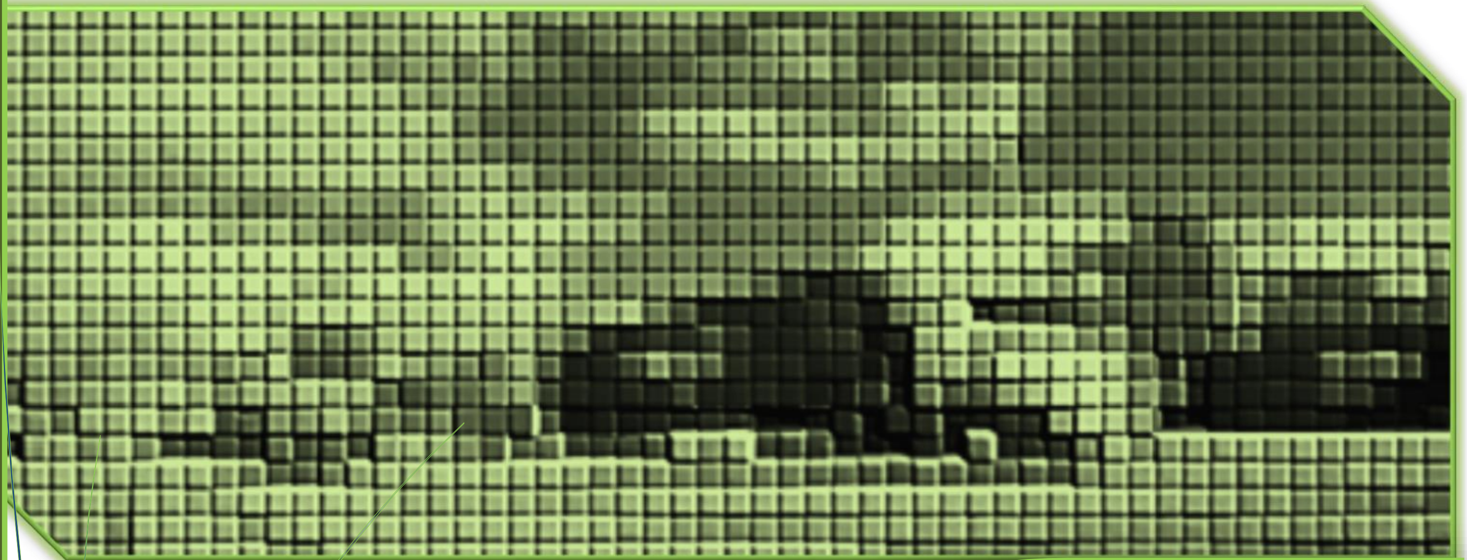
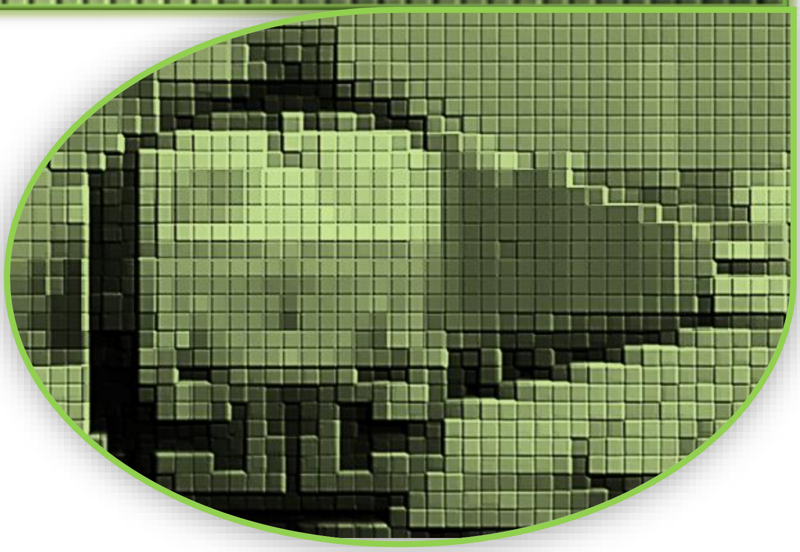


7/26/2014

Green last mile

A study of container transport in the Venlo region





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Abstract

The current container transportation market is a highly competitive market in which corporate social responsibility becomes more and more important. Clients of the transportation market are requesting for greener transportation. Due to technological advances, smarter systems are becoming available to process the rising demand for container transportation. An expected growth of 10-30% is realistic for the hinterland Venlo. Container Trucking Venlo (CTV), a provider of container transportation in the hinterland of Venlo is dealing with these issues. CTV was curious about what they could achieve by implementing those smarter systems. Therefore, this study investigates the research question: "How to create an optimal plan for container trucking by CTV in the region Venlo, taking into account sustainability for the region and equipment usage".

To answer the research question the six research areas are used: (1) vehicle routing problem (VRP), (2) VRP with time windows, (3) truck and trailer routing problem, (4) multiple depot VRP, (5) stochastic VRP, and (6) pickup and delivery VRP. The main goal was to find suitable parameters and to evaluate how they can be incorporated into the model. To solve this type of problems, this study evaluates techniques such as heuristical approach, tabu search, and simulated annealing. Based on these findings, a model was built to evaluate the planning. The model incorporates four construction methodologies to meet the requirements of the initial plan, i.e. worst case analysis, improved worst case analysis, cost-based savings and balance equal. The 'worst case analysis' was used as benchmark. First, the problem was evaluated by constructing four initial plans according to these four methodologies. Second, these constructed initial plans are optimized by either 2-opt or simulated annealing. In contrast to regular VRP models, tabu search was not used for optimisation due to the suspicion of "exploding" in running time in this particular problem. Furthermore, a method was developed to make predictions about future situations generating random sampled data.

The results showed that a reduction of at least 10.75% in total driven kilometres could be achieved. The best performing combination is the balance equal method optimized with simulated annealing. This resulted in more than 12% reduction in driven kilometres. The worst performing combination is the cost based savings method optimized by 2-opt. For optimisation, simulated annealing outperformed 2-opt in all cases. The running rime for simulated annealing was 3 times as long as for 2-opt. However, a running time of 5 minutes per day is reasonable from practical point of view. The method to predict the future demand showed, when the suggested model is used, an expected growth of ≤10% of container volume is not a problem for CTV. Furthermore, results showed a one on one linear relationship between amount of containers and driven containers.

In conclusion, this study suggests that CTV will benefit from implementing a plan model. The optimal plan model was acquired by using the balance equal method and optimized by simulating annealing. This will result in at least 12% reduction in driven kilometres.

Acknowledgements

"The key to everything is patience. You get the chicken by hatching the egg, not by smashing it."(Arnold H. Glasow, date unknown)

I thank my supervisors for their patience with me. They helped me structure this research and guiding to better use of language, however I am still lacking there. As a graduate you always have respect for your supervisors, but in my opinion this can also be too much. This is applicable to me, I think. At first I felt like a fish on dry ground, but as the duo my supervisors are I learned that they can also be wrong and do not know everything. Last but not least I want to thank you both for your work you have done for me outside this research, both of you are in my top three of lecturers. Marco has been there for his crystal clear lectures. Most of them stayed with me long after given, which means a lot given the fact my mind gets bored and shifts easily. Martijn is there for his down to earth attitude and lectures without fuss. One of the best moments I think back to which examples the first, is the time when I asked a question about a project where the answer of Martijn was "read the freaking manual". I appreciated the honest answer. I am happy you have been there for me, I would not chose differently.

I also thank my internal supervisor Joris. His positive energy is always present with him in the room. It made me feel at home from the start at Seacon. His approach to manage his department is something how a modern manager should be in my opinion. But also his concerns for me outside working life was pleasant, with an empty battery inside my car it was not too much work for him to drive by and help me kick-start the car.

Jac also contributed to the feeling of coming home. He involved me within his company by inviting me to out of the office activities. According to Joris I had to watch out that I became not too informal with Jac. Like Joris wrote in my "Sinterklaas" poem: "In his first weeks he quickly gave a shoulder tap to the big boss of CTV".

I also thank Lex and Joanne, they know what they did for me. Last I thank my parents who always supported my no matter what I chose to do or not to do. I feel honoured to be the first Grapendaal in the family to graduate at the University, and I owe it all to them.

It was a pleasant experience. Now the real work starts. Like they say in Limburg "Heywa".

Jarco Grapendaal

Table of Contents

Chapter 1

Introduction: The green last mile region Venlo

This research examines the behaviour of container trucking in the region of Venlo, for Container Trucking Venlo (CTV), a daughter company of Seacon Logistics. The current practice is analysed and a model is developed for the logistical performance improvement. Section 1.1 gives the motivation for this thesis. In Section 1.2 CTV, Seacon Logistics, and the umbrella project "*The green last mile*" is introduced. Section 1.3 gives the research design, objectives and research questions. This chapter ends with the outline for the remaining of this thesis in Section 1.4.

1.1 Research motivation

In the current global market corporate, social responsibility becomes more and more important. Corporations are being judged and condemned based upon their performance regarding the social responsibility. For the region Venlo, the factor environment is a priority. This is due to the fact the region Venlo is known for its leading working matters regarding transport in the hinterland and transportation by road contributes highly to increased emissions. Another important fact is that nowadays, in logistical systems, smarter planning and scheduling becomes more and more popular. This is due to the development of systems such as communication systems in the form of internet portals, GPS and track and tracing. Internally these systems are used in the form of performance measurement and real time decision making. Given the expected growth in volume of container to transportation in the Netherlands the need for the smart systems becomes more essential to cope with these increased volumes in an efficient and effective way.

With promoting the region as a sustainable and green one, Seacon is convinced it can attract interesting organizations to the region. Recently Nutricia came to this region due to the regional capabilities to be greener and sustainable than other hinterland regions (Tenhagen, 2013). This is an indication of confirmation for the previously mentioned statement by Seacon. Since Nutricia is not the only international organization that uses the hinterland and prefers working with sustainable partners, we are convinced that a competitive advantage can be created for this region.

These developments in the market require revisiting the current way of working and adapting operations to cope with increased complexity. Optimisation techniques are required to come up with solutions that take into account the integral cost perspective, because with an increased volume, complexity arise for a planner and it is impossible for a planner to know the overall effect on the planning by his or her made decision. Another important factor is that while volume increases, the load on the current workforce increases. Optimisation techniques are again a solution to reduce the workload in planning activities for the planner, because a computer is able to evaluate the impact of decisions on a plan much faster than a human. A computer can create a feasible plan much faster and most likely it is better from a cost perspective.

Due to the rapid growth of Seacon Logistics throughout the years, intelligent systems become more and more applicable for the company and some of these smart systems are used, but not within the transportation department(s). Seacon Logistic has the data available to incorporate optimisation techniques within the transportation activities, but is currently not using optimisation on their transportation activities. This is because transportation services are left behind in the development compared to the other services Seacon provides (Tenhagen, 2013). In the operations regarding transportation there still is a lot of paperwork and judgement by human planners regarding which jobs should be bundled as a day-task for an individual driver.

In this thesis the focus is on the evaluation, and the improvement of the operation for CTV. The focus lies on decision making regarding the allocation of container-jobs to vehicles, and the sequence of container-jobs on vehicles. Hereby the aim is to reduce the travelled distance, create minimum lateness or earliness, given the available drivers and equipment. The reduced travelled distance directly contributes to a reduction in emission of vehicles. The growth of container volume is evaluated, based on this evaluation recommendations can be made regarding the growth given the current logistical operations of CTV.

1.2 The green last mile and the dominant actors

This section discusses the umbrella project green last mile, and introduces Seacon Logistics and CTV.

The project green last mile

The green last mile is an umbrella project with the goal to make the region more sustainable and environmental friendly. Currently several phases are being carried out. Seacon divided the project into six phases. These phases are:

A. Drafting of requirements of a durable vehicle
B. Development of a model to find out what we can achieve by smarter scheduling and how should greener trucks be allocated as efficient at possible
C. Explore market and market participants in the vehicle technology

D. Drafting a business case
E. Exploration of the market regarding greener vehicles
F. Joint development in both vehicle construction and IT platform

The phases A to F are respectively finished for 100, 20, 100, 80, 80, and 40 % (October 2013), respectively. The previously conducted research, i.e, the phases A and C, concerning the "tangible" technology in the transportation business, has come up with a number of six types of vehicles that could be ordered.

Both phases D and E are close to completion, but since this is a more practical application of the previous phases for Seacon, we are not discussing these phases. The phases B and F both have an intersection with this graduation thesis. So conclusions of this study directly contribute to the phases B and F. Seacon formulates the main question of phase B as follows:

"What is the optimal route planning of container trucking by CTV in region Venlo?"

This question is lacking detail in our opinion, therefore we reformulate this question, see Section 1.3. Important to know is that the phase B was initiated with a radius of maximum 20 km. This is extended to 250 Km, see Section 2.1.

Seacon

The Seacon Group is a holding under which several business units fall, such as Seacon logistics and CTV. From here on Seacon Logistics is addressed by Seacon. Seacon finds it origin in the year 1985. In the next 25 years it grew to one of the largest third party logistics service provider with a maritime character in the Netherlands. Seacon started locally as a family company and nowadays Seacon operates worldwide. Seacon provides solutions regarding logistical operations for both small and large organisations. This is achieved by entering into collaborative relationships worldwide. In total Seacon operates within over 75 different countries. Seacon operates within the subareas overseas logistics, warehousing, European distribution, and supply chain solutions.

CTV

Even though in the hierarchical organogram CTV lies within the Seacon Group, CTV operates as an independent company. By this we mean that CTV does not apply preferred treatment toward a specific partner or player on the local market. CTV is a company that transports containers nationally and internationally[1].

The area we are analysing, is the area that falls in the radius of 250 km around the train terminal in Venlo. This implies that the Ruhr region falls within our scope, and we also capture the harbour of Rotterdam. This is done because sometimes a container must be delivered the next day to the shipping company and when the train from Venlo to Rotterdam is full. So CTV dispatches a truck to deliver the container by road to the harbour of Rotterdam.

CTV does not own any vehicles, but CTV works together with 60 independent drivers each day that have their own vehicle or a vehicle of a transporter the driver works for. CTV owns 120 multifunctional

[1] Only in the regions in Belgium and Germany that fall within a 250km radius of Venlo

trailers to enable transportation of containers. The trailers are rented to the drivers or the company the driver works for. The drivers hired by CTV, are supplied by CTV with the latest communication systems in the area of GPS and GPRS.

The main activities at the office of CTV are: order acceptance and planning the orders. Currently 250 to 300 container-jobs must be scheduled per day. With this number of trips, complexity arises, and it becomes more difficult for the planner to maintain the holistic view. CTV accepts a typical job request up to three days before delivery. A job is then booked upon a preliminary modality e.g. a train or a barge. A job then arrives at the local terminal just before it needs to be transported. Important is that the container is owned by a shipping company.

1.3 Research design

Research objective and research problem

With the green last mile project, Seacon has set two main goals regarding container trucking. These goals are A. sustainability and B. reduction of emission, see Figure 1.

In Section 1.1 we mentioned the decisions that need to be taken. These decision are related to the research areas: (i) truck and trailer problem, (ii) vehicle routing problems and extensions, and (iii) optimisation techniques to come up with improvements for a system. That leads us to our main research question:

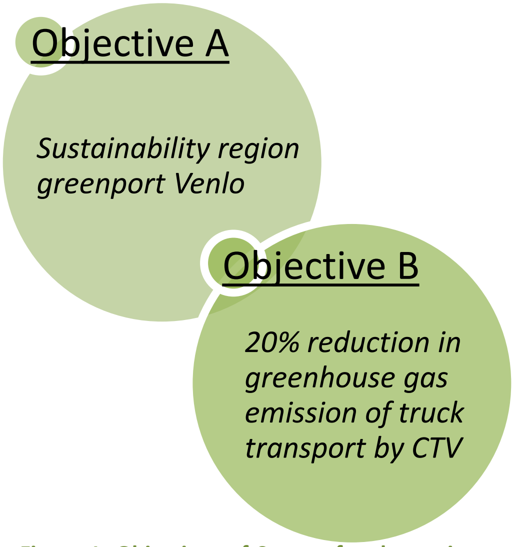


Figure 1: Objectives of Seacon for the project green last mile

Research question:

"How to create an optimal plan for container trucking by CTV in the region Venlo, taking into account sustainability for the region and equipment usage?"

By optimal route planning, we mean a route that:

- Has minimal travelling distance for a working day;
- Is economically feasible;
- Has minimal variability regarding the delivery time;
- Has minimum variability in individual driver payoffs.

Research objectives:

- ***To get insights in the current performance of CTV.***
- ***To analyse in which way and to what extent optimisation of the operational plan is beneficial CTV.***
- ***Further, to develop an optimisation technique that contains the right configuration for the system of CTV to improve their operational plan***
- ***Get insights into possibilities of shifting the business model of CTV.***

Demarcation

We have to demarcate our problem using the following points.

- We consider the problem as a vehicle routing problem in which there are container-jobs that need to be picked up at some terminal, then go to the customer for loading (or unloading) and then must be returned to some terminal.
- All vehicles start and end at CTV
- We distinguish between two types of jobs, jobs with delivery date and times or jobs that can be delivered on some day regardless of the arrival time on that day.
- All jobs are single truckloads.
- Drivers must take a break after some driving time.
- Service times occur at customers, at terminals and when coupling or decoupling a trailer.
- We do not take into account the preliminary phase of container transport by train or barge, but do take into account the arrival process by these modalities from day to day.
- We do not take into account refuelling of a truck.
- We do not try to link companies to our system, but where possible, try to generate valuable output for different players in the system.
- We do not try to optimise order acceptance, but do try to provide insight for lead time reduction.

Research questions

To answer our main research question, we have to find answers to sub questions that contributes towards our main problem. The sub questions and their contribution to the main problem is given below:

I. *How is CTV currently working?*
   To understand the current logistical process of CTV. To gain inside into the process by numerical figures. Perform a brief analyses on those numbers.

II. *What variants of vehicle routing problems are available in literature and what parameters are used by these models?*
   To guide the problem to a model, it must be known what models are available in literature and if possible apply these models or use part of these models for our model.

III. *What kind of solution methods are available in literature and which are useful for the problem at CTV?*
   To make a plan based on data, a solution method must be chosen.

IV. *What effect do different planning methodologies have on the logistical performance, is this any different than random sampling containers?*
   To find out if the solving methodology is a robust one, the effect of random sampling will be evaluated. The demarcation here is that the random sampling performs approximately the same as the historical dataset.

V. *When we are evaluating the effect of growth in container volume how can we use the historical data regarding the growth sampling?*
   Related to IV, a method to generate additional containers form day to day must be selected.

VI. *What is the effect of allowing earliness and lateness on our planning?*

If we guide our solution based upon some time range around the deliver time, what is the effect on overall logistical performance.

VII. *What is the effect of putting up an additional restriction such as max number containers on a vehicle?*
If the solution method limiting our vehicles on a max number of jobs, what is the effect on the overall logistical performance.

1.4 Thesis outline

This thesis is structured as follows. Chapter 2 gives a case description, the analyses of logistical system CTV and answers our sub-question I. In Chapter 3 describes the literature research and answers our sub-questions II and III.

After the Chapters 2 and 3, it is known what models exist and the possibilities to solve them. It is known what parameters are used, and how to incorporate them into a model. Based upon that information additional data can be analysed and made fit for the model. The literature research gives a direction to a model and in Chapter 4 therefore a plan model is given and a mathematical formulation of the model is given. The mathematical model is used as guide in the programming of our model. Chapter 5 gives a description of the model programmed and describes briefly what experiments will be performed.

Based on Chapters 4 and 5, experimentation can be done with the model. Chapter 6 gives experiments, their resulting performance and provides the information to answer sub-questions IV-VI. In Chapter 7 a suggestion for implementing the chosen model is made. This thesis ends with conclusions, a discussion and suggestions for further research in Chapter 8. A schematic representation of the structure is given in Figure 2.

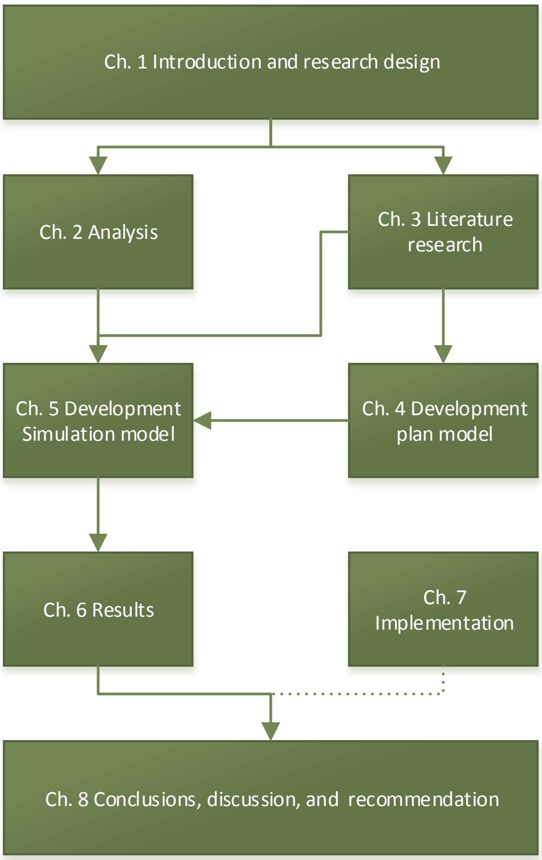


Figure 2: Thesis outline

Chapter 2

Problem description

This chapter describes the practical situation at CTV and the network it operates in. The goal of the chapter is to give an answer to the sub-question I. This is done by providing information on the current practice by the office at CTV in Section 2.1. The network is described in Section 2.2. In Section 2.3 the container jobs are analysed and described. The chapter ends with a conclusion in Section 2.4.

2.1 CTV

Section 1.2 gave an introduction of CTV and information regarding the number vehicles (60) and the number of trailers (120). Before the current situation can be imitated by a model, the current working method of CTV must be known. This section provides qualitative information on the working method at the office of CTV.

Structure

The CEO of CTV is J. Berden. His function requires him to be out of the office most of the time for business meetings, pitches by salesmen and inspection of the establishment in Duisburg (CTV Duisburg). In his absence the floor is managed by an operational manager who supervises the planning and order acceptance. The operations are operated by planners and marketers. The planners dispatch the drivers and the marketers accept the orders.

The flow of a job

A typical job comes in by phone and is placed in the “BPA” system, by a marketer. BPA is the software used to assist the planners in constructing and monitoring the planning. Logically a container-job has to fall within the time boundary, the due date as stated in Section 1.2. In addition, the marketers check the availability of a preliminary modality, to transport the container from the harbour of Rotterdam to Venlo. The customers determine the time the container must arrive at their location. For CTV, the type of container is irrelevant. This is because the trailers are multifunctional. The order is then planned by a planner and the order is processed in the BPA. The order is allocated to a vehicle based on “gut feeling” of the planner. Gut feeling is mainly based on the perception of the planner to provide equal benefits for the drivers. To transport a container transportation papers are needed. The documentation of an order in the transportation business is typically a physical one. The documentation is called a CMR. CMR stands for *“Convention Relative au Contrat de Transport International de Marchandises par Route(Convention for the International Carriage of Goods by Road)”*, which is a standardised legal document by the VN in which mandatory laws are being complied by any party involved in the transport of the freight. An example of a CMR document can be found in Appendix A. The CMR is given to the driver when he needs to handle a container. The driver always needs the CMR to load, unload, pickup and deliver. Not having a CMR means the job is on hold and cannot continue. If this happens, a driver must return to CTV to pick up the reprinted CMR. Once the driver successfully finished his job, he can start with a new job.

Some container-jobs have to be decoupled at the customer. With decoupling we mean, that the driver places the trailer with container in a loading dock at the customer and then leaves the trailer with the container at the customer for loading or unloading. Customers never remove a container from a trailer. In 75.5% of the containers the driver drives to the customer for loading or unloading, waits at the customer and then returns the container towards a terminal. In the remaining 24.5% of the containers, decoupling at the customer occurs. This results in three types of jobs: deliver job, return job, and complete job, see Figure 3. The deliver job is the job in which a container is picked up at a terminal and then transport the container to the customer where the trailer loaded with a container is decoupled. Afterwards the vehicle goes to the next job or first pickup a new trailer at CTV. The return job is the job in which a vehicle without a trailer travels to the customer to couple a trailer loaded with a container, than transports the container to the terminal where the container is removed. At the start of a return job, when a trailer is behind the vehicle, the vehicle first goes to CTV to decouple the trailer. It is of no concern if the container needs to be loaded or unloaded in this problem, only the transportation is relevant. In a complete job, both the pickup and delivery are performed consecutively, therefore some service time is experienced. Task that are present within the service time is given in Appendix B.

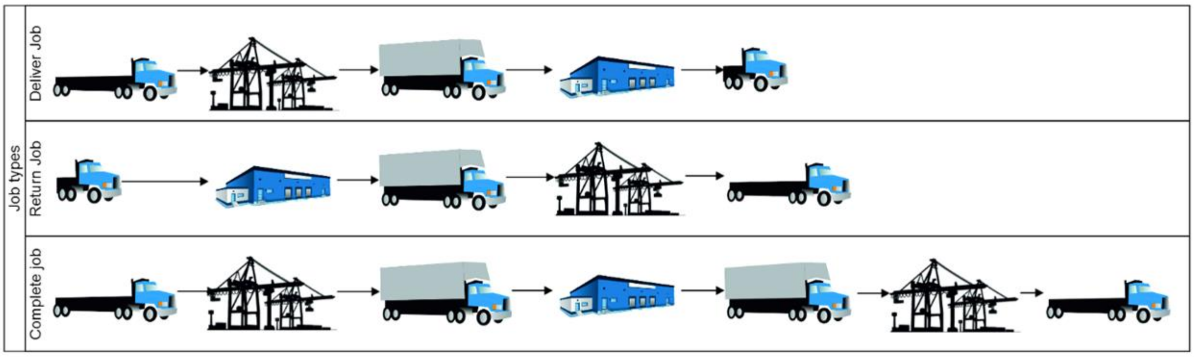


Figure 3: Different types of jobs

Due to decouple actions, CTV does not always have enough trailers to transport all containers within the set job boundaries. Therefore CTV sometimes must rent extra trailers of some external party.

Hiring a trailer cost CTV 22.5 euros per day. If the trailer is rented for a longer period than a day, and the weekend falls within that period, CTV will have to pay the daily fee for the trailer, regardless of the usage.

A driver gets paid based on the location of the customer. The distance from the terminal to the customer is used to determine the payment of the driver. If the distance from the terminal to the customer is less than 100 kilometres, a driver gets a payment of 90 euros. Otherwise the driver gets a payment of 180 euros.

Based on our observations, we notify that mostly the drivers have no clue what to do after they have finished a job. So they mostly return to CTV to ask for another container to transport. We have no clue why this is not done digitally, but we believe this is incorporated in the process due hardcopies of CMR's by law.

System(s)

The system used to monitor a constructed planning is BPA. BPA is a system specifically made for container trucking. The information fields in BPA provide the framework for the planning. The power of BPA is the flexibility it provides to be relatively easily linked to other systems, and the fast service provided by BPA to realize a link to systems and to solve problems regarding the system. The planners use the plan board integrated within BPA to administer jobs, to monitor progress of the realization of the schedule, and communicate with the drivers and their vehicles. The communication is realized by an integration of BPA with TomTom Fleet. TomTom Fleet is a vehicle management program that works with a global positioning system (GPS). All drivers have a TomTom hardware piece which can be placed in a vehicle.

The following important information can be found in BPA:

The progress of today's planning: The user can see which containers still have to be transported, which jobs are in progress and which jobs have been finalized for today.

Containers: All containers transported and containers to transport can be found in BPA. Relevant information such as CMR number, container booking number, to which customer, when to transport, delivery time, when to return to the shipping company, where to pick the container up, the destination, and to which terminal the container must return is also linked to the containers.

Customers: Contact information about customers.

Allocation: The allocation of jobs to drivers.

Drivers: Real time information on the location of drivers and their vehicles by GPS and TomTom fleet.

Times: Information on due dates, arrival and departure times at the train and barge container terminal Venlo.

2.2 Network

This section concerns the perspective of the driver in the network at first, secondly the network entities are discussed.

Drivers perspective

To get a better feeling about the perspective of a driver, their daily work was observed. Based upon these observations, in Figure 4 a flowchart of the drivers working way is given.

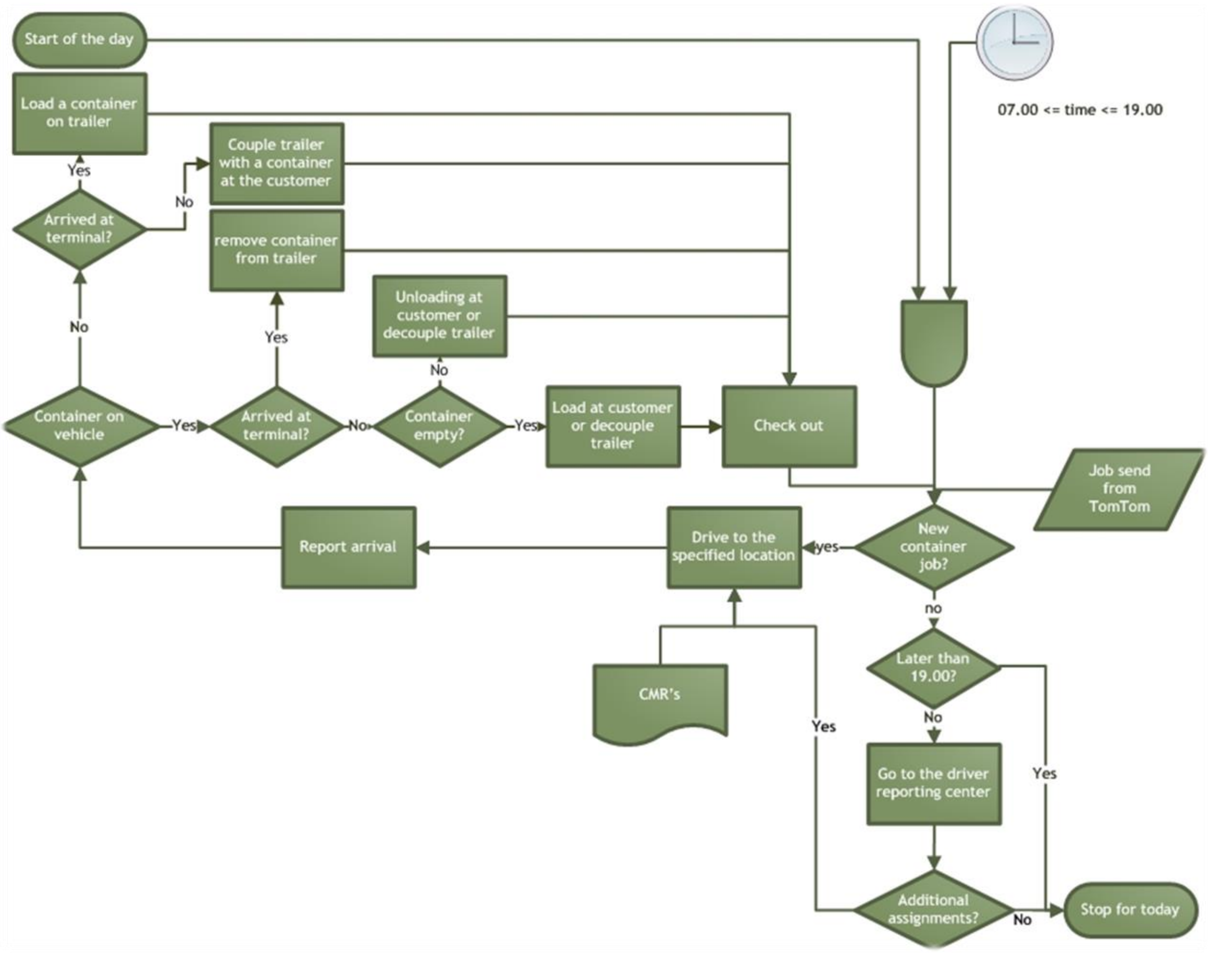


Figure 4: Schematization of the driver view

Points within the network

To get insights in the network of CTV, the train terminal Venlo is put up as a central point. CTV lies adjacent to the train terminal. The input of containers for the network of CTV comes, as mentioned in Section 1.2, from the barge and train. Due to practical errors rush orders have to be performed. In these situations a container must be picked up in another terminal than the terminals in Venlo. As a result the radius of 250 km is needed. Containers can be picked up or delivered in the network of CTV at the following terminals:

- Train container terminal Venlo
- Barge container terminal Venlo
- Terminals Rotterdam
- Terminals Antwerp
- Terminal Duisburg

From a terminal the container must be transported towards a customer. In total CTV has approximately 3300 customers. In total 2848 customers and terminal locations fall within the 250km radius, see Figure 5 for their location. A walk over the surface of the earth of 500 km (the diameter of the circle) is relative small, therefore the longitude and latitude coordinates are not translated to proper X and Y coordinates. The train container terminal lies on the point (6.13463, 51.38971). The two clustered points (4.25, 51.30) and (4.30, 51.85) allocate the port of Antwerp and the port of Rotterdam respectively. What is shown by the Figure 5, the closer to the train container terminal Venlo, the greater the density of customers gets. To come back to the point of increased radius, as stated in Section 1.2, it should be clear that, without the increased radius we would leave a lot of customers out of scope and therefore we could not give a just analysis of the logistical system of CTV.

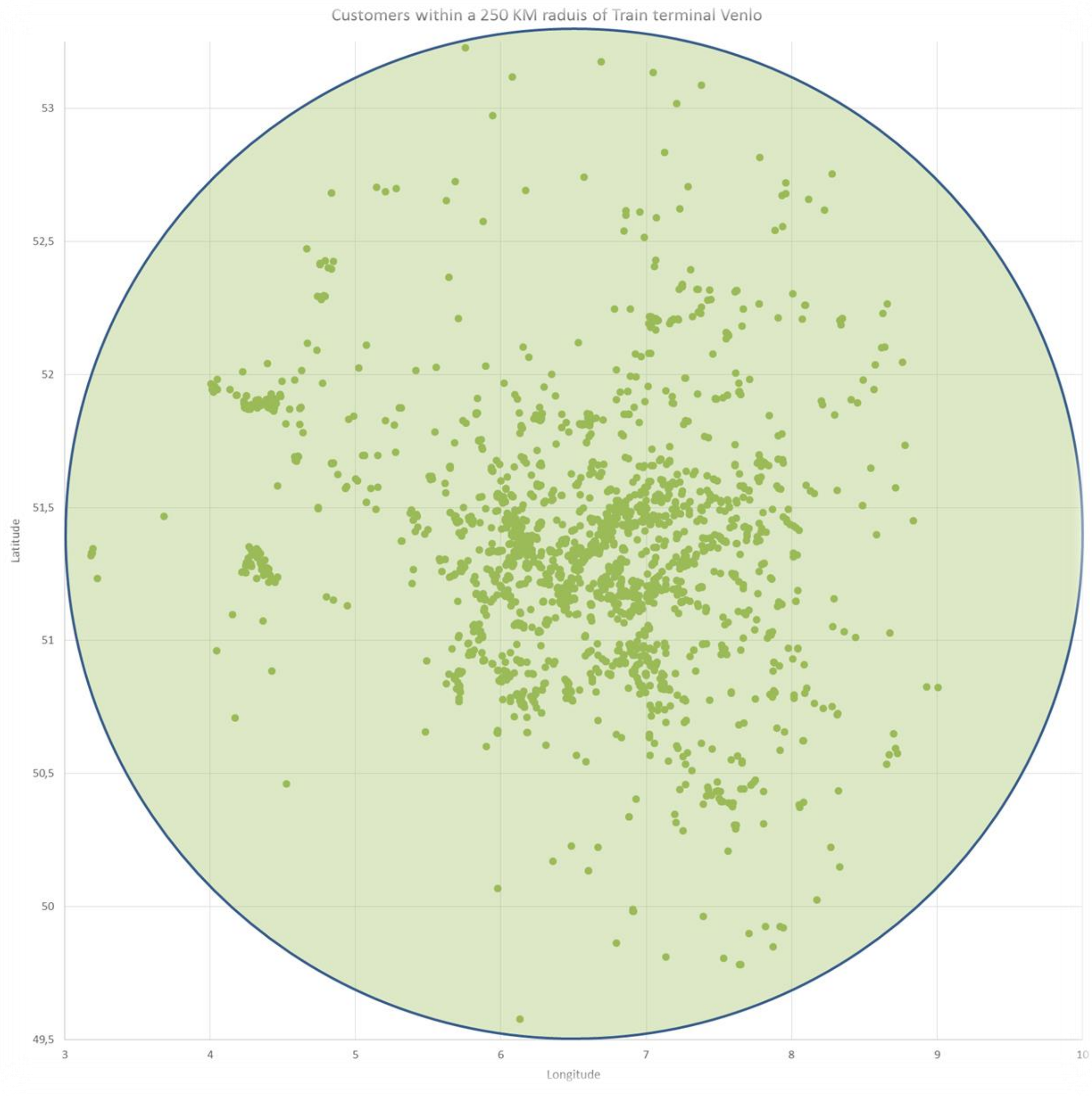


Figure 5: Outline customers within 250Km radius, on a latitude and longitude axis

2.3 Container analyses

As mentioned in Chapter 1, CTV, is working with BPA and there is no straightforward method to obtain all relevant information out of the system. The planner explained that the best way to extract the information on containers was to copy paste per customer in the system. This will make it rather hard to review the current system performance. Out of BPA, the following information regarding containers is obtained:

- Date: The year, week and day when a container must be transported
- Deliver time: The due date of a container
- Container booking number: Unique number corresponding the container
- Return date: If applicable to the container, the year, week and day when the container must be dropped off at a terminal.
- Pickup location: The location of the terminal where a container can be picked up
- Customer location: The location where a container need to load or unload at the customer
- Drop-off location: The location of the terminal where a container must be returned
- Pick up: Indicating the transport from a terminal to a customer
- Delivery: Indicating the transport from the customer to a terminal

The last information points are binary values, and state together the type of job. If these values are 1 and 0 then we must pick up a container at a terminal and decouple at the customer. If delivery is only 1 and pickup is 0, then we need to pick up a container at the customer and return the container to a terminal. If both are 1, than a trucker must pick up a container at the terminal, go to the customer for loading or unloading and then return the container to a terminal. Furthermore the provided data analyses on the empty kilometres and the total CO_2 reduction per year is based upon an incomplete analysis. The legs between consecutive container jobs are left out.

When all the available driven legs of containers are outputted form BPA, a total of four years of data is available. These are the years 2010, 2011, 2012 and 2013 (up to week 47). In Figure 6 the number of containers per year are given, remember this is not the same as driven jobs. As can be immediately observed, the number of containers transported have been rising each year. In 2010 34.809 containers are transported against 50.016 in 2013. Since the transportation in number containers has been increasing each year, we ignore the years 2010 and 2011 as data input for our model. From here on this study continues with the data of the years 2012 and 2013. In Figure 7 the number containers per week is given.

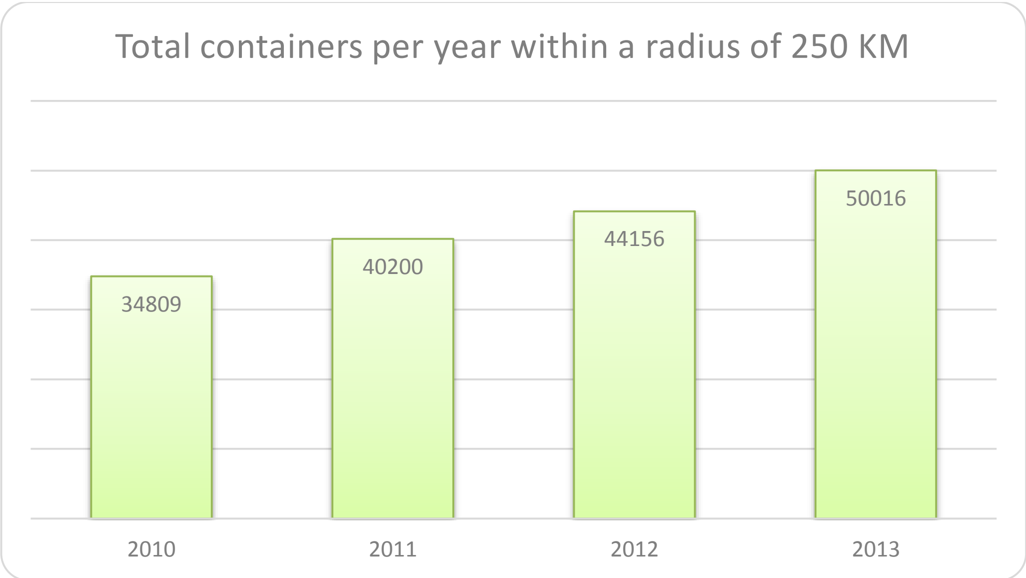


Figure 6: Number containers from 2010 up to 2013 (week 47)

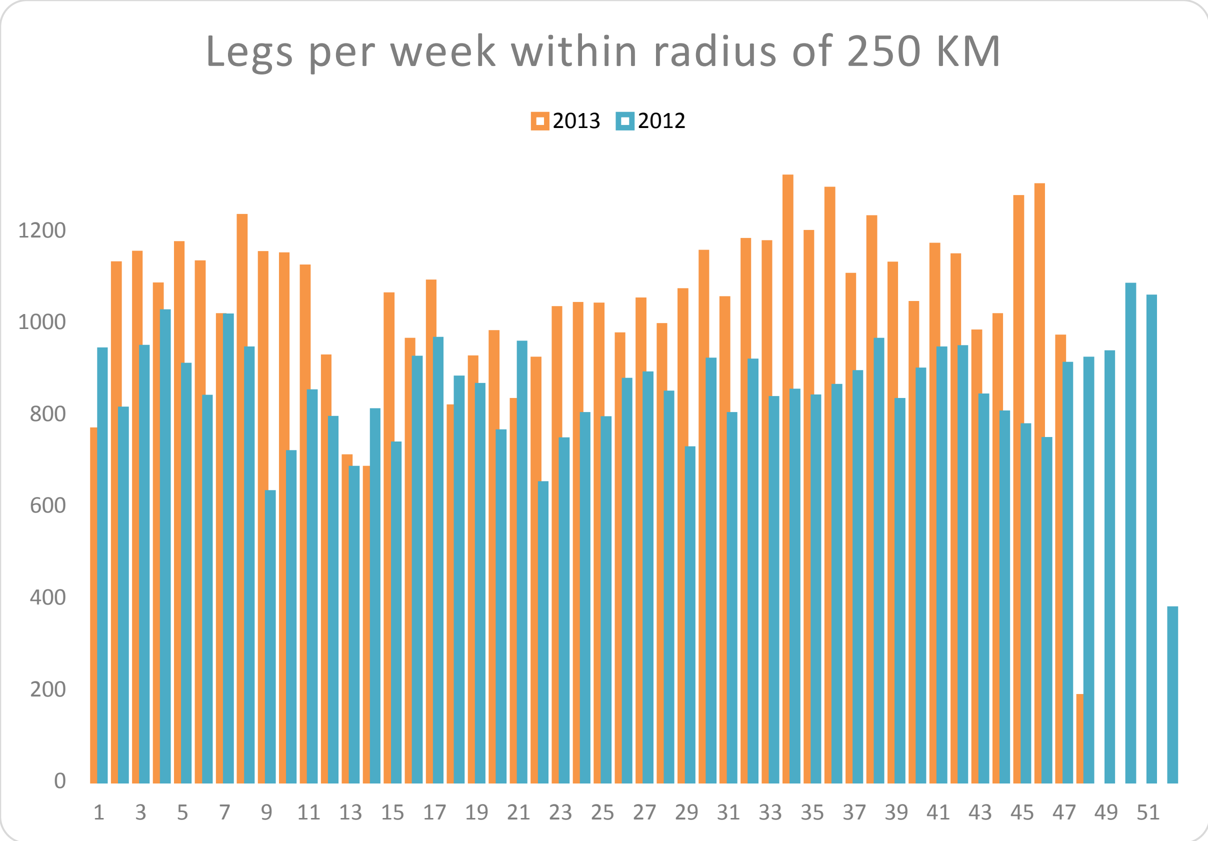


Figure 7: Legs per week from 2012 to 2013 (week 47)

To get a feeling about the number containers to schedule on an average weekday, the average containers per weekday and their standard deviation for the years 2012 and 2013 is given in Figure 8 and Table 1. For completeness we included the Saturday, but in our discussion below the Saturday is left out, because its insignificance compared to the normal working days. Although we believe in the future the Saturday can be of significance. When looking at the variance, a quick observation gives us the indication that the process is become less stable over the years, the standard deviation has been increasing. When calculating the squared coefficient of variation (SCV) from Monday to Friday, an increase in the SCV occur. In 2012 and 2013 the SCV was 0.018 and 0.023 respectively. The increase is small, but the arrival process is indeed become a little less stable. We also observe that the peak of total containers in the week has moved from Wednesday towards Tuesday. The strange thing is that the variance on the days Monday and Wednesday has only slightly changed. The Wednesday is the only day on which the stability of the process has not changed.

Table 1: Daily # containers, the mean and variance per container-day

Appendix

Figure 8: a) Daily average containers (2012) **b) Daily average containers (2013)**

Several possibilities can be the cause of the volatility increase. First the system could be just at its limits in its current form. Second, according to Berden (2013) new customers with specific demands can be the cause of this. For example Primark needs on certain days 30 containers, due to the fact that CTV needs a lot decoupling at the depot of Primark, the decoupled trailers increase and therefore the overall trailer usage.

To make a good estimation of the total number of containers to generate per day when looking at future growth, the arrival process of containers must be determined. First the amount of containers per year were analysed. In total there are 248 days for 2012 and for 2013 225 days. In total there were 3 outliers for 2012 and seven outliers for 2013, based on total number containers. So a total 245 and 218 days are useful for the year 2012 and 2013 respectively. The square root rule was used to determine the number of groups to allocate the number of jobs to. How the number of jobs per day are divided is given in Figure 9 and Table 2 for 2012 and Figure 10 and Table 3 for 2013.

Table 2: Number of jobs per day 2012 in groups **Table 3: Number jobs per day 2013 in groups**

Appendix

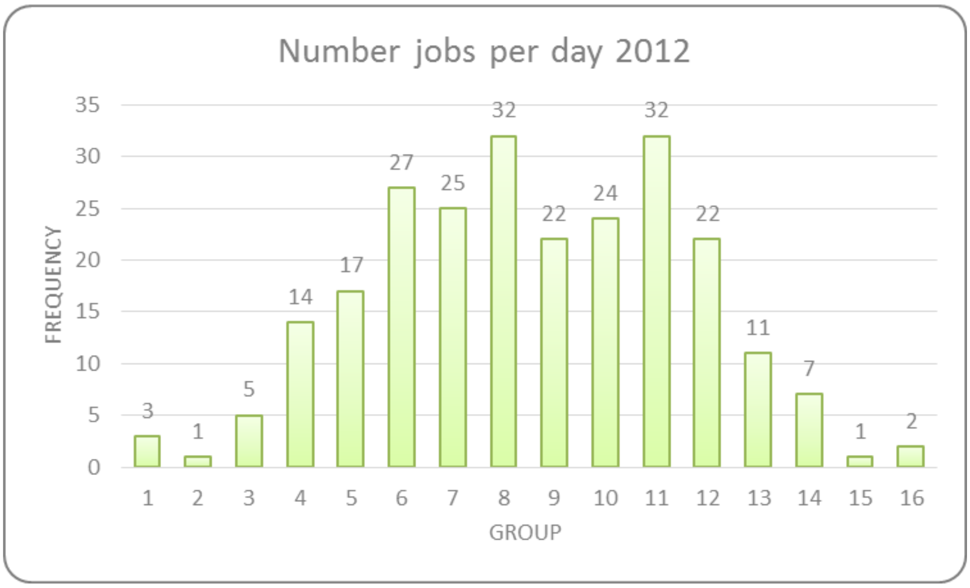


Figure 9: Histogram # job per day 2012

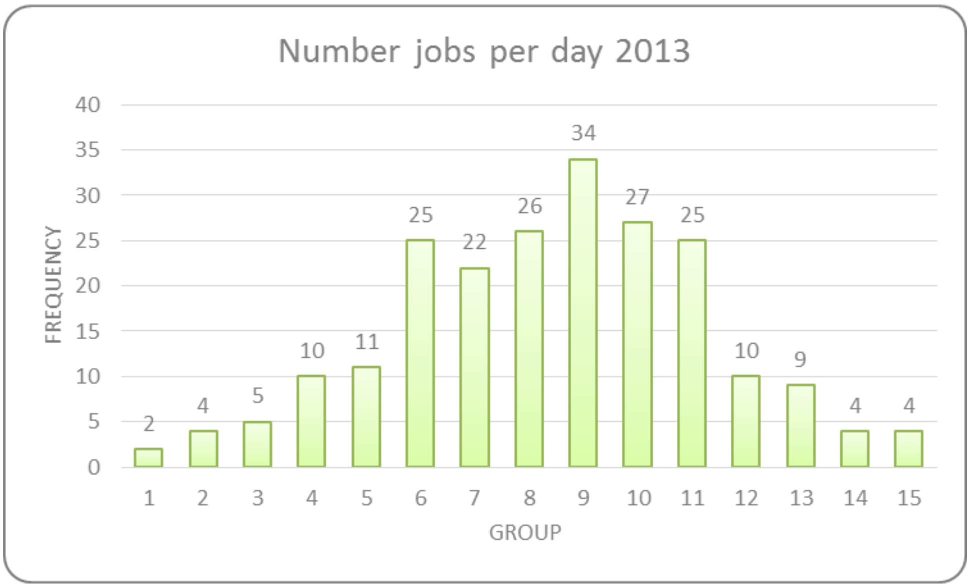


Figure 10: Histogram # jobs per day 2013

The histograms show an indication of a normal distributed number of jobs per day. Out of Figure 8, 9 and 10 and Table 1, 2 and 3, we decided that we were going to construct a different arrival process for every day, because of the little day-to-day difference.

In 2012, the total number of jobs for Mondays was taken into account, based upon statistical analyses, no outliers where found. The square root rule was used to determine the number of groups within the number of containers would fall. When we took the root of 50 usable days and round the value, a total of 7 groups or bins came out, see Table 4 in Figure 11. For the tables and histograms of the other days of 2012, see Appendix C.1 and C.2. For the same figures and tables for 2013, see Appendix D.1 and D.2. We saw that there is no clear pattern for all the days, but we recognize that the individual days of 2012 again show a normal distributed pattern. For the individual days of 2013 this is not always the case, see Chapter 5 for more information.

Table 4: Sorted data on Monday 2012

Monday	*max*	*min*	*range*	*step*
	255	101	154	22
Group	low	high	n<high	n in group
1	101	123	1	1
2	123	145	3	2
3	145	167	13	10
4	167	189	23	10
5	189	211	36	13
6	211	233	46	10
7	233	255	48	2

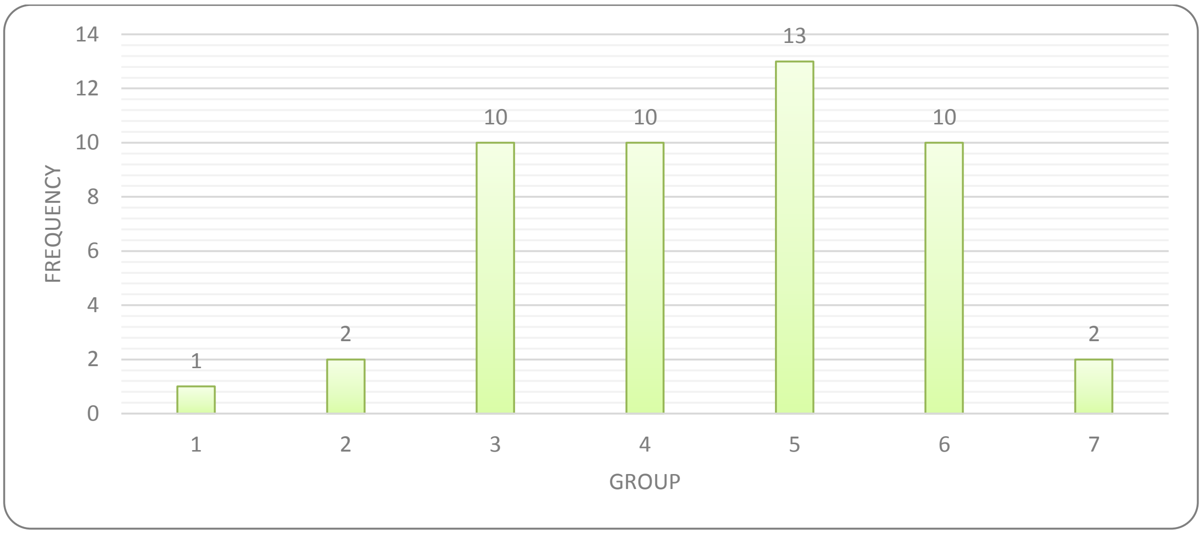


Figure 11: Histogram Monday 2012

Delivery times

Out of the containers data from the years 2012 and 2013, the delivery times were investigated. Out of the total containers 0.222% have a requested delivery time between 0 – 6 hour. 0.222% is small, so the deliveries before six in the morning are aggregated with the delivery time of six ‘o clock. The delivery times were analysed, and no pattern was found. The analyses showed that the full hours are more prominent than the half hours. Figure 12 shows the fractions of requested delivery times over all customers. In total 17% are free to deliver all day long, while the remaining 83% are to be delivered on a fixed point in time. The customer has to allocate a team to unload or load a container, so the delivery times are not flexible.

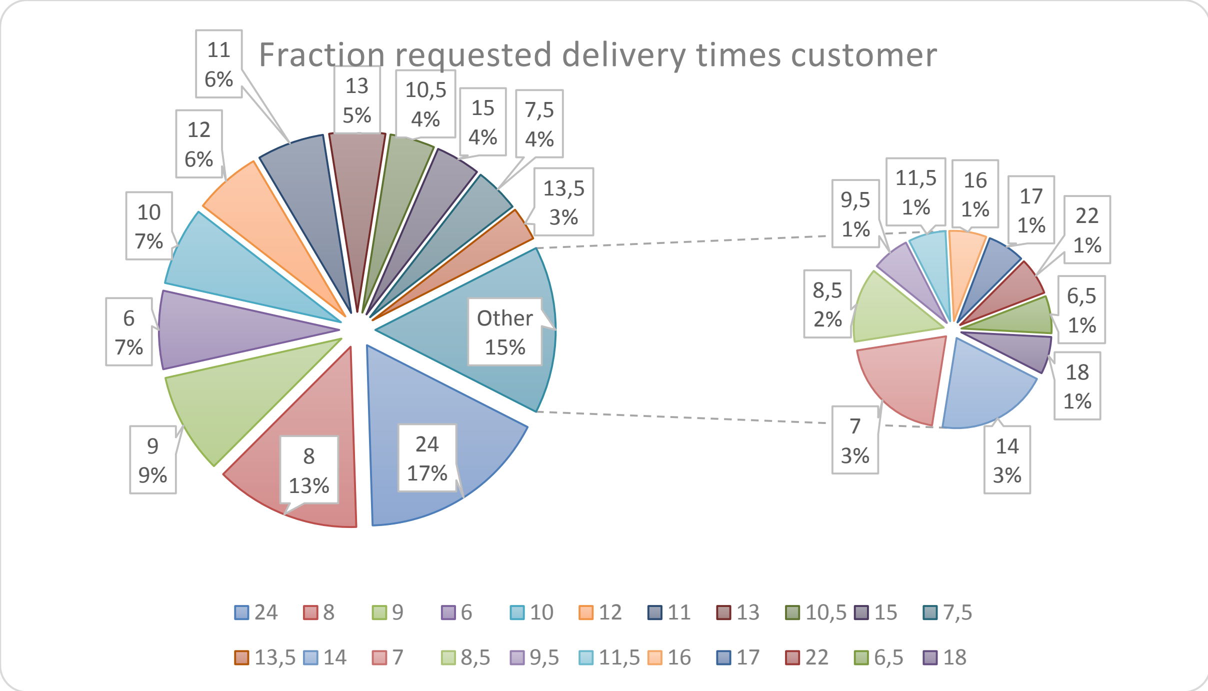


Figure 12: Weights requested delivery times

Time decoupled container

In Figure 13 the days a container is stalled at the customer is given in fractures of the total decoupled containers. Sunday is not counted as a working day. The value of 28 days therefore represents (28 modulus 6) four weeks and four days. The container stays 4 weeks and 4 working days from now at the customer. The figure shows that 58% of the decoupled containers is picked up and returned to the terminal on the same day. The remaining containers are returned to the terminal from the next day up to four weeks and four days from now. Picking the container up more than ten days from now is rather unusual as the figure shows that 99% of the decoupled containers is picked up within ten days. As stated before 24.5% of the containers is decoupled.

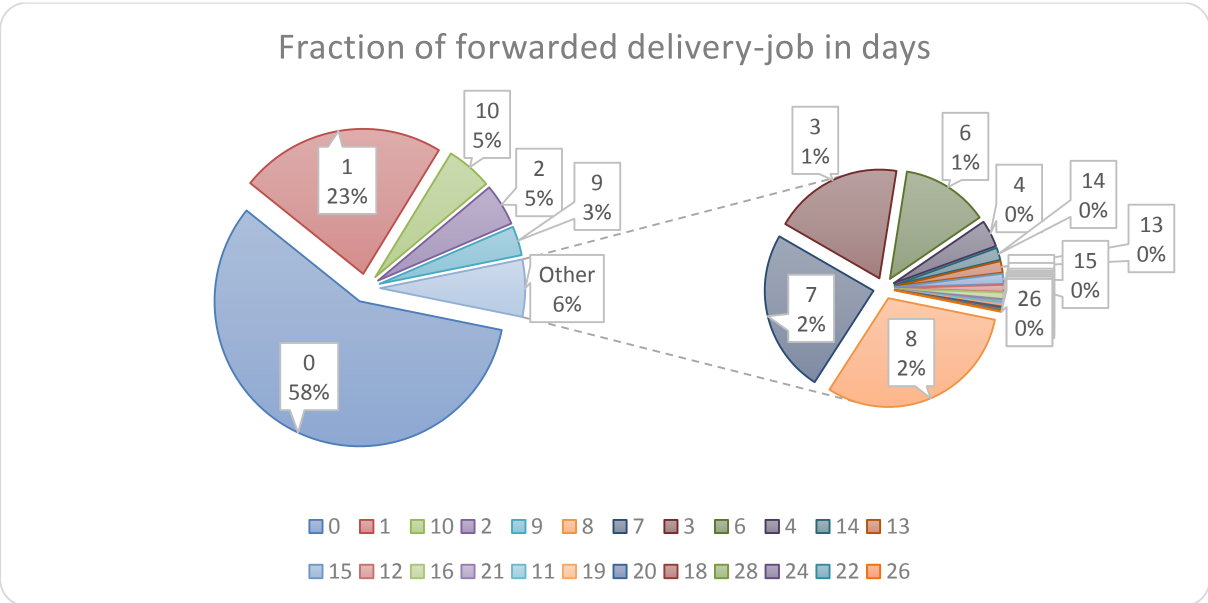


Figure 13: Weights of length of stay of a container at the customer

Container locations

In the upcoming Figures 14, 15, and 16 the fractions of pickup, customer, and return locations are shown. These fractions are calculated by looking at the total containers that were analysed.

Figure 14: The pickup locations of the containers are shown, this is a snapshot of the 96% of all terminal visits relevant for the problem at hand. The most relevant terminals are the barge and the train terminal in Venlo, contributing a weight of 83% and 11% of the total pickup locations of all terminals respectively.

Figure 15: The customer locations are shown, this is a snapshot of the 76% of all customer visits. In total there are 1195 relevant customers in the last two years, out of the 1195 40 customers contribute to 76% of the total visits. Importantly seven customers account for 54% of the visits. The remaining customers are contributing between 2% and 0.00000045% to the total weight as individual. The figure also shows that the spread of customers is large, and besides the first seven customers, the remaining customers are in visit weight not significant to the total visit weight to customers.

Figure 16: The delivery locations of the containers are shown, this is a snapshot of the first 95% of all relevant terminal visits when returning a container. As with the visits for picking up a container at the terminal, the most relevant terminals are the barge and the train terminal in Venlo, contributing to 73% and 9% of the total visits respectively. Now 18% of the return visits are coming from the terminals Antwerp, Rotterdam, and Duisburg. This is a rather large increase and we didn't expect this, since we expected more or less the same visit pattern as with picking up a container. This is caused by rush orders, as stated in Chapter 1.

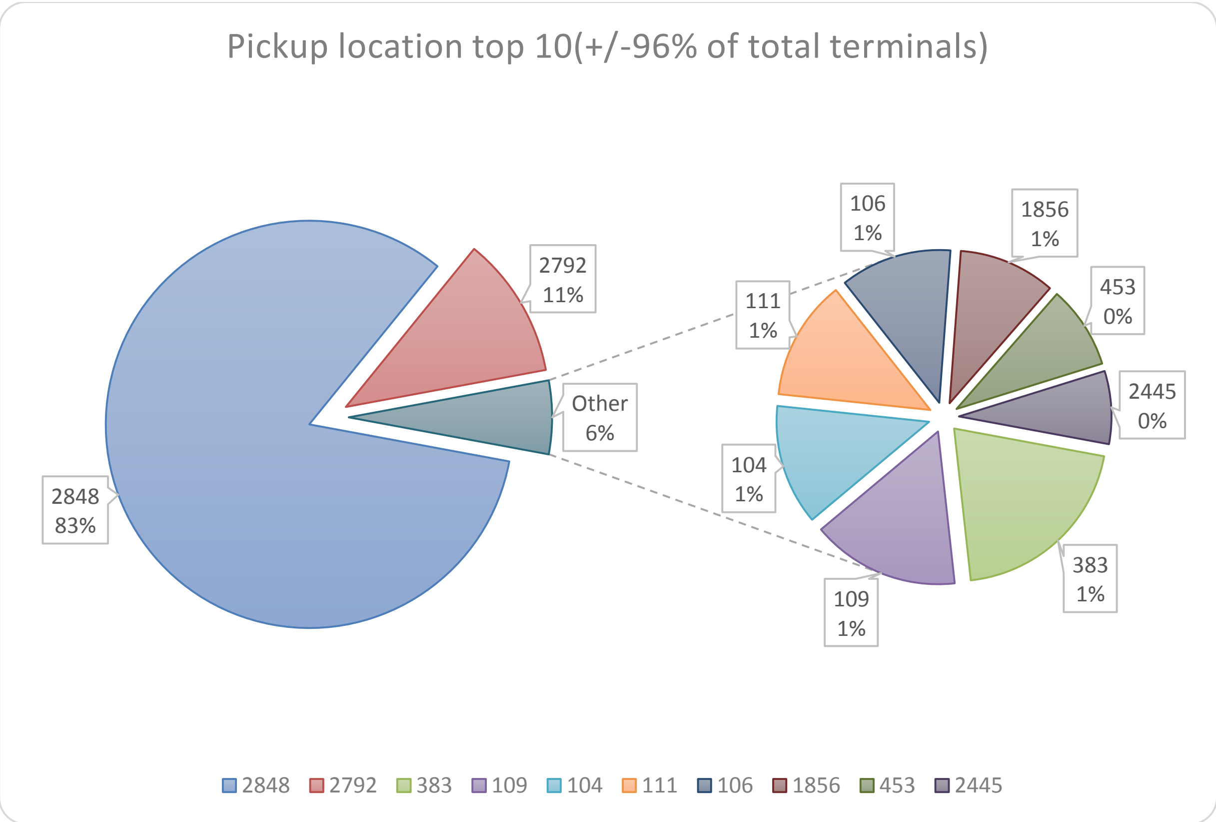


Figure 14: Visit weight of terminals to pick up a container

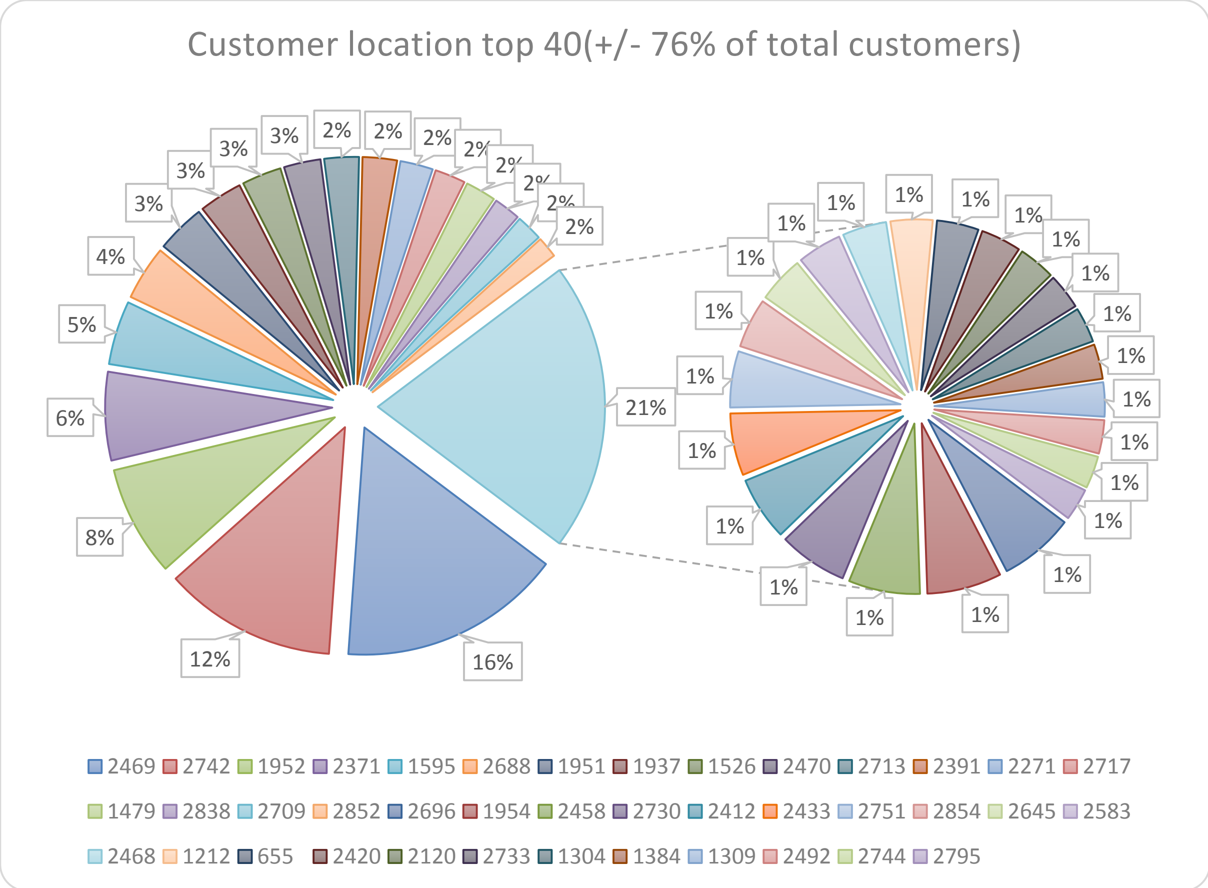


Figure 15: Visit weight of customers, the 40 biggest weight contribution

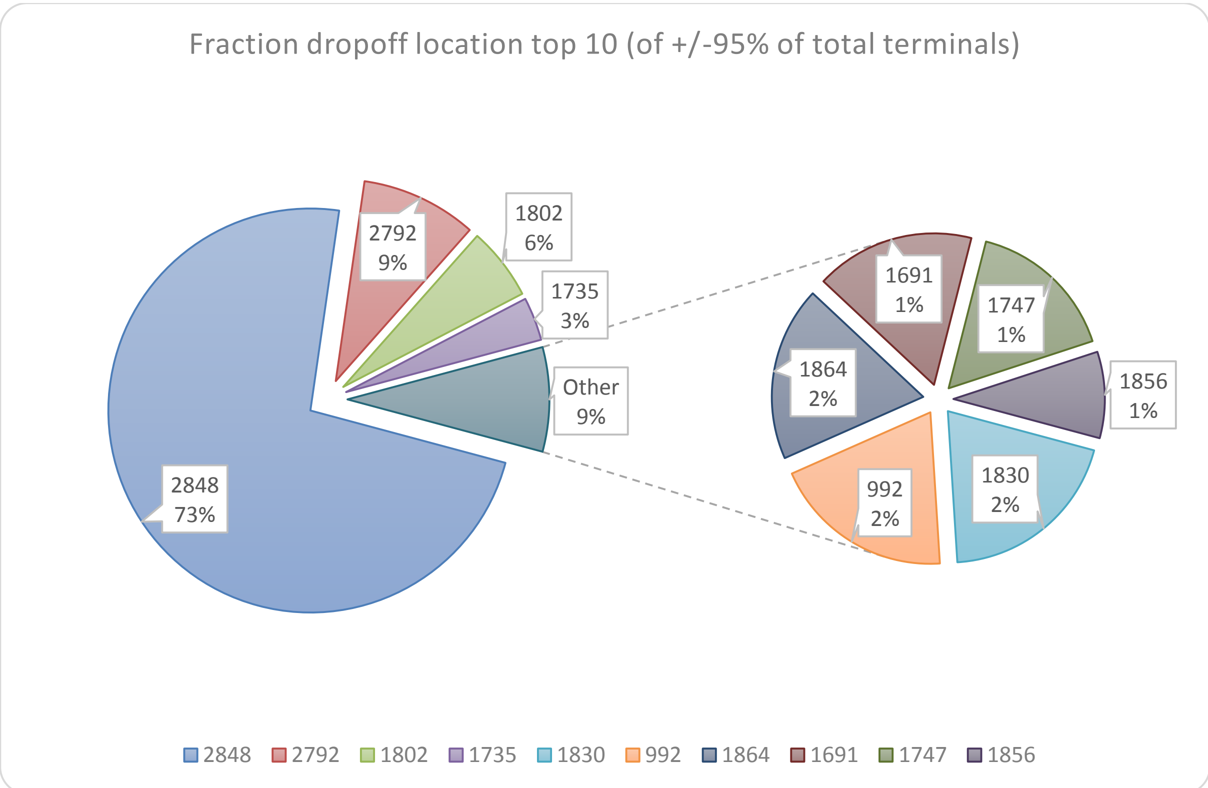


Figure 16: Visit weight of terminals when returning a container

2.4 Trade-off

Out of Section 2.3 the following problem at CTV was identified: a trade-off between the number of trailers used and the waiting time for the driver at the customer for loading or unloading. Hence, the more containers are decoupled, the more trailers are used. Since, when a driver decouples, the driver needs a new trailer in two of the three types of upcoming jobs; complete job and delivery job.

To get a better understanding of this trade-off, a parallel towards the formula of Little's was made, see formula 2.1(Little & Graves, 2008). The formula of Little is used to show the throughput of the system. Depending on the type of system, different throughputs are desirable. A hospitals need a low TH on their emergency department to be effective. Production companies have a desirable TH of approximately 0.8. A TH of 1 is always undesirable, this is because otherwise the system "explodes".

$$TH = \frac{WIP}{Cycletime} \qquad (2.1)$$

The throughput of a system i.e. the average output of a system is dependent of the work in progress (WIP) and the cycle time (CT). The WIP indicates the current number of jobs in the system that is in progress between arrival and departure. The CT is the average time of a job spends in the system, from arrival to the system to departure from the system.

When we look at the WIP of little's formula, and translate it to the system of CTV, the conclusion can be made that in fact the number of decoupled containers are viewed as WIP. Containers all need a different trailers and therefore the number of decoupled containers have an impact on the utilisation of trailers. So when a system has a certain TH, and in the situation CTV decouples more containers at the customer, the WIP increases. Logically so does our utilisation of trailers. To keep the same throughput of the system, also the average time of a container spent in the system will increase.

Out of Section 2.1, Figure 3, it was stated that CTV is dealing with three types of jobs. It was stated that with decoupling addition kilometres are made, these are empty kilometres. Decoupling occurred to skip the service time at the customer, which requires more trailers. The number of decoupled containers and additional empty kilometres must be in balance with service time at the customer, see Figure 17. So minimize the least empty kilometres, all jobs have to be complete jobs, however if CTV would never decouple, service times might become relatively large. In such situations it becomes impossible to perform all jobs for the drivers within a day. So decoupling is needed for the logistical system of CTV.

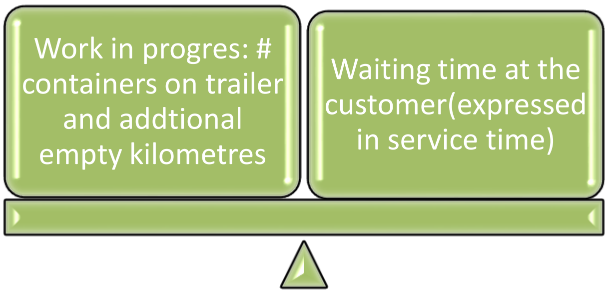


Figure 17 Trade-off between waiting at the customer, and decoupling and additional empty kilometres

2.5 Conclusion

In this chapter the dominant actors, the flow of a typical job and the network have been discussed. Now it is known that CTV is dealing with three kind of jobs, what systems are used and what information the system contain. The three types of jobs were:

- Delivery job

- Return job
- Complete job

In the section driver perspective the behaviour of a driver in the network of CTV was given. This will help us in Chapter 5.

Out of the network analyses the information regarding the logistical system is obtained. It was explained by Figure 5 why the radius of the surface was expanded. This is due to the integral approach to the problem. In total 2848 points lay on the surface of the area that is analysed. These are customers and terminals.

With the information out of the system the containers are analysed. It was decided to continue with the years 2012 and 2013. Important findings are:

- In the year 2012 44156 container-jobs were processed. In the year 2013 50016 container-jobs were processed. The year 2013 is analysed up to week 43.
- In total 24.5% of the containers are decoupled at the customer.
- The variability has stayed stable from the year 2012 to 2013.
- Different means and standard deviations for the days have been given. They showed a normal distributed pattern.
- Fractions/weights have been assigned to delivery times. In the morning the most containers are requested by the customer. Full delivery hours are preferred by the customer. 17% of the containers are free to schedule over the day.
- Out of the 24.5 percentage of containers that gets decoupled 58% are picked up the same day. The remaining 42% stays at the customer between 1 and 28 days.
- 95% of the containers are picked up in Venlo at the barge or train terminal. The remaining pickups occur at terminals outside Venlo.
- In total there are five customers each contributing more than 5% weight compared to the total.
- 82% of the containers gets returned In Venlo. The remaining 18% gets returned to terminals outside Venlo.

Most findings are usable later within the model. What is rather strange is that the inflow of containers in Venlo is bigger than the outflow. It is concluded that the return (outflow) process is less controlled than the delivery (inflow) process. It falls outside our scope, but we feel in the return process an increase in efficiency can obtained.

In the last section, Section 2.4, the underling trade-off of the problem is introduced. It was a trade-off between service time, and additional empty kilometres and used trailers. The suspicion is that only the fraction of decoupling is influential on the trade-off.

Chapter 3

Literature research

Chapter 3 is devoted to the research areas: the truck and trailer problem, vehicle routing problems and solution methods. In Section 3.1 the truck and trailer problem is discussed and stated why it is not applicable to our problem. In Section 3.2 various routing problems are discussed. The section starts with a standard vehicle routing problem and various elements in addition to the standard vehicle routing problem are discussed, because in practice we have additional restrictions. In Section 3.3 solution methods out of literature are discussed. In Section 3.4 a statement is made regarding modelling the system and we dig a litter deeper in to simulation modelling. We end this chapter with conclusions in Section 3.5.

3.1 Truck and trailer routing problem

In name, the truck and trailer routing problem (TTRP) seems to be our leading model. As far as we know the TTRP is first mentioned in literature by Chao (2002). Chao states the absence of real literature on the TTRP(Chao, 2002). On TTRP, 20 relevant accusable articles including the paper of Chao can be found. Out of the article of Chao (2002), the following important statements on the TTRP were made:

- The TTRP models assumes that there are a fixed number of trailers and a fixed number of vehicles.
- Most TTRP are about empty container repositioning. The empty reposition problems are the problems in which an empty container is picked up at Customer A after the customer unloaded the container and reused at customer B for loading. This instead of returning an empty a

- Chao refers models in literature that are related to the TTRP in the sense of equipment usage. These models name a vehicle with a piece of equipment behind it a **complete vehicle** (Chao, 2002). We adopt his definition, for a vehicle with a trailer behind it. He also refers to related models that have to assign similar equipment as our trailers to routes. What is interesting is that in these models the trailers are assigned to vehicles before jobs are assigned to a vehicle (Chao, 2002).

These statements of TTRP were enough to come to the conclusion that the models in literature are not directly applicable for the practical situation of CTV. This due to the following:

- CTV has a fixed number of trailers, but has also the option to rent additional trailers.
- Empty repositioning is not used in practice at CTV. CTV is no allowed to reposition empty containers in their current practice by the shipping company. Empty container repositioning could be applied in the current practice to only 24.5% of the containers.
- Assigning trailers to vehicles before we allocate a container to a vehicle has no additional value in the current practice. This is because some trailers are decoupled and some are not. So in the current practice a container-job has a strong influence on the usage of trailers.

Based on these points we go back to the basics of vehicle routing problems. To strengthen the argument, it is stated by Chao that the TTRP models out of literature cannot be directly applied to solve the TTRP. In practice each model must first be modified to handle the truck and trailer routing problem(Chao, 2002). In the next Section, 3.2, we go back to the basics in the form of a vehicle routing problem and expand the classical model with restriction to come to a mathematical model in Chapter 4.

3.2 The vehicle routing problem

The first variant of the VRP that came to light was the truck dispatching problem by Dantzig and Ramser (Dantzig & Ramser, 1959). The VRP is a generalization of the travelling salesman problem (TSP) (Cordeau, Laporte, Savelsbergh, & Vigo, 2007). From there on it was quiet for several decades. In the nineties the interest from scientists into the VRP came back and in the 21th century the vehicle routing problem area was gaining real momentum. To overcome any discrepancies about what is intended by a VRP, the following definition is adopted(Lawler, Lenstra, Kan, & Shmoys, 1985):

"The distribution problem in which vehicles based at a central facility are required to visit – during a given time period - geographically dispersed customers in order to fulfil known customer requirements are referred to as Vehicle Routing Problems."

Vehicle routing problems are NP-hard. This implies that it is not possible to find the best solution within a reasonable time. The vehicle routing problem can be graphically represented as a graph. In a graph there are nodes (points) for the depot and the customers to serve. Besides nodes a graph consist of edges, the lines to connect the nodes. Based on the decision to serve customer j after customer i a connection, the edge, between customer i and j is established. These customers are served for example, by vehicle k in the VRP. In a VRP multiple vehicles are available and all the available vehicles are identical, and homogenous. All customers that have a request, must be served. So a route for each vehicle must be constructed. All vehicle routes are starting and ending at the depot. The objective of a VRP is to minimize the integral transportation cost. The objective can be expressed in the form of travel cost, travel time or travel distance. A representation of how a graph can be used to come to a solution by the VRP, see Figure 18. In this example, there are limited ways to move between points. In practice, a connection from one point between all points might be possible.

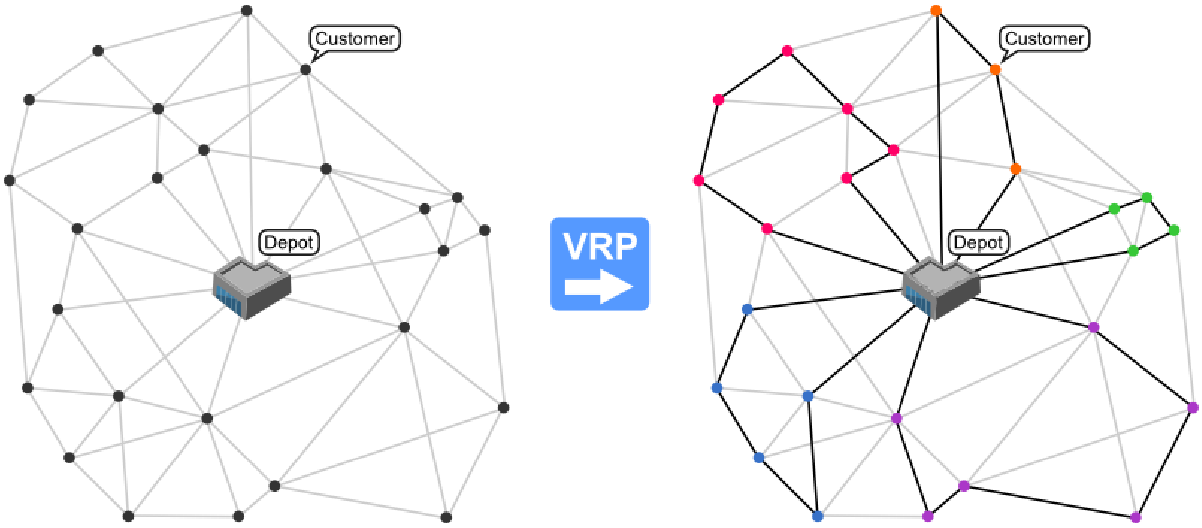


Figure 18: Example from a graph to a visualisation of a solution by VRP

A VRP can be translated to mathematical formulation. In a typical mathematical formulation the following components are present: Indices, parameters, decision variables, restrictions and an objective function. A typical mathematical formulation with examples from a VRP point of view contains the following elements:

- *Indices: Counters of e.g. customers, vehicles, etc. Indices are integers.*
  Example: i (and j) to identify a customer by a unique number, k to identify a unique vehicle by number. Normally the total number of customers or vehicles present are denoted by a capital of the indices identifier, so for the total number of customers I or J is denoted and for the total number of vehicles K is used.
- *Parameters: these are fixed values e.g. cost parameter, fixed distances in matrix form, max number of vehicles to use, time windows etc.*
  Example: $c_{i,j}$ represents the costs when the trip from customer i to customer j is carried out.
- *Decision variables: Variables which represents a decision e.g. which customer is served by which vehicle, which customer comes before and after customer i, use some vehicle or not, etc.*
  Example: $x_{i,j}^{k} \begin{cases} 1 & if\ vehicle\ k\ travels\ from\ customer\ i\ to\ customer\ j, i \neq j \\ & 0\ otherwise \end{cases}$
  The example is a binary decision variable. When a non-binary decision variable is used, it is possible to allocate for example a fraction of a job to a vehicle.
- *Objective function: A mathematical equation, which in the case of some vehicle routing problem is typical minimized. Its value represents how good or bad the solution is.*
  Example: $\sum_{i=1}^{I} \sum_{\substack{j=1 \\ i \neq j}}^{J} \sum_{k=1}^{K} c_{i,j} \cdot x_{i,j}^{k}$ if the decision is to travel from customer i to customer j by vehicle k, certain costs are involved ($c_{i,j}$). To view this from an integral point of view this is minimized for all i, all j and all k.

- *Restrictions: This is a set of equations in which we make sure the solution does not violate any constraints. E.g. we cannot exceed the capacity of the vehicle, we cannot permit the customer to be visited more than once, etc.*
  Example: $\sum_{i=0}^{I} \sum_{j=0}^{J} t_{i,j} \cdot x_{i,j}^{k} \leq D \quad \forall k \in \{1,2,\dots,K\}$ The duration of a route by vehicle k cannot exceed the maximum allowed duration D of a route. Here $t_{i,j}$ is a parameter and stands for the time it takes to travel form i to j. The summations make sure that all chosen connections are evaluated for vehicle k.

The standard vehicle routing problem

As stated above a route is constructed for each vehicle. The vehicles are homogenous in a standard VRP i.e., the vehicles are identical. Each vehicle has capacity *Q*. All vehicles start and end at a central depot. Each customer I has a demand q_i. All vehicles have a maximum driving duration, this is expressed by *D*. The cost for each connection $c_{i,j}$ is based upon a distance matrix C, where $c_{i,j} \in C$. The examples for a mathematical formulation on the previous page can be used directly for the standard VRP, but extra constraints must be added to ensure: route continuity, driving time is not violated, capacity is not violated, that a vehicle is not scheduled more than once, and that a vehicle starts and end at the depot(Fisher, 1995).

Indices

- Vehicle k of the truck fleet, $k \in \{1,2,\dots,K\}$, with K the total number of vehicles;
- Customer i,j or p which represents the location of the customer, i, j, p ∈ $\{1,2,\dots,N\}$;
- Depot i=0.

Parameters

- $c_{i,j}$: cost of traveling between (customer) node i and j;
- $t_{i,j}$: time it takes traveling between (customer) node i and j;
- Q: capacity of a vehicle;
- q_i: load of request by customer I;
- *D*: maximum duration of a vehicle route.

Decision variable(s)

- $x_{i,j}^{k} \begin{cases} 1 & if\ vehicle\ k\ travels\ from\ customer\ i\ to\ customer\ j, i \neq j \\ & 0\ otherwise \end{cases};$

Objective function and constraints

$$minimize\ Z = \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{K} c_{i,j} \cdot x_{i,j}^{k} \qquad (3.0)$$

Subject to

$$\sum_{i=0}^{N} \sum_{k=1}^{K} x_{i,j}^{k} = 1 \qquad \forall j \in \{1,2,\dots,N\} \qquad (3.1)$$

$$\sum_{j=0}^{N} \sum_{k=1}^{K} x_{i,j}^{k} = 1 \qquad \forall i \in \{1,2,\dots,N\} \qquad (3.2)$$

$$\sum_{i=0}^{N} x_{i,p}^{k} - \sum_{j=0}^{N} x_{p,j}^{k} = 0 \qquad \forall p \in \{1,2,\dots,N\}, \forall k \in \{1,2,\dots,K\} \qquad (3.3)$$

$$\sum_{j=0}^{N} q_j \cdot (\sum_{i=0}^{N} x_{i,j}^{k}) \leq Q \qquad \forall k \in \{1,2,\dots,K\} \qquad (3.4)$$

$$\sum_{i=0}^{N} \sum_{j=0}^{N} t_{i,j} \cdot x_{i,j}^{k} \leq D \qquad \forall k \in \{1,2,\dots,K\} \qquad (3.5)$$

$$\sum_{j=1}^{N} x_{0,j}^{k} \leq 1 \qquad \forall k \in \{1,2,\dots,K\} \qquad (3.6)$$

$$\sum_{i=1}^{N} x_{i,0}^{k} \leq 1 \qquad \forall k \in \{1,2,\dots,K\} \qquad (3.7)$$

$$x_{i,j}^{k} \in \{0,1\} \qquad \forall i,j \in \{1,2,\dots,N\}, \forall k \in \{1,2,\dots,K\} \qquad (3.8)$$

$$x_{i,i}^{k} = 0 \qquad \forall i \in \{1,2,\dots,N\}, \forall k \in \{1,2,\dots,K\} \qquad (3.9)$$

The objective function 3.0 minimizes the total travel cost. The restriction 3.1 stands for that each customer j is exactly visited once by exactly one vehicle k. The second restriction, restriction 3.2, stands for that each customer i is exactly visited once by exactly one vehicle k. Restriction 3.3 is used to make sure that the constructed route for vehicle k is a continuous route. So restriction 3.3 evaluates the fact that when a customer (node) is visited by vehicle k, vehicle k also leaves the customer. To make sure a vehicle is not carrying more freight than the capacity of the vehicle, restriction 3.4 is present. Each customer i in the route must be served so the sum of the demands by customers should not exceed the capacity of the vehicle. Restriction 3.5 is explained in the example of a mathematical formulation. Restriction 3.6 and 3.7 are the restrictions to start and end vehicle k's route at the depot. Furthermore they make sure that if a vehicle leaves the depot, this is not done more than once, since only one routing per vehicle is permitted in the standard VRP. Restriction 3.8 describes the range of values the decision variable can become. Restriction 3.9 makes sure the vehicle does not drive from the same location to the same location.

The standard VRP is now formulated and gives a basics for the model for CTV. In Chapter 2 due dates used by CTV were mentioned. So it is know that the standard VRP cannot be used to represent the practical problem at CTV. More restrictions are needed. In the upcoming indention time windows are discussed.

Time windows

The VRP with time windows (VRPTW) consists of designing a set of minimum cost routes, originating and terminating at a central depot, for a fleet of vehicles which services a set of customers with known demands (Desrosiers, Dumas, Solomon, & Soumis, 1995). The time window describes the time range in which a delivery must be realized. Hard time window do not allow any form of lateness at the customer (Desrosiers et al., 1995). In literature also soft time windows are mentioned. Soft time windows are time windows in which there is a certain range in which a delivery must be made, but it is allowed to violate the range of delivery opportunity. Violation of soft windows is allowed at some penalty (Desrosiers et al., 1995). Below we give examples and mathematical formulation of both type of time windows. First the hard time windows are discussed.

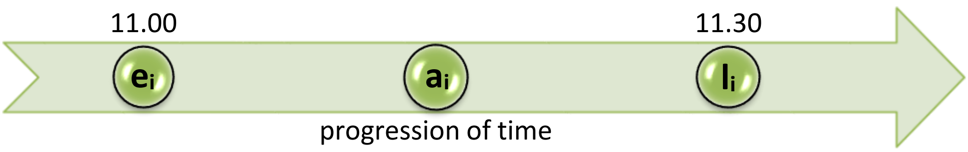


Figure 19: Double sided hard time window

Hard time windows can be one sided or double sided. A one sided hard time window is for example a delivery must be made for sure before a predetermined time. A double sided hard window is the range of delivery opportunity between two predetermined times, for example not before 11.00 and not after

11.30. In Figure 19 a visualisation of a double sided hard time window is given. In Figure 19 e_i, a_i and l_i represents the following:

- Opening time of the time window e_i, earliest allowed arrival time;
- Ending time of the time window l_i, latest allowed arrival time;
- Actual arrival time a_i at the customer.

The opening and ending of a time window are predetermined values and therefore they are given parameters. Due to the hard windows the following formulation for all customers i must be true: the arrival time of a job cannot be before the opening time of the window and not later than the ending time of the window. In mathematical formulation this is expressed as: $e_i \leq a_i \leq l_i \quad \forall j \quad \in \{1,2,\dots,N\}$ (3.10). By a formula the actual arrival time must be specified. The arrival time at customer j is greater or equal to the arrival time at customer i plus the time it takes to travel from customer i to customer j. This must be done for all vehicles and all customers. This is expressed by mathematical formulation as the following: $\sum_{k=1}^{K} \sum_{i=0}^{N} x_{i,j}^{k} \cdot (a_i + t_{i,j}) \leq a_j \quad \forall j \quad \in \{1,2,\dots,N\}$ (3.11). This does not have to be done for the depot where a vehicle starts and ends. This is because VRPTW assumes that the vehicles are located at the depot at the beginning of the day, logically $a_0 = 0$ (3.12).

For soft time windows we build upon the hard double sided windows. A soft window is the same as the hard time windows as described on the previous page, only the earliness and lateness may be violated at some penalty ρ per unit of time. In soft time windows it is possible to set a maximum allowed earliness and maximum allowed lateness. The hard time windows are in theory a specific type of soft windows where the maximum allowed earliness and lateness are set to zero. In Figure 20 a visualisation of a soft time window is given. In Figure 20 two new variables are present, E_i^{max} and L_i^{max}, representing the maximum allowed earliness and maximum allowed lateness. In essence the max earliness is not used in the practice to solve problems and therefore omitted. In practice the max earliness replaced by some waiting time. This means that if the vehicle arrives too early at the customer, the driver must wait until the customer can handle him/her. In the indention service- and waiting times, waiting times are discussed in detail.

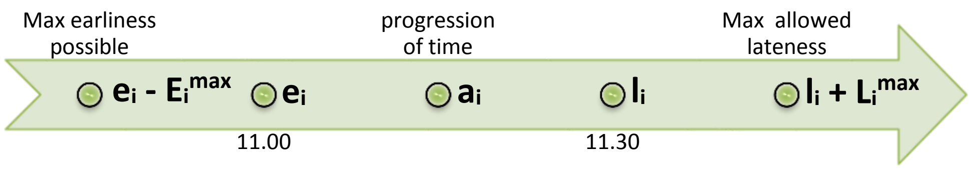


Figure 20: Soft time window

The lateness at customer i, L_i, can be calculated by: $L_i = \max\{0, a_i - l_i\} \,|\, a_i \leq L_i^{max}$. By this formulation the L_i is equal to zero or the positive difference between the soft time window and the arrival time, under the condition that the arrival time is before the maximum allowed lateness. To make (3.11) suitable a soft window, l_i is expanded to $l_i + L_i^{max}$, $e_i \leq a_i \leq l_i + L_i^{max} \quad \forall i \quad \in \{1,2,\dots,N\}$ (3.10b). A penalty ρ was mentioned, the penalty should be added to the objective function 3.0. This is realized by adding the sum of the lateness for all customers and multiply it by the penalty parameter ρ. $minimize\ Z = \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{K} c_{i,j} \cdot x_{i,j}^{k} + \rho \cdot \sum_{i=1}^{N} L_i$(3.0b).

From here on, hard time windows are used to continue with expanding the VRP model.

Service and waiting times

Service times are the times to perform some handling at a customer. The service time is expressed by s_i. Service times can be deterministic or stochastic. We return to stochastic service times in the indention stochastic service times, for now the service times mentioned are assumed to be deterministic. The waiting times are as mentioned the times a vehicle waits before or after arrival at a customer. This is sometimes needed to arrive in the time window of a customer. Waiting times are expressed by w_i. The standard models that make use of service and waiting times, assume that these times for the depot(s) are zero. This is because in these models the assumption is made, that the vehicle is loaded at the start of the route, and that there is always enough capacity at the depot so no waiting is needed. To incorporate the service times and waiting times into the VRP, both terms must be added to the restrictions 3.11 and 3.12. Restriction 3.10 is only expanded by w_i. This is expressed as follows:

- $e_i \leq a_i + w_i \leq l_i \qquad \forall j \in \{1,2,\dots,N\}$ (3.10c)
- $\sum_{k=1}^{K} \sum_{\substack{i=0 \\ i \neq j}}^{N} x_{i,j}^{k} \cdot (a_i + t_{i,j} + w_i + s_i) \leq a_j \qquad \forall j \in \{1,2,\dots,N\}$ (3.11c)
- $w_0 = s_0 = a_0 = 0$ (3.12c)

Stochastic service times

Stochastic VRPs are an extension of the standard (deterministic) VRP. Making it stochastic means that some randomness is incorporated by introducing some probability function into the model. There are several parts on which we can incorporate randomness in the processes. Cordeau and Vigo argue that a differentiation can be made between three major types. The most common types are (Cordeau et al., 2007):

- Stochastic customers: customer i is present with probability p_i and absent with probability $(1 - p_i)$;
- Stochastic demands (to be collected, say): the demand d_i of customer i is a random variable;
- Stochastic times: the service time s_i of customer i and the travel time $t_{i,j}$ of edge (i,j) are random variables.

When incorporating stochastic processes into a model, some probability distribution to describe the duration of an arbitrary process is used. Law (2007) gives us thirteen applicable continuous distributions. It is not proper to just assume a probability function. A proper distribution is one that fits the existing data by a goodness of fit test. To perform a goodness of fit test, the parameters to describe the data have to be estimated. Parameters for the distributions are estimated by maximum-likelihood estimators (MLEs), which are obtained by solving the likelihood function with the method of Newton[2](Averill, 2007)

Besides the distributions Law mentions, some special probability distributions e.g. the Burr and Dagum can be used. The Dagum is a distribution that is related to the Burr and the Burr on term belongs to the family of Gamma distributions. These distributions are incorporated into our research since they contain an extra shape parameter to describe the shape of the distribution more accurate.

[2] It is also possible to use the solver function in excel

In the case the data is absence or of such poor quality that it is impossible to suspect some distribution, one can be assumed. The Beta, Log-logistic and the Weibull distribution are a suitable replacement in these situations (Averill, 2007).

Out of Chapter 2 network description, it is known that there are multiple terminals. In literature VRP models can be expanded with multiple depots. For this problem the terminals can be seen as depots or customers, with some handling time. In the case terminals are seen as a customer, a different function must be used for the handling time than normal customers. Later in Chapter 5 probability distributions for the terminal times and customer are given.

Vehicle types and characteristics

In standard vehicle routing problems there is a homogenous set of vehicles. It is possible to introduce multiple types of vehicles. The total number of types is denoted by T. Vehicles of a specific type might have a unique capacity. In restriction 3.4, *Q* is replaced by q_k. The parameter q_k represent the capacity of vehicle k. Based upon the vehicle type different cost per connection between i and j can occur, due to for example difference in efficiency of vehicles. The cost parameter $c_{i,j}$ than must be adapted to $c_{i,j,t}$. This implies that we also must sum over the vehicle types in the cost function. Furthermore a binary parameter is used to identify if the vehicle is of type t. For now theta (θ) is used for that purpose. An example:

$$\theta_t^k \begin{cases} 1 & \text{if vehicle } k \text{ is of type } t, \forall k \in \{1,2,\dots,K\}, \forall t \in \{1,2,\dots,T\} \\ & 0 \text{ otherwise} \end{cases}$$

The objective function changes to:

$$minimize\ Z = \sum_{i=0}^{N}\sum_{j=0}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T} c_{i,j,t} \cdot x_{i,j}^{k} \cdot \theta_t^k \quad (3.0e)$$

Restriction 3.4 is adapted to:

$$\sum_{j=0}^{N} q_j \cdot \left(\sum_{i=0}^{N} x_{i,j}^{k}\right) \leq p_k \ \forall k \ \in \{1,2,\dots,K\} \quad (3.4e)$$

Pickup and delivery vehicle routing problems

The last expansion of the standard vehicle routing problem discussed in this study, is the pickup and delivery vehicle routing problem. Berbeglia, Cordeau, Gribkovskaia and Laporte provided a paper with an excessive overview of the classifications of the pickup and delivery problems in literature. They mention that the development of these problems might be applicable in the future(Berbeglia, Cordeau, Gribkovskaia, & Laporte, 2007). A standard pick-up and delivery problem is referred to a pickup at some arbitrary location, say A, and deliver the load to some arbitrary location, say B. By definition it is not applicable to our problem. But the strategies formulated by Nagy and Salhi are discussed.

Noticeable is that the authors mention the different routing strategies (policies) in article to build-up a solution. The three strategies discussed are: 1. deliver-first, pickup-second, 2. mixed pickups and deliveries and 3. simultaneously pickups and deliveries(Nagy & Salhi, 2005).

1. *Deliver-first, pickup-second* is the strategy where most researchers make the assumption that the set of given customers can be divided into two groups. The linehauls and the backhauls. Customers that receive goods are revered to as linehauls. Customers that send goods are

revered to as backhauls. An additional assumption in deliver-first, pickup-second is that a vehicle in the fleet must first deliver all the present cargo on the vehicle before it can pick up cargo at a customer sending goods. The last assumption is made because in practice it might be difficult to rearrange the deliveries and pickups on a vehicle after each delivery or pickup. Furthermore the model is simplified this way because the vehicle start with a load that first must be delivered until the vehicle is empty and then the vehicle picks up load at customers until the vehicle is fully loaded again or till no further pickups are present.

2. *Mixed pickups and deliveries* is the strategy without the obligation to first deliver all load until the vehicle is empty. Backhauls and linehauls are served in any desirable sequence in the vehicle's route. The pickup and delivery problems with the strategy deliver-first, pickup-second and mixed pickups and deliveries both fall under the collective noun: vehicle routing problems with backhauling.
3. *Simultaneously pickups and deliveries* is the strategy where the customers are not linehauls or backhauls, but can be receiver and sender at the same time (simultaneously). When all the customers puts the load of receiving or sending to nil, but not both to nil, they can be split to linehauls and backhauls. So in essence the mixed pickups and deliveries strategy is a special case of the strategy simultaneously pickups and deliveries with customers that put either their amount of receiving or sending load equal to zero.

Conclusions

In this section VRP and different relevant flavours of the VRP in the form of additional restrictions and strategies are discussed. Later in the study, in Chapter 4, the knowledge of this section is used to form a mathematical model and to study the logistical system of CTV. In the next indention relevant solution methods are discussed.

3.3 Solution methods

VRPs can be solved by e.g. integer linear-, dynamic programming, and heuristics approaches. Some solution methods may contain parts of other solution methods. Given that, there is no "best" way to evaluate combinatorial optimisation problems, they are dependent on the specific environment we are trying to model. As mentioned by Tan, Chew, and Lee (Tan, Chew, & Lee, 2006) due to the inherent variations in real world environment, the solution to each vehicle routing problem is often unique and satisfies an exclusive set of constraints and objectives according to the problem scenario. To get a good overview of how the standard VRP develop throughout the decades and more important their way of solving these problems, we refer to Fifty Years of Vehicle Routing by (Laporte, 2009) or (Assad & Golden, 1995), or (Pillac, Gendreau, Guéret, & Medaglia, 2013). In some solution procedures a construction methodology with a local search improvement step is used(Caris & Janssens, 2009). For a good example, see Caris and Janssens (2009).

Solution methods to the VRP with time windows

If we look at the solution methods of the VRPTW, methods as integer linear programming, dynamic programming and heuristic approaches are used in literature(Cordeau et al., 2007). According to the authors, there is no best way to solve the problem, hence they do not even try to evaluate what the best method is; they only provide us with a bulk of possible methods to solve the VRPTW. Desrosiers also has an excessive review of the solving methods regarding time constrained VRP, in his article he claims the column method developed by Danzig in cooperation with the Lagrange relaxation method is one of the most powerful tools (Desrosiers et al., 1995) . This is only for static schedules. They also argue heuristic approaches to be a viable tool to solve the VRPTW.

Solution methods to the VRP with pickup and delivery

Over the last decades, in the field of dynamic pickup and delivery problems, a number of solution procedures have been developed. The proposed algorithms however cannot be directly compared to other algorithms. This is because, no standardized simulation environment has been used by more than one group of authors to evaluate the algorithms in a proper way. Benchmark instances are available; e.g. those used referred to in Mitrović-Minić and Laporte (2004) and Mitrović-Minić et al. (2004)(Parragh, Doerner, & Hartl, 2008). Parragh argues that future research will involve the incorporation of additional real life constraints, the effects of dynamism and knowledge about future events, in terms of probability distributions. This is because the authors argue that, the pickup and delivery problem has not been tested extensively to real data instances except for the two pickup and delivery problems by Vigo and Toth (1996) and Schang and Cuff (1996)(Parragh et al., 2008).

Conclusion

Due to the argument that no standard simulation environment is has been used to evaluate the algorithms. The ones that are being tested are not tested extensively. This implies no applicable benchmark is available for us. This is due to the lack of testing and that such environments must inherit real time variations of the environment that is being modelled. CTV uses a rather odd business model according to the standards in the market. The model started off from scratch as stated in Section 3.1, and so will the solution methods to the model.

In the upcoming indentions we discussed the solution methods: heuristic approaches in the form of a constructive- and local search heuristic, which are viable tools according to the statement by Desrosiers in the indention “Solution methods on VRP with time windows”. This also seems to be a proper starting point if you look at the solution methods since we cannot argue for sure that one of the other methods is great in the sense of computation time, and we know for sure we can approximate a optimal solution by heuristically approaches, more on this in Constructive heuristics.

Constructive heuristics

A heuristic is a term that is descended from the ancient Greek word “Εὑρίσκω”, which means “find” or “discover”. A heuristic is used there were other methods are too slow to come up with a solution in reasonable time. In NP-hard problems this technique is useful, since heuristics “find” or “discovers” a feasible solution. With heuristic approaches it is not certain that an optimal is found. There are constructive heuristics and local search heuristics, this indention concerns constructive heuristic(s).

With a constructive heuristic, guidelines are followed to come up with a feasible solution. The construction of the solution is performed, while keeping a keen eye on the cost of the solution. In essence a constructive method explores just a small area within the solution space. The small area it explores however is the area in which promising solutions are(Caris & Janssens, 2009).

There are a lot of heuristics known. This study will only concern the Savings algorithm of Clarke and Wright. This is because it is one of the best performing methods in practice. Later this will provide us with a benchmark based on literature. It has proven itself since 1964 as a method that generate a relative good solution. The savings algorithm can come up with the construction of the solution based upon a sequential (one route each time) or parallel (multiple routes simultaneously) version of the algorithm(Clarke & Wright, 1964)(Altinkemer & Gavish, 1991)(Poot, Kant, & Wagelmans, 2002).

The savings algorithm is explained by a simple example with four customers to visit and one depot. The example concerns the sequential version of the savings algorithm and one truck. Consider Figure 21, here a visual representation of the savings algorithm is given. The figure explains the steps to come to the feasible. The building of the solution starts with making a connection between the depot and all present customers. The cost associated with the connection from the depot to customer i and back to the depot are as follows: $costs(0, i) = c_{0,i} + c_{i,0}$, where i is the customer number. Based on the biggest savings, a connection is made between customers. To calculate the total savings to connect two customers, the following formula is used: $s_{ij} = c_{i,0} + c_{0,j} - c_{j,i}$. The savings formula is interpreted as follows, we remove one connection from the depot to customer i, remove one connection from the depot to customer j and then we add the connection between the customer i and customer j. This is calculated for all possibilities and then the savings are sorted from large to small, the bigger the savings the better. In our picture this applies first for the customers 1 and 2. Next, customer 4 is incorporated into the route, and as last customer 3 is added into the route. If a connection would violate any constraints, the possibility to make a connection is not present and we look at the next instance in the sorted list of savings. A new route would be formed once the vehicle is reaching its limits in form of for example capacity or action radius.

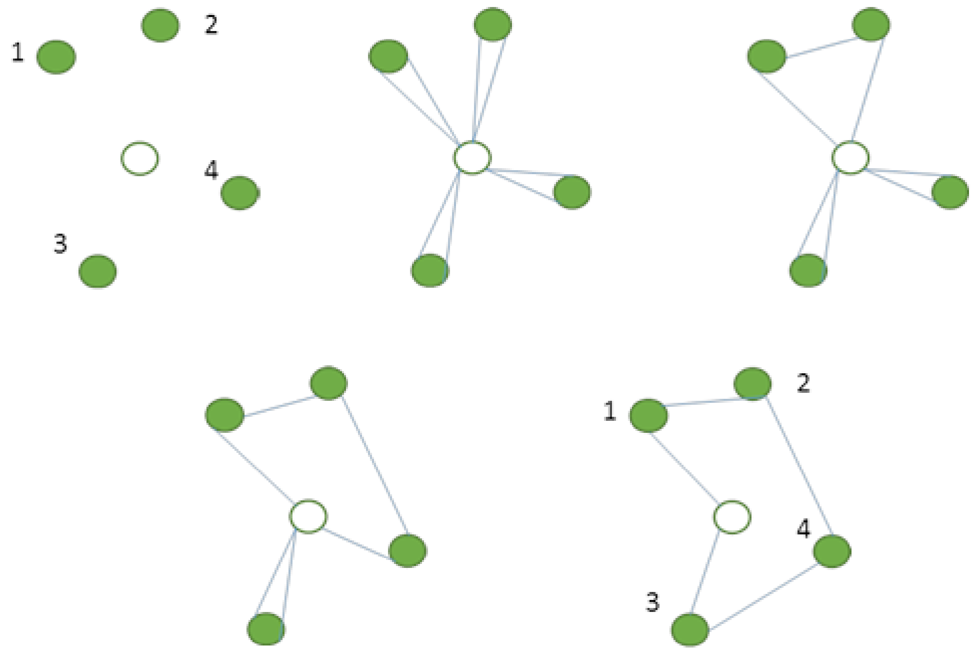


Figure 21 Outline steps in a sequential savings algorithm

The most common strategies in VRPs regarding algorithms are the 1. cluster-first, route-second, and 2. route-first, cluster-second. In the cluster-first, route-second heuristic the jobs are first clustered to be assigned to a vehicle, afterwards the consecution of customers to visit is determined. For, route-first, cluster-second, the opposite is true. Here first consecution of customers is determined, and afterwards they are assigned to vehicles. This is done in the second by ignoring the constrains of limited vehicles at first. This implies that a free number of vehicles can be assigned. The prominent known algorithms of the strategy cluster-first, route-second are the Fisher and Jaikumar algorithm, the sweep algorithm and Taillard's algorithm(Fisher, 1995). It is unknown to us if the second type of algorithms is competitive in relation to the first type of algorithms, therefore these are omitted from here on. Once a feasible solution is constructed, it is possible to search the solution space based upon the current feasible solution by slight modifications in the allocation of customers to vehicle routes, and the sequence of customer visits within a vehicle. This is called local search or improvement step.

Local search heuristics

K-Opt

The k in the k-opt stands for the number of customers exchanged per step in the improvement procedure. This can be done within a route, but also between routes. When a number of customers is exchange between routes, the exchange is accepted as long as it brings an improvement of the overall value of the objective function. When the solution gets worse, another possible exchange is evaluated. The mechanism brings improvement to the objective function, but it can be stuck in a local optimum.

Simulated annealing

Simulated annealing is discussed, because simulated annealing is capable of escaping local optima where k-opt would be stuck. Simulated annealing finds it origins in a chemical process. The idea is to emulate a cooling down process of a solid, until its structure is "frozen". When values of temperature of the cooling down process are relatively high, the method accept improvements as well as deterioration of the objective function. Once it is more cooled down and closer to its ending temperature, the method accepts only improvements of the objective function. The mechanism of simulated annealing works as follows(Lin, Yu, & Lu, 2011)(Pinedo, 2005):

1. Set the constructive solution as best solution and set the corresponding objective value as best objective value.
2. Start the method and continue as long as there is time left (based on temperature) and the objective function is not below some desired value, then go to 3. Else go to 9.
3. Update the temperature (cooling down schema): according to a formula which is problem depended.
4. Set a neighbour solution to inspect.
5. Calculate the objective value of the neighbour solution.
6. Acceptance probabilities: We accept the solution based on a value P, which is a random value between [0,1]. Input for P is the current objective value, the neighbour objective value and the current temperature. This probability value is high at high temperatures and low at low temperatures.
7. If the new objective function is better, the solution is accepted with certainty.
8. If the computed objective function is better than the best found solution so far, the best solution is updated with the current solution.
9. Go back to 2 until there is no time left (based upon the temperature of the cooling down process) and the objective is not below a desired value.
10. Give the best found solution.

Once simulated annealing is done, the final best solution is given and the search is done. What is unknown so far is if the method is a robust one. To evaluate the robustness and the stability of a constructed solution, a simulation model is constructed. Why a simulation model is used is described in the next Section 3.4.

Tabu search

Tabu search belongs to the descent methods of improvement methodologies. Tabu search starts with an initial solution within the solution space. Based on that solution Tabu search looks at its neighbour solutions and picks the best one each iteration. In Tabu search it is allowed to move to a neighbour that deteriorates the current solution. This is the main advantage from Tabu over the classical descent methods(Pinedo, 2005). The method avoids cycling in the solution space by temporary placing a solution on the Tabu list. Tabu search relies on forbidding certain solutions within the solution space. IN the problem at hand this implies that certain sequencing of jobs are forbidden. Due to this this, Tabu search requires a lot of memory, and because this memory needs evaluation cause the improvement step to require relatively large computation time. Moreover if common sense regarding the Tabu list is used, we believe that the Tabu list in our problem causes problems. This is because out of Section 2.3 it was found that 83% of the container consist of the same pickup location(2848) and 73% of the containers have the return location(2848). So if say job B is evaluated to be placed after say job A, and B has the pickup location of 2848 is placed on the Tabu list, logically so will 83% of all container-jobs. By this the Tabu list because rather large leading to slow solving speed.

In literature it was also found that models regarding Pickup and delivery were a burden to solve by Tabu search, especially once the problem became bigger(Caldas, Carpente, & Lorenzo-Freire, n.d.). The study of Thangiah, Osman and Sun shows that Tabu search performs just slightly better than simulated annealing, Tabu search however shows more time needed to come to the better solution according to the same research(Thangiah, Osman, & Sun, 1994).

3.4 Simulation

System: Is a collection of entities is used to define a system (Averill, 2007). With entities we mean for example people or machines that act and interact together toward accomplishment of some logical end, purposed by Schmidt and Tylor(1970). In practice, the definition of a system must be adapted towards the specific situation and the formulated objectives.

State: A state is defined as being a set of variables that are necessary to describe a system at a specific point in the time, relative to the objectives of a study (Averill, 2007). On that time the variables have unique values.

Systems can be divided into two categories, discrete and continuous (Averill, 2007). A **discrete system** changes its state variables at separated, specific fixed points in time directly (Averill, 2007). A **continuously system** changes its state variables continuously in the time, regardless of the point in time on the time horizon(Averill, 2007).

In practice however, systems are rarely completely discrete or continuously. Still for simplicity these two systems are in theory divided into one of the two categories. This is because it is likely that one kind of system is dominant based upon the change of time dimension. By taking the dominant change as the leading indication for separation of the two systems, it is possible to classify most systems into one of the two categories. (Averill, 2007)

An example of a continuous system given by Law, is about dealing with a plain traveling through the air. Law argues that due to the fact the position of the plain changes every millisecond in speed and acceleration. Regardless the classification of the system, a system in itself can be studied in multiple ways.

In most practical situations the experiments with the actual system are far too expensive. This is also the case in our situation. If we would apply several planning rules, we are not sure what the effect is. A physical model is by far too complex to construct, especially if we would take the range of customers into consideration. As said, the current operations system at CTV is far too complex for an analytical model. In cases of highly complex systems, the researcher ends up with modelling by simulation (Averill, 2007), see Figure 22.

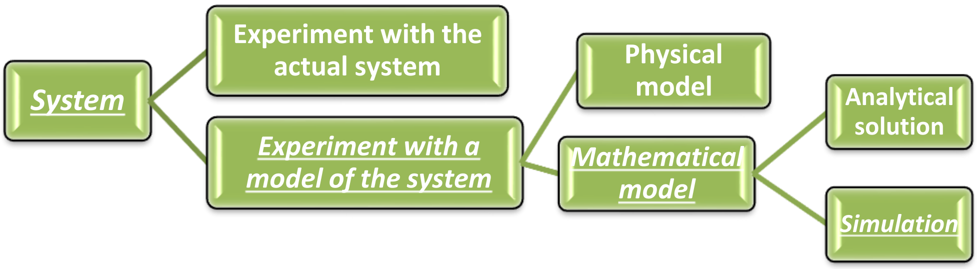


Figure 22: Ways to study an arbitrary system(Averill, 2007)

In addition Law provides a framework to perform a simulation study, see Figure 23.

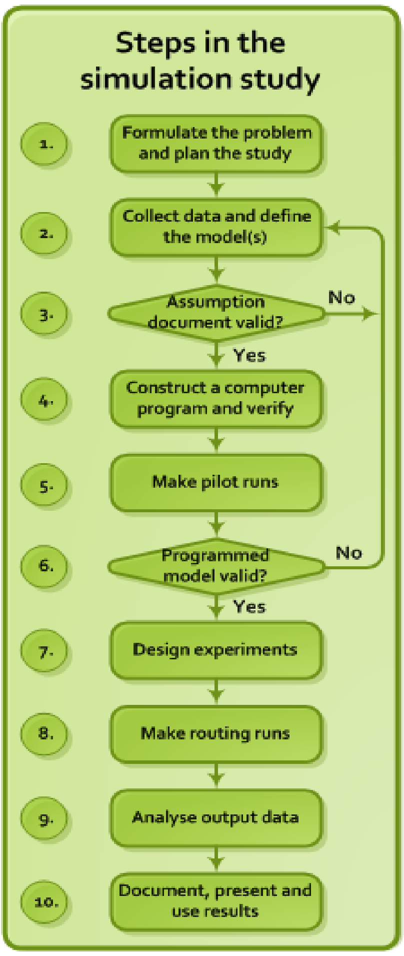


Figure 23: Steps in a simulation study(Averill, 2007)

3.5 Conclusion

In this chapter shows the elements to answer the questions II and III.

II. *What variants of vehicle routing problems are available in literature and is one of these problems applicable to our problem? What parameters are being used?*

III. *What kind of solution methods are available in literature and which are useful for our problem?*

We covered the VRP and all relevant expansions. This was done because no model was directly applicable. This answers partly the question II, there is no model directly applicable. The VRP and the relevant extensions: time windows, multiple depots, service times, waiting times and strategies for the pick-up and delivery problems are explained and discussed to set up a model for the logistical system of CTV. A setup is given for electric vehicles once they are needed to be incorporated into the model. This answers other part of question II, the variants relevant for our problem and parameters can be found.

The solution methods are discussed, and the main finding was that no suitable benchmark is available, and more importantly there is no best way to solve the problem. Due to this relevant constructive and local search methods are covered. As mentioned, only a model specific for the environment is going to give us relevant results. Due to the multiple possibilities to solve the problem at hand, in this study a heuristically approach to the problem at hand is developed in Chapter 4. The savings algorithm is used to evaluate the solution based on literature. Out of literature, the k-opt and the simulated annealing methods are selected as methods for the improvement of a constructed solution. An introduction into model building has been given and it is stated why a mathematical approach to the problem is better than starting experimenting with real time practice. Steps to take to develop a model have been identified.

Chapter 4

Planning model

In Section 3.2, the standard vehicle routing problem is described and adaptions to the standard model were made. In practice the model must be able to run from day to day, this implies, that the different VRP models are expanded by day indices. As a result of this perspective, the trailers that spend the night at the customer are left out at first. In reality, however, there is sometimes a dependence, upon containers over days. But since for now the allocation of trailers is omitted, this does not have an effect on the solution. Since the container-job still needs to be transported, regardless on which trailer it is moved. In addition we assumed, that the connection decision variable $x_{i,j}^{k}$ knows when a container is transported, where to start a trip of a container, and where it ends. This means that in $x_{1,2}^{k}$ and $x_{2,3}^{k}$ the location 2 means two different things. For the first decision variable X it means the travel of the current location to the pickup location of the container-job 2(this can be a terminal or a customer) and in the second decision variable X it means the travel of the current location to the delivery location of the container-job 2, this can be either a customer or a terminal. So $x_{1,2}^{k}$ means the delivery location of container-job 1 to the pickup location of container-job 2, and $x_{2,3}^{k}$ means the delivery location of container-job 2 to the pickup location of container-job 3.

Out of Chapter 3, we get our possible restrictions and which parameters to use. Using that chapter a mathematical model for guidance purpose was made. The appendix provides a description of the mathematical model and the restrictions, see Appendix E.

First this chapter describes the restrictions used in the model. In Section 4.2 an overview is given how the model builds up a feasible solution. In Section 4.3 we come up with a description of a heuristically procedure to construct an initial plan. In Section 4.4 the improvement methodology is described. Section 4.5 provides a description of the allocation of trailers to the containers and how the model is able to cope with dependency of trailers to containers over days. In the second-last section, Section 4.6 the procedure to allocate waiting times is described. This chapter ends with a conclusion in Section 4.7.

4.1 Plan restrictions and decisions

According to Chapter 2, the planning model must be able to form routes for the vehicles. The routing is based upon the sequence of container-jobs that must be performed by vehicles. There can be only one container-job upon one vehicle per time unit and a container-job can only occur once. The vehicle must start and end its route for the day at CTV. The vehicle must take a break of half an hour, after 4.5 hours of pure driving. The vehicles are homogenous and therefore all vehicles have the same properties regarding speed and capacity.

Drivers are assumed to be equally skilled and therefore omitted in the construction. Additionally, the expectation of the model is that regardless the time, a driver can drive any given time period in a day, as long as the driver takes a break after 4.5 hours of driving. We expect in some cases that when a container must be delivered far away from Venlo early in the morning, a driver must start somewhere during the night.

Customers can be visited more than once, since they can request more than one container per day. It is assumed there is always an empty dock in which the trailer with container can be stalled. This is because we assume that the customer knows to occupation of its own loading docks regarding timing, hence the customer demanded a specific due date.

Equipment utilisation of the trailers is omitted at first, however the planning model calculates the timing a trailer would take to decouple or couple in any situation. It is assumed that there is always a trailer available. In reality we have 120 own trailers and we can rent additional trailers that might be or not available, however the planning model assumes that there are always additional trailers to rent. Why this is done that way, see Section 4.5.

Container-jobs contain a customer location and job type. So a container inherits all needed information for the model to transport the container, this includes the information about the type of job. The job type’s delivery- and complete job, require a container to meet some delivery time, the due date. Return jobs are allowed to be returned any time during the day, this is due to the practical properties of a terminal. Containers are allowed to arrive before the due date, but not later. This is done this way because the model can correct for too early arrivals. The model does this once the planning of the day is made by setting waiting time. Additionally, the planning model will use the opportunity, when constructing the waiting times, to allocate the break into one of the waiting times. This is done so that no time is wasted. The return type of job is not allowed to be handled before 12 o’clock, unless it is a return job triggered from days before today. Containers are homogenous; in reality we have 45 ft. 40ft. 22 ft. and various other containers, but since a vehicle can only transport a single container, it is valid that the containers are modelled as homogenous transportation jobs.

4.2 *Construction of the solution*

As stated in Section 3.1, equipment should be allocated to vehicles before allocating a container if literature is followed. For the model of CTV this is not right. This is because when allocating the equipment, a trailers, to a vehicle, this is not giving any additional information about routing or timing. The cause of this is that CTV allows decoupling at the customer. In addition due to the three types of jobs (Figure 3) it is not always the case a complete vehicle is needed for a specific job, this is only known once a job is allocated to a vehicle. In practice, a trailer has to be allocated to a vehicle first to make it a complete vehicle, but for the construction of a solution this does not have an additional value. So it is decided to construct a solution based upon a vehicle-container-combination, while taking into account the time it would take to couple or decouple and when to pick up a trailer at CTV. Basically we do "as if" we have unlimited trailers and afterwards try to allocate minimum trailers on a daily bases, based upon the constructed routing plan for that day. Results of the model are made as follows:
At first a route construction step is performed, second the constructed solution is optimized by an improvement step, and at third the allocation of trailers to this container-vehicle-combinations is made. Afterwards we complete the plan by adding waiting times and breaks towards the generated sequence of jobs on a vehicle. For a schematisation of these steps to come to a solution, see Figure 24.
The steps involve different decisions to make, for step one the following two decisions (recall Chapter 3) are involved:

$$Sequence\ r\ of\ the\ container\ on\ vehicle\ v\ on\ day\ d, where\ r = \{1,2,\dots,R_d^v\} \tag{4.1}$$

$$X_{c,d}^{v,r} = \begin{cases} 1, if\ vehicle\ v\ transports\ container\ c\ on\ day\ d\ as\ rth\ container\ of\ his\ trip \\ 0, \quad else \end{cases}$$

$$where\quad c = \{1,2,\dots,C_d\},\qquad r = \{0,\dots,R_d^v\},\qquad v = \{1,2,\dots,V\},\qquad d = \{1,2,\dots,D\} \tag{4.2}$$

The objective is to minimize the empty travelled kilometres. Remember that is impossible to optimize the legs from the pickup location of container to the customer and from the customer to the delivery location. The planning model does optimises the sequence of container-jobs on a specific vehicle. Remember Figure 3, the none-complete type of jobs are the jobs in which the biggest contribution towards optimisation can be made. So only the connection between the end of a job and start of the consecutive jobs can be optimized.

The improvement step, step 2, optimizes the decisions 4.1 and 4.2 by a local search. This can be k-opt or simulated annealing. In the third step the decision to make, is the decision to allocate which trailer to which container. The container is already bounded to a vehicle due to the first two steps, and the timing of trailers is also taken into account in these steps. In step 3, only the trailers have to be assigned in such a way the utilisation of the total number of trailers from an integral point of view is minimized. At last a simple algorithm is used to set the waiting times, and based upon the waiting times the opportunity to set a break in the waiting times is explored.

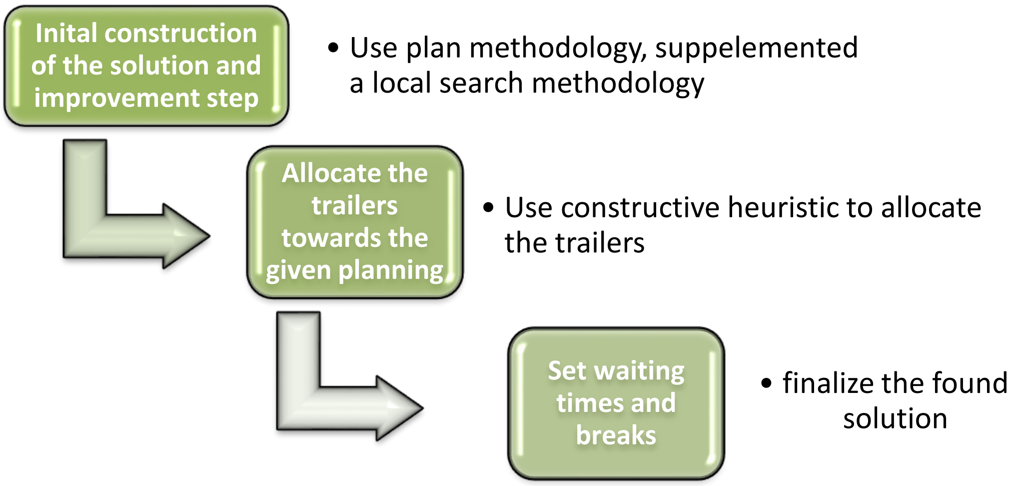


Figure 24: Steps of the simulation from a planning layer perspective

4.3 Construction of an initial schedule

How to come to an initial feasible plan, four methodologies are discussed. The first planning methodology will be used later as the worst case analysis.

First planning methodology: Worst case analyses (WCA)

At the start of a day the total number of container-jobs arrive. These needs to be allocated and sequenced on vehicles. All jobs must satisfy the restrictions as stated in Section 4.2. The container-jobs arrive at accessing order in due date. The plan model than lets a “new” vehicle start working if it is needed to make sure the next container to schedule arrives on time. So in the case of that the next ten container-jobs have a due date of 6 o’clock in the morning, for each container-job a new vehicle is used.

Due to the fact, the human planners allocate containers according to gut feeling, the insight is that the current performance might be very close to a worst case scenario. At least creating the worst case scenario should be a proper starting point to come up with a benchmark for the model. This is done by allocating the next container to schedule, to the vehicle that is first available based upon timing, without looking at any other property. So for example; when we have vehicle 1 that is available on 09:00 and vehicle 2 that is available on 09:05 with respectively additional kilometres of 150 and 50, the model always chooses vehicle 1, regardless if they would both be able to arrive on time. If no suitable vehicle is available, a new vehicle is made available in the system. A new vehicle starts his routing so that it arrives just in time at the first customer. Once a container is allocated its next available time is computed, and stored in a list of available vehicles.

When setting the worst case scenario, all vehicles are forced to first return to CTV after they completed their job. So the next available time here, is always the time that a vehicle is located at CTV. The list then is sorted on the first available time of the active vehicles. For a detailed schematization, see Figure 25.

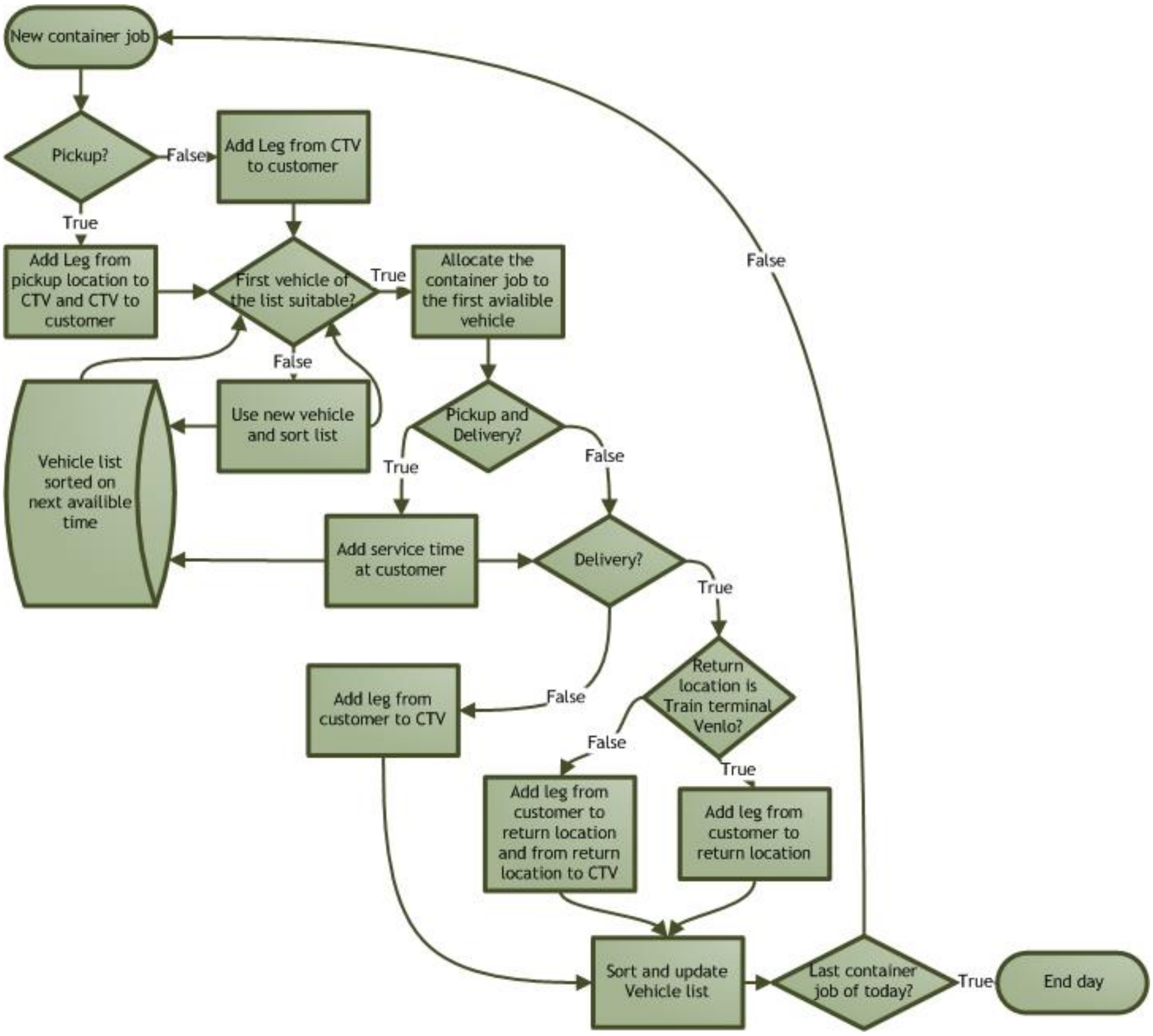


Figure 25: Steps first planning methodology

Second planning methodology: Cost based savings

As second constructive planning methodology, the parallel savings algorithm is used. Recall Section 3.3 for details on a route construction. In the example of Section 3.3, in that example it was only allowed to construct 1 routing per time (sequential). Here we allow the construction of multiple routes at the same time. In the planning model the parallel savings algorithm is used to calculate the combinations that have the biggest savings. These combination are sorted based on largest to smallest savings. Since the algorithm combines the best combinations at first, at least the biggest savings are made by the methodology. Again they have to fall of course within the restrictions as stated in Section 4.2. Once the list of savings becomes negative in our savings algorithm, a “new” vehicles is used for these negative savings as long as the methodology still can open new vehicles. Recall that in total at most 60 vehicles are allowed to be active. If no combinations can be made any longer, we quickly finish the initial schedule by allocating the remaining containers in a random order. The improvement step will make up for stupid decisions made by the random allocation of the last few containers of today's schedule.

Third planning methodology: Improved WCA

To improve the first planning methodology, a smarter allocation of the container in the construction of the schedule is set. This is done by not looking at the first available vehicle that meet the restrictions, but look at all the vehicles that meet the restrictions, and then look for the vehicle that adds the least additional kilometres. By this methodology, the construction of the schedule is steered fast to a more local optimum. Once the schedule is completed for the day, this methodology should lead to lesser travelled distances in an integral point of view, compared to the first methodology. However, due to this, the improvement step might be stuck in a local optimum faster.

The keynote here is that because the vehicles are not forced back to CTV once they finished a container-job, there is an initial reduction compared to the first methodology that is related to this. It should logically not lead to more usage of vehicles, but can lead to less number vehicles used. For a detailed schematization, see Figure 26. The red circle indicates the additional step compared to the first planning methodology.

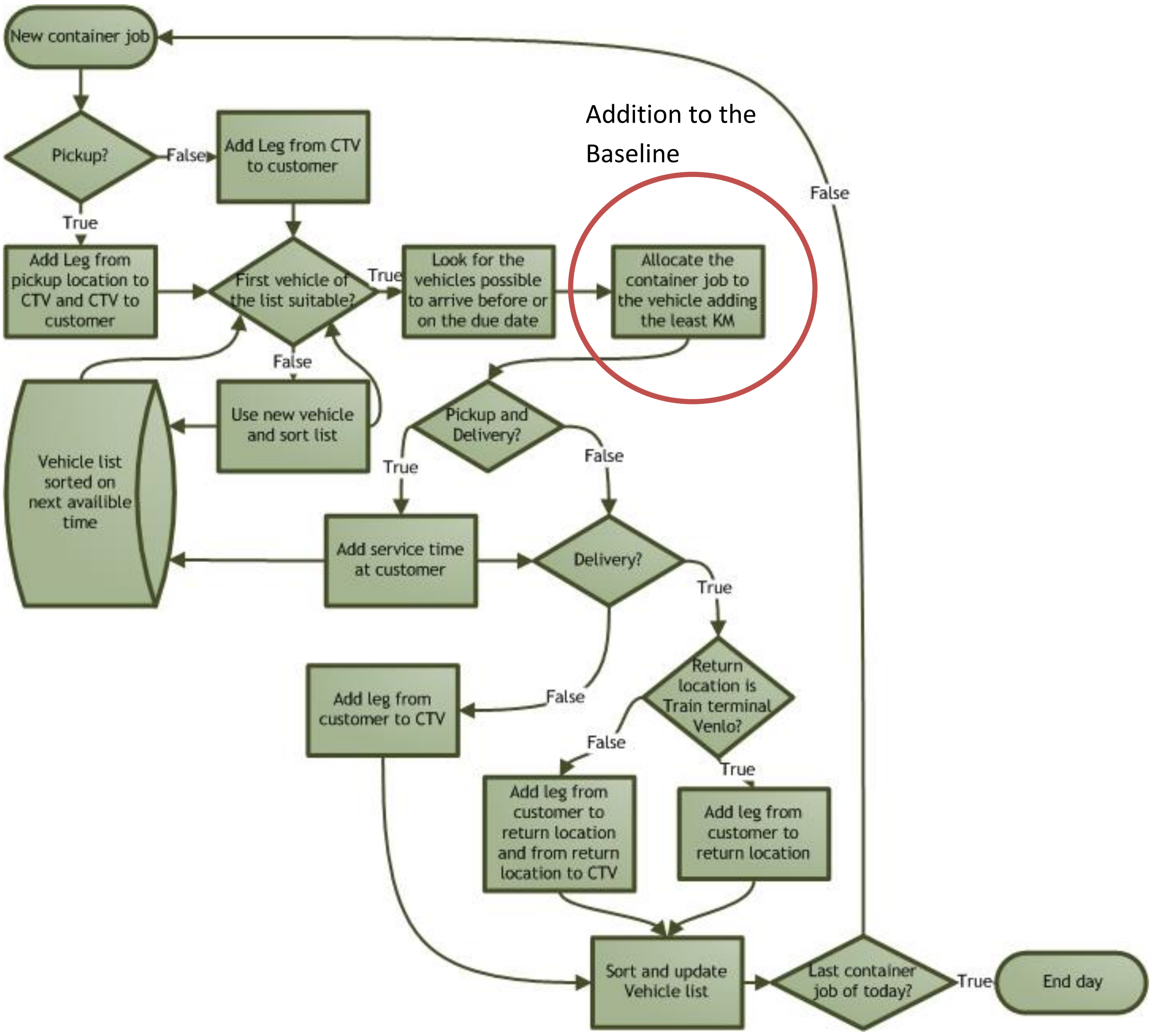


Figure 26: Improvement of the WCA

Forth planning methodology: balance equal

The last planning methodology tested is the methodology in which the model balances the number of container equally among the vehicles. This is done as the follows:

The first container is assigned to the first vehicle, the second container to the second vehicle, etc. This is repeated until the last possible active vehicle is reached, vehicle 60, than container number 61 is allocated to vehicle 1 again. The next containers are added to the vehicles until all vehicles have two containers to handle. If all vehicles have two containers to handle, the remaining containers are added to the vehicles until all vehicles have three containers to handle. This is repeated until no containers for today are left to allocate. A visual representation of the balance methodology is given in Figure 27.

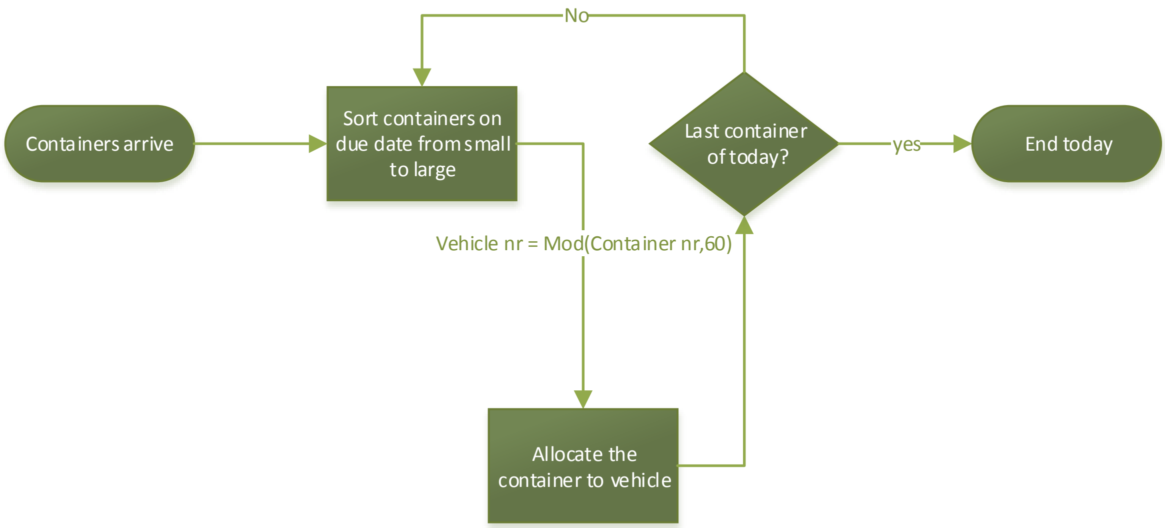


Figure 27: Balance equal methodology

Conclusion

Each planning methodology is able to come to a feasible plan, a constructive schedule, but there are differences. These differences leads to different results. The main differences is between the second plan mythology against the first and third. The first and third both use a sorted list of containers, while the second methodology uses a list of savings. How these plan methodologies are improved, is given in the upcoming section.

4.4 *Optimization by local search*

In addition to a constructed solution, by the worst case scenario, the savings algorithm, the improved baseline or the balance methodology, the solution is improved by a local search. The following methods are tested consecutive to the construction: a 2-opt and a simulated annealing.

The 2-opt is a swap mechanism where we swap 2 random containers between vehicles or on the same vehicle but swap the routing. Here a swap is accepted once it leads to a reduction in overall kilometres. Here again the restrictions of Section 4.2 are taken into account. The limitation here is that the solution might get stuck in a local optimum.

To tackle the problem of a solution that gets stuck within a local optimum, a simulated annealing procedure is intruded into the model. How simulated annealing works can be found in Section 3.3.

Here the same types of swaps are made as in the 2-opt, but due to the fact sometimes a deterioration of the solution is accepted, the method is able to escape a local optimum. Normally, the last solution found of the simulated annealing procedure is the best.

4.5 Allocating the trailers to container-vehicle combinations

Based upon the constructed plan, trailers are allocated. An important aspect is to realize that if currently we are dealing with a job that needs returning at a terminal we end up with a complete vehicle. A complete vehicle was a vehicle with a trailer behind it, see Section 3.2. If a complete vehicle is the end of a container-job, and the next job on the vehicle is a pickup at a terminal, the same trailer is used. If the next job type would be a delivery job as stated in Figure 3, than the vehicle must be made incomplete first. This implies we need to return to CTV to decouple the trailer, hence additional kilometres would be made.

In Section 4.4 this is taken into account in the construction of the schedule so for the allocation model, only the administration of the timing of the trailers needs to be generated. The trailer allocation heuristic, does try to find the best possible combination given the current set of trailers. If more trailers are needed then CTV owns, the model is able to create additional trailers. When taking a generated solution of Section 4.4 as the input for the trailer allocation heuristic, this should lead to a limited solution space for the allocation of the trailers.

The allocation heuristic does however allocate the trailers as efficient as possible given a constructed plan. This heuristic needs to use something smart to cope with the dependence of container-job types deliver and return of Figure 3 over the days. This is because, in reality sometimes containers on a trailer are located at the customer for several days. This implies that those trailers are unavailable for several days. The model must keep track of which trailers are available and which are not. This implies the trailer output of the model for day d, is the input for the model for day d+1. For a detailed schematization on the trailer allocation heuristic, see Figure 28.

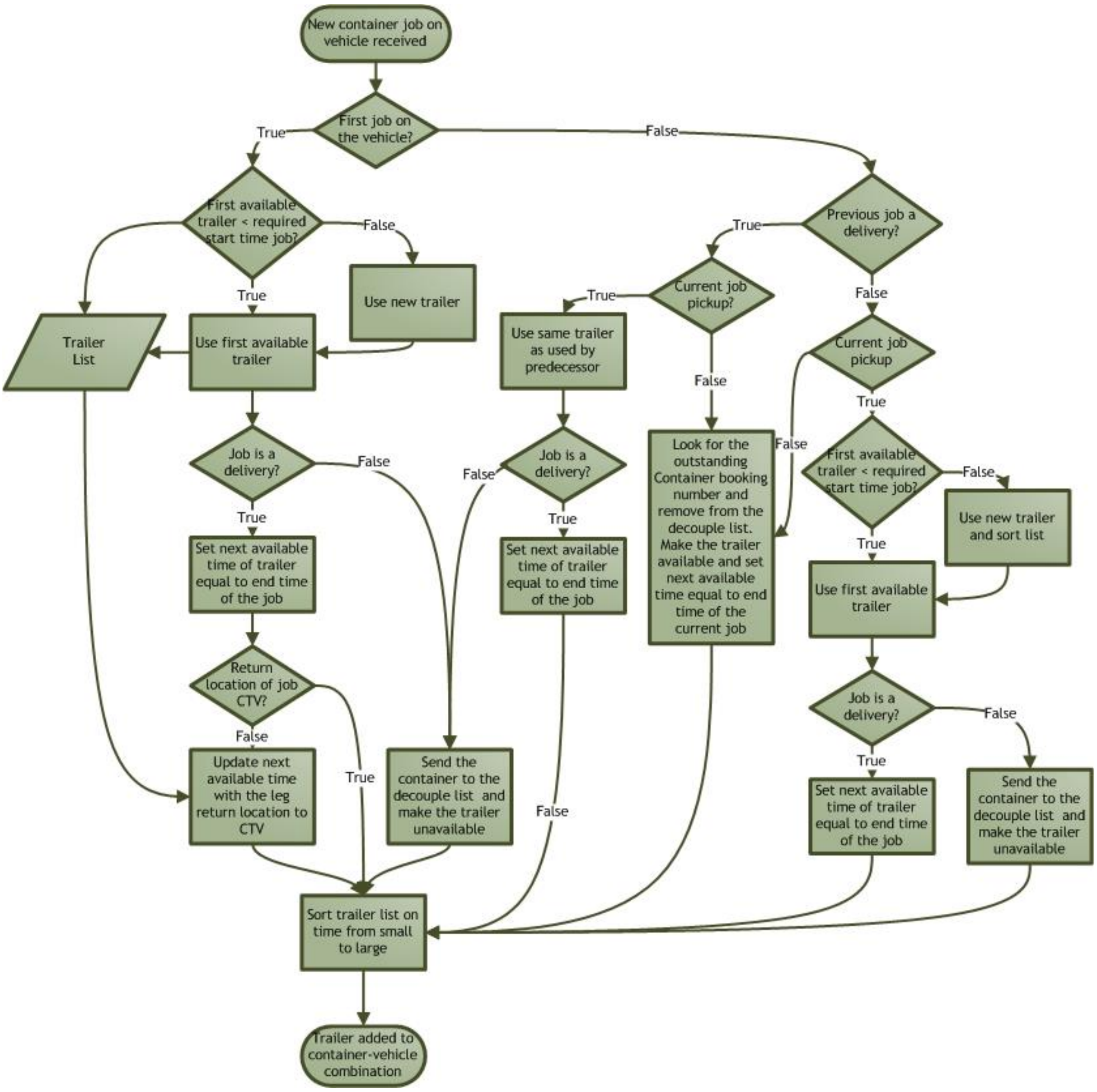


Figure 28: Allocation of a trailer

4.6 Set the waiting times and breaks

As stated within Chapter 4 afterwards the allocation of the trailers waiting times can be set by the model if needed. Waiting times are needed if a job arrives too early at the customer, to time the arrivals of our jobs better waiting times are introduced in those cases by the model. Within the set waiting times the model tries to find a suitable place for the breaks, if no waiting time is as large as 30 minutes, additional waiting time(in the form of a break) will be introduced by the model. This is done as the following:

1. Set i to 0. And j to 0.
2. Increase i with one as long as the earliness time of container i+1 is bigger than the earliness time of container i
3. If the waiting time of container i+1 is smaller than set the waiting time of container i, set this waiting time to all containers between container j to container i+1.

4. Update the earliness of the containers greater then i with the subtraction of the set waiting time.
5. As long as j is not the last container, set j to i+1 and return to 2.

Chapter 5

Simulation model

In this study, simulation is used to evaluate different interventions which are too costly or too risky. For CTV these arguments apply because the current practice is suspected to be or close to its limits. More importantly experimenting in practice could result in the loss of important clients. Since the current practice involves a lot of paperwork, implementing a new strategy to the current practice of the system is therefor hard to evaluate. First a short introduction about the approach to the simulation model is given. In Section 5.1 five major steps to construct a planning are discussed. The steps are discussed in more detail by the subsections of Section 5.1. In Section 5.2 will be explained how the model is evaluated and what is the benchmark of the model. Which experiments are performed by the model is explained in Section 5.3.

Approach to the simulation model

To build up the simulation model, the programming language Delphi was used. Because no current program is used to construct a planning, the model was formed from scratch. The program is able to come up with a suggestion for the planning of today, given an input of container-jobs for that day, and the input of the containers located at the customers of the previous day. The model is capable of:

- Statistically allocate service times for a terminal, as for service time at the customer.
- Sample containers from day to day for a year, given a growth factor. The year should represent the year 2013 if the growth factor is 1.
- Differentiate between complete jobs, pickup and delivery job.
- Differentiate between pickup jobs in time. This implies that the model is allowed to pick up a container at the customer before 12 if and only if the delivery part was not on the same day.

Since CTV is working with hard time windows and it is not within our scope to research what the customer thoughts are about time windows, a general hard time window for all customers is assumed. This implies all e_i and l_i are of the same value for all customers, logically they are predetermined values, but they no longer belong to a customer location i. What also is different from the mathematical formulation is how the model keeps track of the days. In the model years, weeks and days are used.

5.1 Construction of the simulation model and random sampling

In the model different steps were used to construct a schedule. First, the locations of the customer and the terminals, and all container-jobs were loaded respectively. Second, a choice can be made to construct a plan according to one of the constructive methodologies. Third an optimization method can be chosen. Last the generated schedule was written to an output file. The output contains the performance indicators and the schedule. For the construction methodologies to come to a feasible plan, see Chapter 4. An outline of the simulation program is given in Figure 29.

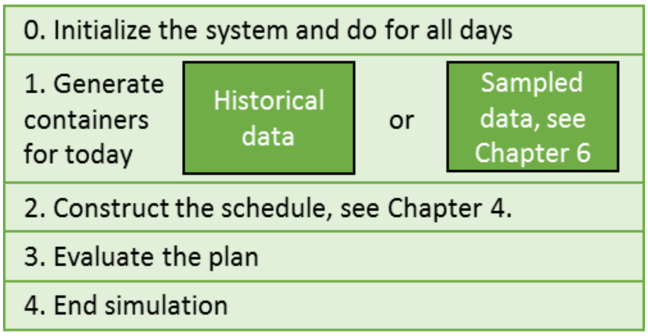


Figure 29: steps in the simulation

Structure in the simulation model and initialisation

The entities in the simulation model are the years, the weeks, the days, the vehicles, the trailers, the container jobs, and the customer and terminals. To come to a value added analyses, specifications of these elements needs to be administered within the model. The entities and their specifications are given below and for an outline of the structure, see Appendix F.

Year contains:

- Year ID: Unique counter to keep track of the year;
- Weeks: A set of weeks.

Week contains:

- Week ID: Unique counter to keep track of the week;
- Days: A set of days.

Days

- Day ID: Unique counter to keep track of the day(Monday = 0, Tuesday = 1,…, Saturday = 5);
- Containers: A set of container jobs;
- Vehicles: A set of vehicles.

Vehicles

- ❖ Vehicle ID: Unique counter to keep track of the vehicle;
- ❖ Planned container jobs: A set of container jobs that are planned on the vehicle;
- ❖ Total driving time: Time the driver is driving on the day;
- ❖ Total kilometres: Total kilometres the vehicle has been driving on the day;
- ❖ Total empty kilometres: Total driven kilometres that are empty;
- ❖ Previously known location: The last known location of the vehicle so it is known where the vehicle is positioned.

In addition the following administration is generated:

- ❖ Start time: The time a driver should start driving from CTV;
- ❖ End time: The time a driver stops working for today and vehicle is parked at CTV.

Trailers

- ❖ Trailer ID: Unique counter to keep track of the trailer;
- ❖ Due date: The time the container job must arrive at the customer;
- ❖ Usage: Keep track if the trailer is standing in a dock of a customer;
- ❖ Previously known location: The last known location of the trailer so it is known where the trailer is stalled.

Containers jobs:

- ❖ Container job ID: Unique counter to keep track of the container job;
- ❖ Due date: The time the container job must arrive at the customer;
- ❖ Pickup location: This is an abbreviation to identify the terminal where the container must be picked up;
- ❖ Customer location: This is an abbreviation to identify a customer;
- ❖ Customer city: City name which is used to make sure when the fixed triangle to drive is set, the right customer location is picked (sometimes needed when multiple customer locations are present);
- ❖ Return location: This is an abbreviation to identify the terminal to return the container to;
- ❖ Fixed distance 1: A value to be filled in by the model when all container jobs are loaded. This is the distance from the pickup location to the customer. This value will not change;
- ❖ Fixed distance 2: A value to be filled in by the model, when all container jobs are loaded. This is the distance from the pickup location to the customer. This value will not change;
- ❖ Pickup: Binary value to identify if the trip form pickup location to the customer must occur;
- ❖ Delivery: Binary value to identify if the trip form customer to the return location must occur. Together with pickup it is determined if we need service time at the customer;
- ❖ Arrival time: denoted the actual arrival time at the customer, this is dependent on the sequence of the container job on the vehicle;
- ❖ Scheduled?: Boolean, that keeps track if the container job is allocated or not;
- ❖ Terminal service time: Time it takes in a terminal;
- ❖ Customer service time: Time it takes at the customer.

Administration of decisions made:

- On vehicle: Keep track to which vehicle the container is allocated by the vehicle ID;
- Sequence on vehicle: Keep track of the sequence on the vehicle, identified with a integer number;
- On trailer: Keep track to which trailer the container is allocated by the trailer ID.

Customer locations

- Location ID: Unique counter to keep track of the location;
- Customer code: Code of the customer;
- Longitude: Horizontal geographic coordinate (west to east);
- Latitude: Vertical geographic coordinate (north to south);
- City: The city the customer establishment is located.

Initializing of the system: Filling the Indices and parameters in the model

Without giving numbers to the entities in our model, the model means nothing. Below all needed information is given to construct a plan.

Indices

- Years, $year\ numbers = \{0,1\}$, the year zero stands for the year 2012 and 1 for the year 2013
- Weeks, $week\ numbers = \{0,1,..,53\}$,
- Day d in the planning horizon, $day = \{0,1,\ldots,5\}$, with 0 is Monday, Tuesday is 1,…, Saturday is 5.
- Vehicles of the fleet, $vehicle = \{0,1,\ldots,59\}$
- Container-job c $c = \{1,2,\ldots,C_d\}$, $C_d is\ the\ total\ number\ of\ container - jobs\ for\ day\ d$;
- Customer location i which represents a possible customer locations and the terminals in the network, I ∈ $Locationlist$
- Trailer ch of the trailer park $ch = \{0,1,\ldots,inf\}$, where the first 120 trailers represents the trailers of CTV and all trailers above that number are the trailers rented at some external party.

Parameters

Geographic coordinates of the location where containers can be picked up and returned. Based upon a formula, to be specified, a straight walk over the earth between the points can be calculated.

- $\delta_c\ return\ location\ of\ container\ c, on\ day\ d, location\ is\ a\ unique\ duo\ of\ geographical\ coordinates$
- $\varphi_c\ pickup\ location\ of\ container\ c, location\ is\ a\ unique\ duo\ of\ geographical\ coordinates$
- $Cust_c\ customer\ location\ of\ container\ c,\ location\ is\ a\ unique\ duo\ of\ geographical\ coordinates$
- $f_{DISTANCE}(\varphi_c, \delta_c)$: $a\ formula\ used\ to\ calculate\ the\ distance\ between\ node\ i,j\ based\ upon\ Geographic\ coordinates\ longitude\ and\ latitude\ of\ i,j, where\ i,j = \{1,2,\ldots,I\}$

By a set {longitude, latitude}, locations are defined on a map. How this are spread on the map, recall 2.2. To estimate the distance to travel between two nodes, various different formulas regarding the radius have been used. The Haversine formula calculates a straight walk over the earth between two points(Chopde & Nichat, 2013). It gives the distance between two nodes with an accuracy of three meters. The formula works as follows:

Parameter:

R = 6371 Radius of the earth

Steps:

1.a Lat1 = Latitude of point 1 converted to radians
1.b Long1 = Longitude of point 1 converted to radians
1.c Lat2 = Latitude of point 2 converted to radians
1.d Long2 = Longitude of point 2 converted to radians
2. $\delta\text{Lat} = \text{Radians}(\text{difference in latitude coordinates}(\text{point 1} - \text{point 2}))$
3. $\delta\text{Lon} = \text{Radians}(\text{difference in longitude coordinates}(\text{point 1} - \text{point 2}))$
4. $haversine = a = \sin^2\left(\frac{\delta\text{Lat}}{2}\right) + \sin^2\left(\frac{\delta\text{Long}}{2}\right) \cdot \cos(lat1) \cdot \cos(lat2)$
5. $c = 2 \cdot Atan2(\sqrt{haversine}/\sqrt{1 - haversine})$[3]
6. $Crowflight = R \cdot c$

A walk over the earth is based upon a straight line between two points, but roads are not just straight. Therefore the estimated distances by the Haversine formula is too short on kilometres. To cope with this inaccuracy in estimating distances, a single scaling factor is used. Out previously conducted research this is converses to 1.2 fast(Levinson & El-Geneidy, 2009), see Appendix G. 1.2 is the value used in the model, see parameter CCF. When the locations in the model are loaded for all possible connections, distances are calculated and stored. These values are later loaded when allocating the fixed distances a container must travel for sure. Additionally this matrix is used when evaluating the consecutive containers on a vehicle. The model stores a distance matrix with the size of (number customer locations + number terminal locations)^2.

In the introduction of this section, it was explained what kind of time windows the model can use. For the service times, a function is used to incorporate the randomness involved. How these distributions are assumed, see the subsection Service times of this section.

- $\tau_i = \text{ stochastic service time at node } i, \text{where } i = \delta_c \in \{1,2,\dots,I\}$
  $\tau_i \text{ follows a probability distribution when the location is a terminal}$
  $\tau_i \text{ follows a probability distribution when the location is a customer}$
- $a_i = \text{arrival time of container at customer } i, \text{where } i = \delta_{c,d} \in \{1,2,\dots,I\}$
- $w_i = \text{waitingtime of container for customer } i, \text{where } i = \delta_{c,d} \in \{1,2,\dots,I\}$
- $l_i = \text{end of hard time window of customer } i, \text{where } i = Cust_c \in \{1,2,\dots,I\}$
- $\lambda_i = \text{actual lateness of containerlocation } i, \text{where } i = \delta_{c,d} \in \{1,2,\dots,I\}$

[3] Watch out with the function Atan2 in excel, there you have to switch the denominator and the nominator

If the distance is known, by an average speed per time unit, the time it takes to travel between two points is known. The average speed for a truck within the transportation industry is assumed to be 68 kilometres per hour (Seacon, 2013). Out of literature, we adopt a correction factor for straight walks over the earth of 1.2. In Chapter 2, the max driving time was given (9 hours).

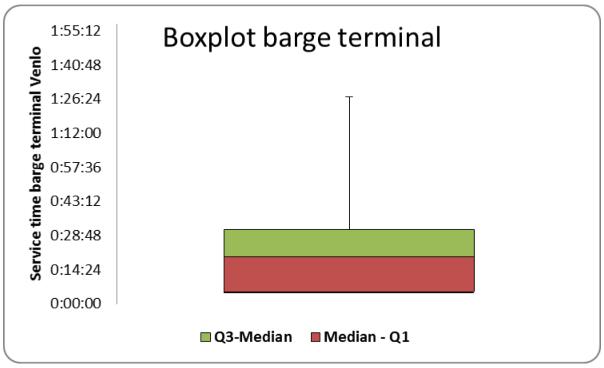
- $DC = max\ driving\ time\ of\ a\ driver$(9 hours);
- $CCF = crowcorrectionfactor\ to\ come\ to\ more\ realistic\ distances$ (=1.2)
- $SP = Average\ speed\ of\ a\ driving\ truck(68\ km\ p/h)$

Service times

Out of Section 3.2 it is known, suitable distributions for the service times for the terminals and customers can be estimated. In our model we are using the Dagum to approximate the service time of a terminal. For the service time at an arbitrary customer a rough model will be used. This is done by a self-constructed probability distribution based upon agreement with experts.

To come up with a suitable probability distribution which can represent our terminals, we first looked at the barge terminal and rail terminal independently, but came to the conclusion that they are more or less the same in time spend as is shown in Figure 30.

We aggregated the service times of the know terminals and based upon the same mean, variance and descriptive statistics, we could get an indication of which distribution we should use. We discussed the time that a driver would spent at the terminal in the best case; we set the minimum service time at 5 minutes. Every service at a terminal that took less than 5 minutes is discarded from the dataset. How the times are deviated among a probability distribution, a histogram is shown in Figure 31.



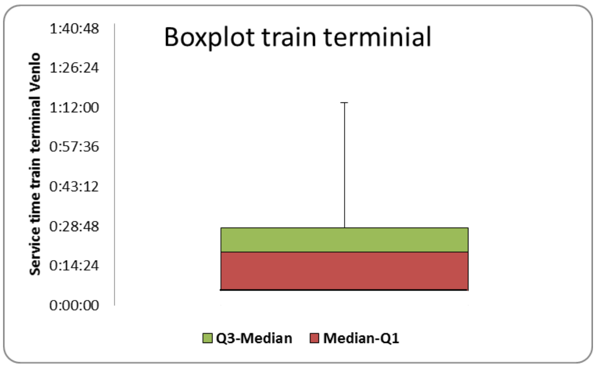


Figure 30: Boxplots a) Train b) Barge

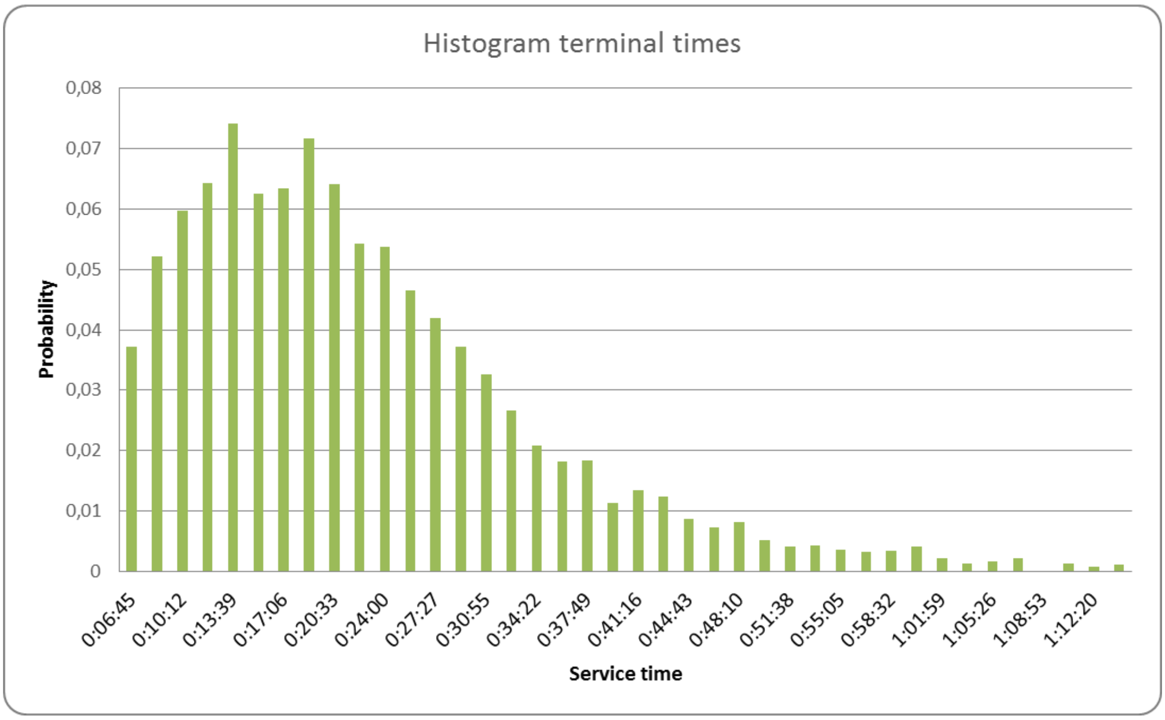


Figure 31: Histogram of aggregated terminal times

Based on the Figures 30 and 31 several distributions are suspected. The following distributions are suspected: Gamma, Weibull, Lognormal, Beta, Pearson type VI, Log-logistic and Johnson S_b. Out of these continues probability functions, only the Weibull distribution(at an alpha up to 0,2) would be accepted. The critical value found, the value on which the distribution can be accepted/rejected the suspected distribution is relatively high. Out of literature the scope is broadened with the Burr and Dagum distributions as stated in Section 3.2. The nice thing about these distributions is, that there is an extra parameter to make the shape of the function fit the historical data better. The fit of either the Burr or Dagum is better than the Weibull.

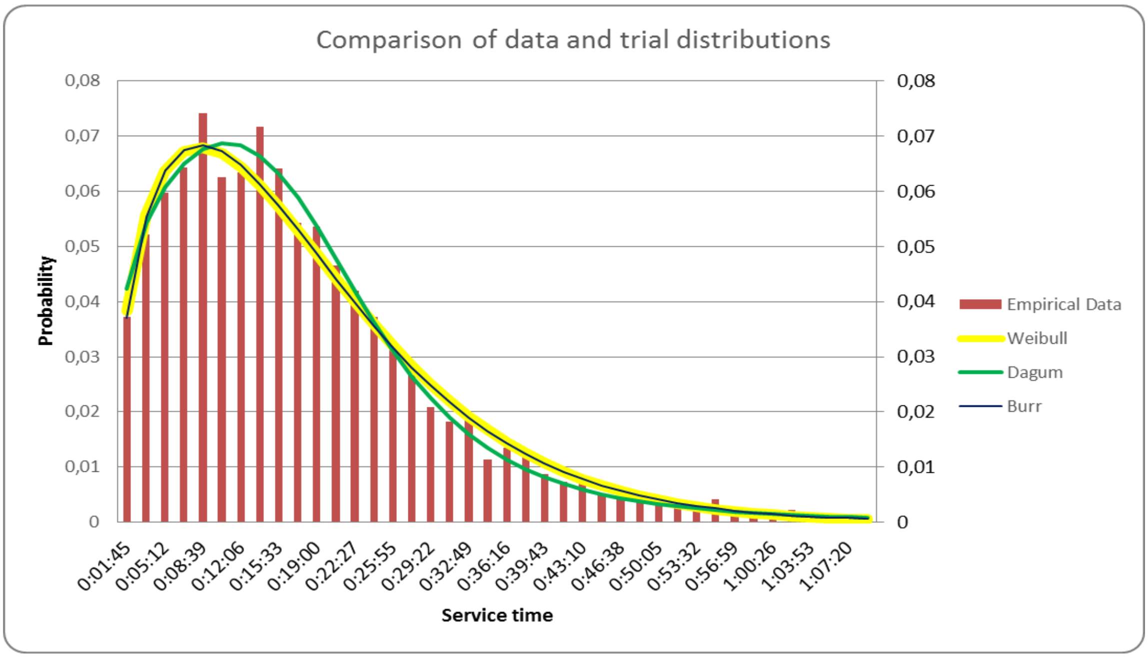


Figure 32: Three most prominent probability distribution with a shift of -5 min

As can be seen in Figure 32, the difference between the Burr and Weibull distribution is rarely noticeable. There is a slight improvement based on the critical value and acceptance at different alphas. But the best result is obtained when following a Dagum distribution. For an overview of the three distributions which are accepted, see Figure 32. For detailed information on the goodness of fit tests, see the Appendices, H, I, and J.

For the probability distribution function for the service time at customers, we aggregated all data available for the loading/ unloading. There is no clear difference in data out of BPA for loading and unloading, therefore all data on service times at the customer is aggregated. We started working with the data, which was in our opinion rather strange, it is incomplete and values are intuitive too high. Based upon the shape not a single distribution can be assumed, see Appendix K. Besides the flaws in the data, 3300 useable data points out of the 170000 is rather incomplete. After consulting several experts in the area of container trucking within Seacon and CTV, the decision has been made to use a rough model for the service times. Recall Section 3.2 about what can be done in the absence of suitable data or no data at all. It was possible to assume a probability distribution, specifically the Beta, Lognormal and the Weibull distribution. Aspects to cover are:

- There is some minimum time the driver would be (un)loading; Set to 20 minutes;
- We have a high probability mass at the left part of the distribution, 20-30 minutes fill 50% of the probability;
- Weak, but long tails, with a maximum of 2.5 hours(150 minutes);

These specifications result in a Beta distribution, see Figure 33.

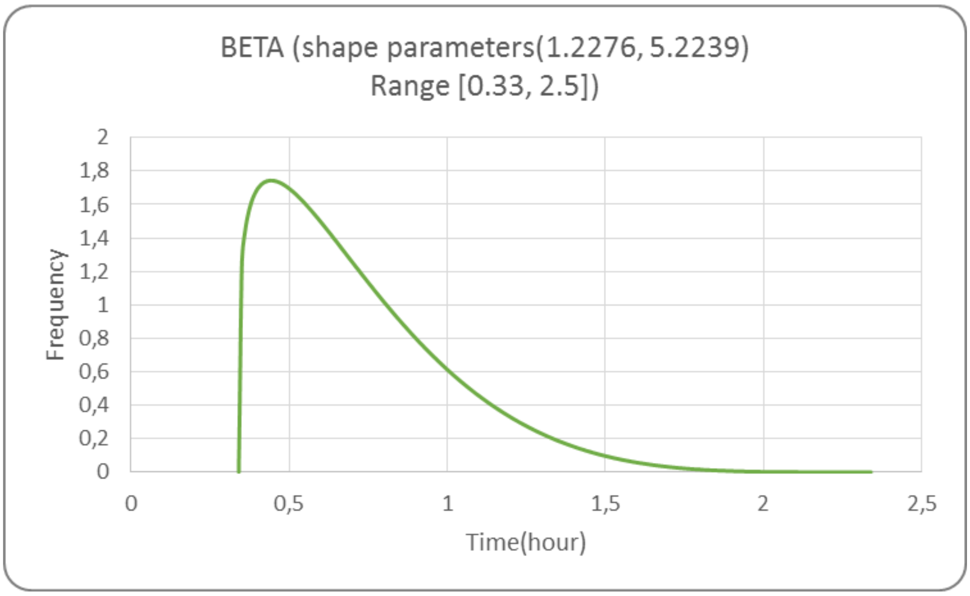


Figure 33: Constructed Beta distribution in the absence of proper data

For coupling and decoupling of trailers, a deterministic time of 10 minutes will be used. This is based upon agreement with CTV. In their opinion random times based upon a distribution, as is done with the terminals and customers, is unnecessary because for the drivers this is a routine handling and normally no problems occur when coupling or decoupling.

So the following times are assumed:

- (Stochastic) terminal service time: Dagum (3.40483, 0.0166449106, 0.3528712898)+5 minutes;
- (Stochastic) service time at the customer: Beta (1.2276, 5.2239)+ 20 minutes;
- (Deterministic) time for coupling or decoupling a trailer: 10 minutes.

When the container jobs are loaded into the model, the stochastic times will be allocated to the container jobs as if they are known in advance. So we fill in the specifications terminal time and customer service time. The second is only filled in and only if both the Boolean values of pickup and delivery are stated as true.

Decoupled containers at the customer

As mentioned in Section 4.4, something must be used to deal with the 24.5% of containers that are decoupled. These containers stay overnight on a trailer. To keep track of the container jobs and the trailers they are on, a list within the model is used. At the start of each day the trailers still in use of the day before must be made unavailable. To recognize the proper container, the booking number of a container is used.

Used data and data sampling

As data, the historical data out of the BPA system can be used or containers can be randomly sampled. As stated in Chapter 1, one of the questions to answer is about future perspective and growth up to 30%. Additionally nothing is known about possible future containers. If the current pattern is growing however, something can be stated about future capabilities of the logistical system. For this study, containers per day are created for a whole year, the method goes as follows:

1. Generate a total number of containers to sample based upon the data pattern as described in Section 2.3. Out of Section 2.3, the assumption was made that exponential distributions would be used for different days, the mean and standard deviations are adopted from Section 2.3, see Table 5.

Table 5: Values for the exponential distribution for all days

   Appendix
   From the generated total number of jobs, the containers already forwarded for that day must be subtracted (see step 5.b what intended forwarded container-job). Execute the steps below as long as there are still containers to sample.
2. Generate a random number for the type of container, if this is above 0.245, then the container is a complete container. Else, the container must be divided into a pickup job and a delivery job. At last assign a unique container booking number to keep track of the container.
3. Generate three different random numbers. These random numbers will go into a procedure within the simulation environment to determine the locations the container must go to. The procedure returns a location based upon the historical dataset and the location type (pickup customer or return), how the continuous cumulative distributions look, is given in Appendix M.1.
4. Generate a random number for the due date of a job. This will follow the same procedure as 3, only with its own continuous cumulative distribution function, see Appendix M.2.
5. Based on the random number of step two, data is allocated.

a. In the case of the complete job, a dummy job is used to assign all data, up until now, the locations are known, the timing is known, and logically the type of job is known. So in the case of the complete job, now the Dagum and the beta distribution are used to generate the timing at the terminal, and at the customer.
b. In the case of a job in which the complete job must be divided into a delivery job and a return job, two dummy variables are used. The generated locations are known, but for the pickup job the return location gets the value 9999, and for the return job the pickup location is set to 9999. Based on 4, the due date is assigned to the delivery-job. Both inherit the same container booking number. The service times are assigned, and in addition a random number is generated to determine the date of return. For the return job a due date of 24 is set, since it does not matter when a container returns to the terminal in the current logistical system. Since the return job does not follow any rules in date of returning, the job must be send forward in time or assigned for today. For forwarding of the delivery a continuous cumulative distribution is used. Again this is based upon historical data patterns. How this continuous cumulative distribution looks like, see Appendix M.3.
Note: If you look at the structure, we do not have to assign more values, since now it is not required to perform manipulations to recognize the proper locations of the containers. This is due to the fact that, we now work with numbers instead of the address codes, as was done with the historical dataset.
6. Place the container-job(s) in the data structure and return to two as long as there are containers left to sample.
7. If all the containers have been generated for a day, the containers for that day are sorted based on the first due date first.

In Figure 34 a visual representation of the seven steps to generate containers is given.

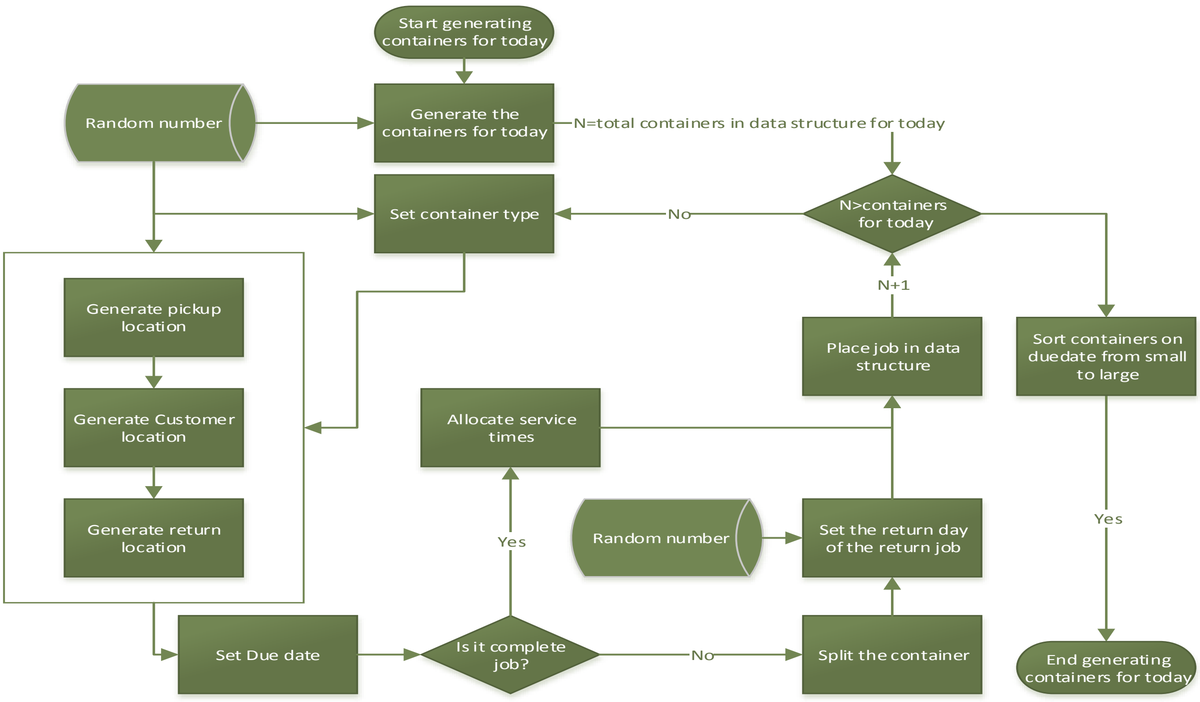


Figure 34: Generating containers on a day

Events

In Chapter 4 the planning method is given, in the simulation the following events are used to construct a plan: new container, next available time of a vehicle, new vehicle event, new day, and end day.

The new container event is the arrival and the assignment to a vehicle of a new container. As stated in used data, this can be according to the historical data, or based upon random sampling. In both methods, the containers are sorted on their due date. So the earliest container is allocated first. The allocation of a container to a vehicle, is based upon a planning methodology as given in Chapter 4.

The next available time of a vehicle is based upon the allocation of the container to the vehicle, according to procedures the time specifications are assigned to both container and vehicle. Once the times are passed on to the vehicle, its next available time is processed to the available vehicle list. The times are dependent on the state a vehicle can be in. For the possible states of a vehicle, see the subsection States.

The new day event, starts the opening of the first vehicle, and allocating the first container to that vehicle. In addition it releases all container to plan for that day according to their due date. Dependable on the day or number of containers to plan on that day, the improvement step will be released after the construction of the schedule. The improvement step will only start running if there are more than 10 containers on that day.

The end of the day event, clears the availability list of vehicles. Additionally, the vehicles are sent back to CTV. This event only starts once all containers are allocated to a vehicle. The start day event already set the release of the improvement step, but the end day event triggers it after the allocation of all containers to vehicles.

States

Out of Chapter 2, 12 states are acknowledged, see Table 6. Remember the terminology form Chao that was adopted, a complete vehicle, a vehicle with a trailer behind it. In Appendix K a transition matrix is given, which has no added value for this study, but might be useful for the company in the future for additional studies. It has no value for this study because the probability $p_{i,j}$ is unknown.

The next possible situation a vehicle can be in is dependent on the specifications of the next container job to handle. This gives a direction of possible options to consider for the next state of a vehicle. In Table 6 for each event just passed, the future possible situations are given.

Table 6: States of a vehicle

State	Vehicle	Container	Event just passed	Next possible situations			
0	Incomplete	n.a.	Start of the day	7	1	5	
1	Complete	Full	pickup at customer	8			
2	Complete	Full	loading at customer	8			
3	Complete	Full	pickup at terminal	4	9		
4	Complete	empty	unloading at customer	8			
5	Complete	empty	pickup at customer	8			
6	Complete	empty	pickup at terminal	2	9		
7	Complete	n.a.	Just coupled a trailer	6	3		
8	Complete	n.a.	Drop-off at terminal	6	3	10	

9	Incomplete	n.a.	Decoupled at customer	11	1	5	7
10	Incomplete	n.a.	Decoupled trailer at CTV	11	1	5	
11	Incomplete	n.a.	End of the day, park CTV	0			

5.2 Evaluation of the schedule and benchmark

As discussed in Chapter 4, the first planning methodology as standalone, provides us with a methodology that might be close a worst case scenario of the current practice. It might be the worst case because once a vehicle completes his current container-job, the vehicle is first send back to CTV and we plan the vehicles on first come first served. Since we do not know the proper current performance of the logistical system, the worst case scenario is used as a benchmark. As worst case scenario, the first planning methodology.

Worst case analyses

For the benchmark results of the year 2012 and 2013, based on the historical dataset planned with the first planning methodology, see Table 7.

Table 7: Benchmark WCA historical data 2012 and 2013

Appendix

The table shows that 365 out of the 44156 container-jobs is late. For the year 2013 this are 1045 out of the 50016 containers-jobs. That is 0.83% against 2.09%. So the fraction of lateness increases in 2013, and remember that this was a year that is not totally complete (up to week 43). What is interesting however is to look at the times the containers being late. It is noticeable that the containers that are late several hours, are the containers that we identified as rush orders due to mistakes in practice. The containers of 2012, see Figure 35, up till 150 inherit one of the two following specifications: 1. the container is pickup up at a terminal in Rotterdam and then delivered or 2. The container is picked up at the customer and then transported by road to a terminal on the border of the 250 km radius. In practice these containers are containers that are for example are forgotten on a preliminary modality, or are not in time to make the proper modality before it leaves. This can be for example due to breakdown of a vehicle. The planners in practice do not meet the requirements in sense of delivery time, since they solve the problem by returning the container directly to the shipping company instead of using the barge or train terminal of Venlo, and the set delivery time is not just any longer. For the year 2013, see Figure 36, a different conclusion must be made. Here the containers up to approximately 200 are containers that involve the same explanation of risk as for the lateness of the containers of 2012. However, we see a lot more containers that are between 2 to 3 hours late, and do not involve the rush orders due to mistakes in practice. They have one thing in common though, they are all involved in the later segment of the year 2013, say between week 35 and 43. This gives us clear indication that the system is close to its limits. We say close since we hope by smarter planning we can reduce the lateness or remove it completely.

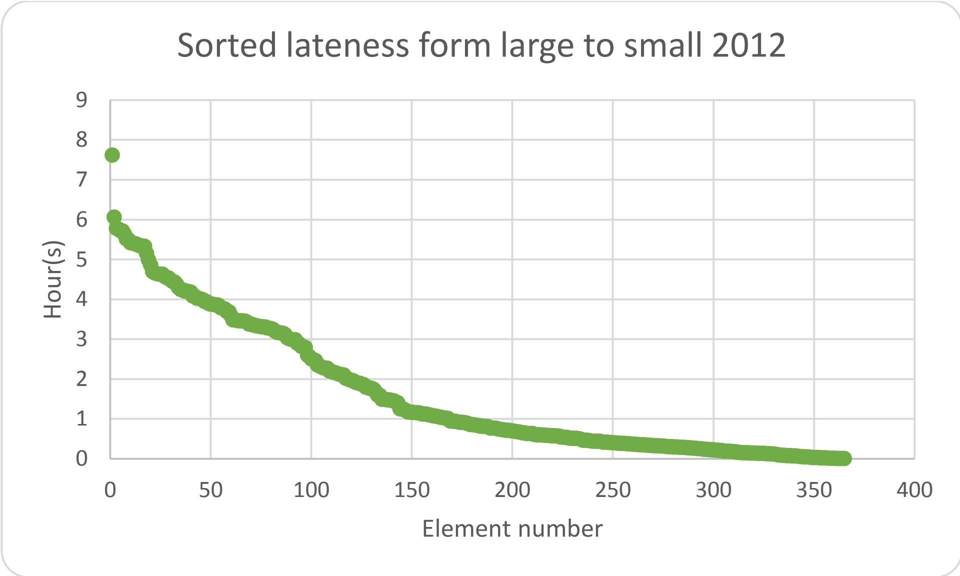


Figure 35: Lateness of benchmark WCA historical data 2012

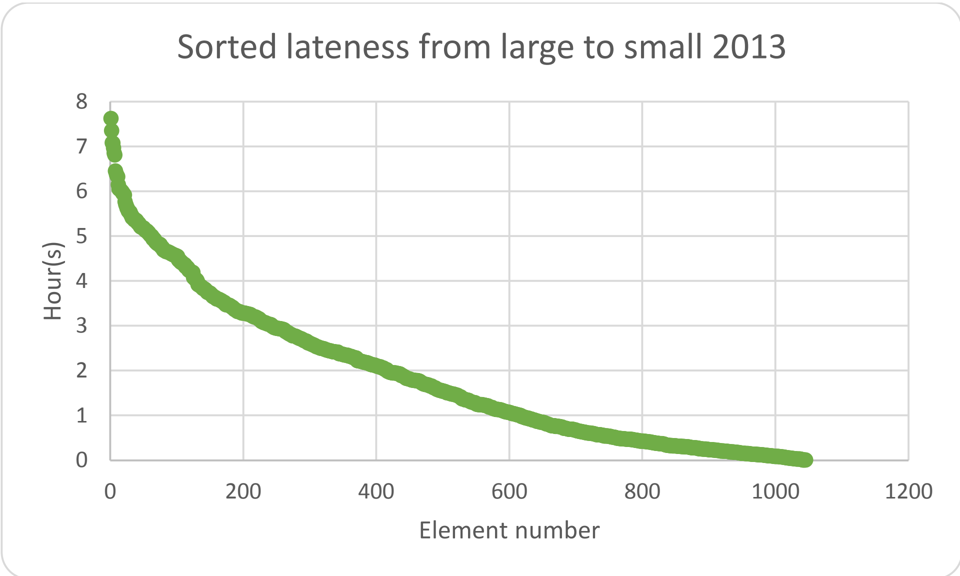


Figure 36: Lateness of benchmark WCA historical data 2013

Balance equal

In the Table 8 and Figures 37 and 38 the same figures are given as with WCA only now they state something about the balance equal. This methodology can also be used as benchmark in our opinion. It provides a better reference point from the perspective of the driver, because by this methodology the drivers gain on average the same amount of containers to transport. What can be seen out of Table 8, is that as stand-alone plan model balancing equally is not a good idea due to the amount of containers being late. The main cause of this is the fact that with the balancing equal plan model, the model at first ignores time constrain when building the solution. This is necessary because otherwise the model must inherit difficult procedures in the plan layer, which is time consuming and unnecessary.

Table 8: Benchmark balance equal historical data 2012 and 2013

Appendix

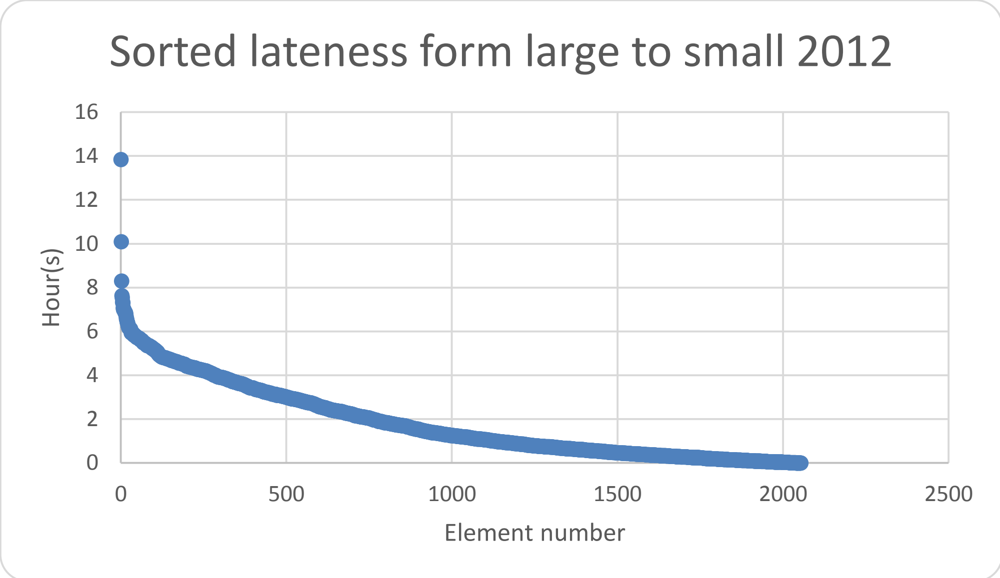


Figure 37: Lateness of benchmark balance equal historical data 2012

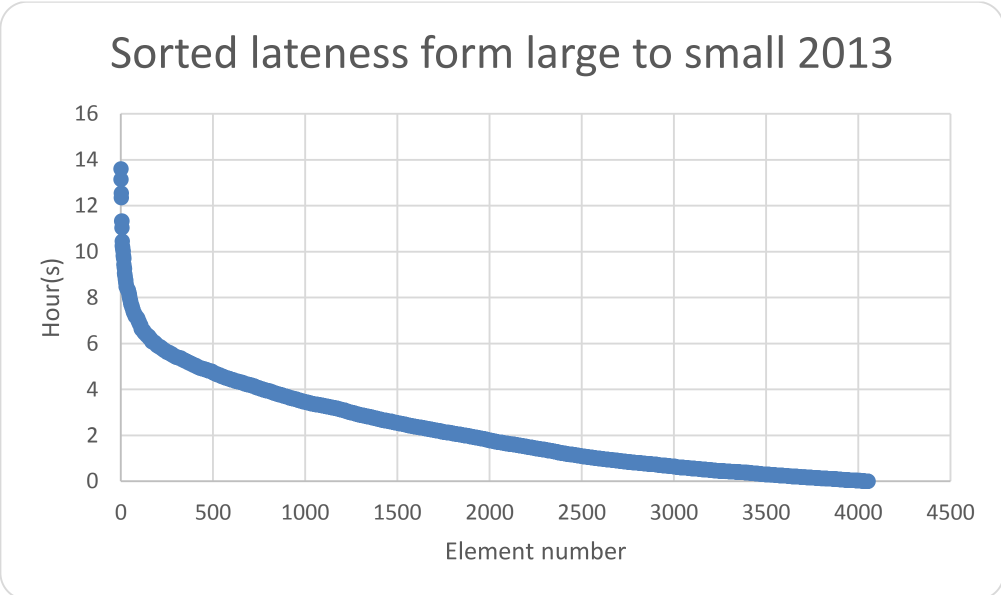


Figure 38: Lateness of benchmark balance equal historical data 2013

5.3 Experimental design

Experiments

To see how the planning methods performs, following experiments are used in the simulation:

I. Varying in construction methodologies: WCA, Improvement of the WCA and parallel savings.
II. Varying improvement methodologies: 2-opt and simulated annealing.

III. Varying the percentage of increase in container volume: In Section 5.1 a method to sample containers is given. The model is given a factor to increase the total number of containers over a year. This study concerns the increase of [110%, 120% and 130%].
IV. Hard time window: Max allowed lateness + [0, 2.5, 5, 7.5, 10, 12.5, 15, 20, 30, 60] minutes.

The first two points, I and II, are named interventions. The third point is a scenario. The last point belong to the sensitivity analyse.

Replication/deletion method

A used technique in literature to cope with the warm up period of the system – some time to enter a steady state – is the replication deletion method. In none terminating simulation like the one we build, this is a valid assumption. The warm up period in our system is necessary due to the return containers-jobs that do not occur on the same day as the delivery-job. This is because in the system of CTV trailer are decoupled at the customer, and for ease the outstanding containers at the start of the dataset are deleted. Due to this no initialization of the outstanding trailer-container combination is needed. To determine the warm up period we make use of Welch's graphical procedure described by Law. How much days of result must be deleted is given in Chapter 6.

The term replication stands for the fact, that the system must run multiple instances. To determine the number of replications, we refer to the book of Law. Law describes the sequential procedures to calculate the number of replications. We make use of an alpha of 0.05 and a Gamma of 0.05, where alpha represents our confidence level and our gamma our relative error. For our model, a year of container data will be sampled. How much years must be generated and how the replications are generated in the model, see Section 6.4.

Common random numbers and synchronisation

To reduce the variance between two configurations of the system, we introduce positive correlation between the two systems. This is called common random numbers (CRN). By doing this systems are better comparable, because CRN is in essence making sure that both systems use the same random numbers. For the model of CTV it concerns the service times of the terminal and customer. So we need to synchronise the service times of different systems. This is done by assigning the service times to the containers, before they are planned by the model. We do "as if" we know in advance what the service times will be for both terminal and customer service time.

Chapter 6

Results

In this chapter the model of Chapter 5 is evaluated. In Section 6.1 the running time of the two improvement methodologies are discussed and set to times that are manageable. The results of the interventions are discussed in Section 6.2. Section 6.3 is devoted to the sensitivity analysis of the model. Predictions about possible future scenarios are discussed in Section 6.4. In the sections 6.2 to 6.4 the results are given from an integral perspective, but also on vehicle level. This chapter end with a conclusion in Section 6.5.

6.1 Running time

To come up with a running time for the different optimization techniques, the total kilometres on a day are monitored per second. This way it is possible to show how fast the methodology converses towards a local optimum. This is tested for multiple days. An arbitrary daily result is given in Figure 39. The figure shows that the daily solution is conferencing towards a local optimum within a minute. This applies for all days. The 2-opt method is steered in computation time based on the following formula: number of serious swaps$= 250000 + 15 * (number\ containers\ of\ today)^2$. By a serious swap the following is meant: a swap that falls within the constraints of the model that may or may not improve the driven kilometres. By setting the formula as a maximum number of swaps that can be made per day, the model runs between a minute and a minute and a half per day. Due to the variable “number containers of today” the model is forced to evaluate more options on days that are busier than other days. It was mentioned that the methodology converses to a local optimum within a minute, but the running time is set on days to a maximum of 1.5 minute. This is done this way so the method is able to evaluate more containers when coping with future demand.

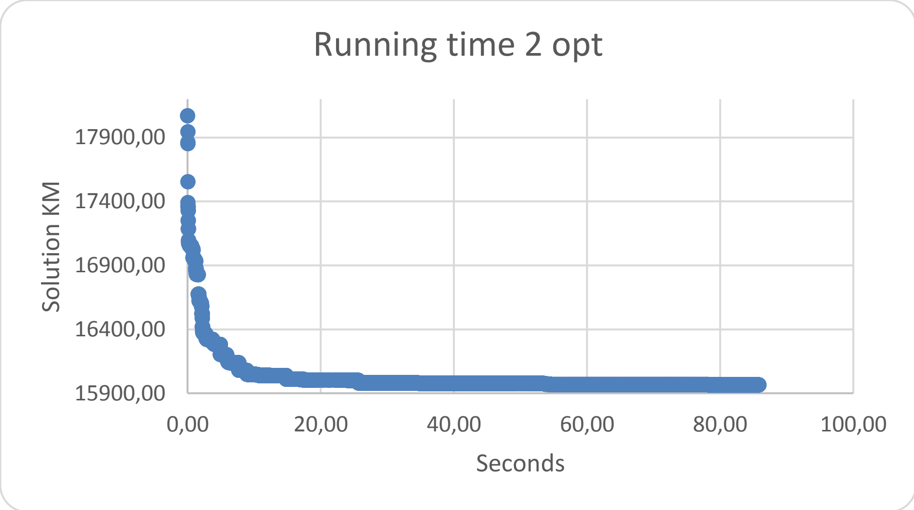


Figure 39: Converse speed of 2-opt on an arbitrary day

For simulated annealing more time is needed. This is due to the sub-goal of escaping a local optimum. After trial and error, the awareness came that only a relatively short amount of time should be spent to escape the local optimum, and the method should allocate more time in improving the solution. To achieve this, the start temperature is set to 40, the end temperature to 2, the decrease factor to 0.9, and the Markov chain is set to 300000. The simulated annealing procedure runs approximately five minutes per day. The settings additionally imply that on an average day the model is able to look around the current solution with a broadband of 500 KM. This seems to be sufficient because it corresponds to the longest possible travel distance. This is the radius of the area we are analysing for CTV, e.g. from CTV to a terminal in the harbour of Rotterdam. How the solution behaves on an arbitrary day when executing the improvement methodology simulated annealing, see Figure 40. The figure shows how at first the methodology has a wider range of improvement and deterioration of the solution, and closer to the end time a smaller one. Remember the figures in this section are based on arbitrary days, so the days are not the same.

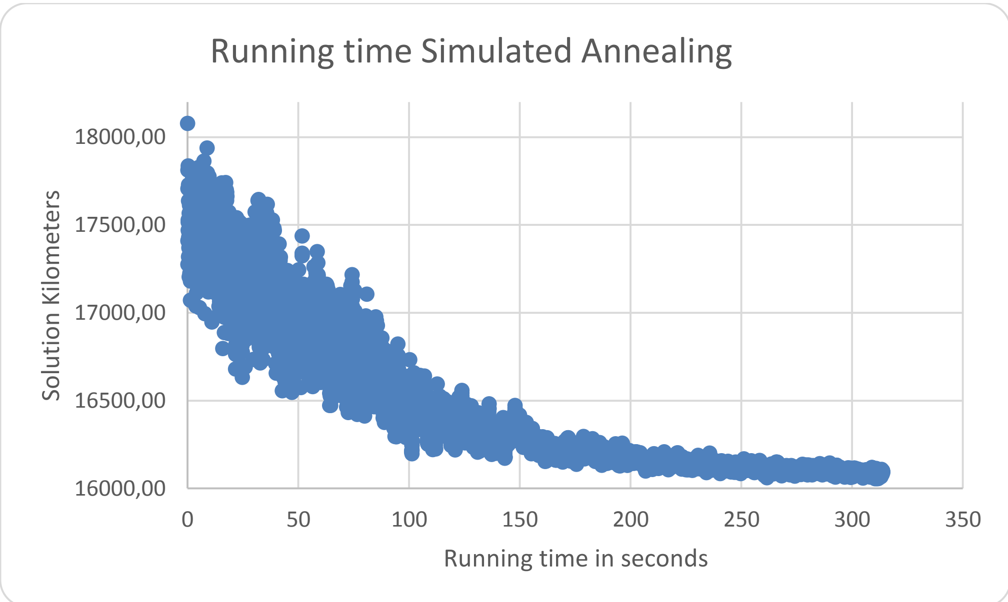


Figure 40: Converse behaviour of simulated annealing on an arbitrary day

6.2 Interventions

In this section the methodologies of building the solution are discussed. Before they are discussed, the improvement methodology is omitted. This is done because out of Section 6.1, it became clear that the simulated annealing procedure is fast enough to converge to a local optimum. Now the results of the methodologies worst case, balancing methodology, and cost based savings are discussed. All are given with the consecutive execution of one of the improvement steps. All methodologies are compared to the set worst case benchmark out of Section 5.4. This one is chosen because the other is better in essence of kilometres and the evaluation should be based upon the worst case. Additionally the number of containers being late is a bit unrealistic with the stand alone balance equal methodology.

Worst case analyses

Table 9 shows the results of WCA plan methodology with the 2-opt improvement methodology. Figure 41 and 42 show WCA with consecutive the 2-opt for respectively the years 2012 and 2013. What is shown by these two figures, is the improvement per day compared to the benchmark set. In Figure 43, the difference in containers being late are shown and their hours being late. The figure shows that the long tail can be eliminated by the improvement step. The 144 containers being late were investigated in more detail and found out that this were in all cases containers that had pickup locations outside of Venlo. This were rush orders due to errors that occurred during the operation, caused by failure of a vehicle or errors from the preliminary modality.

Table 9: Results WCA with consecutive 2-opt

Appendix

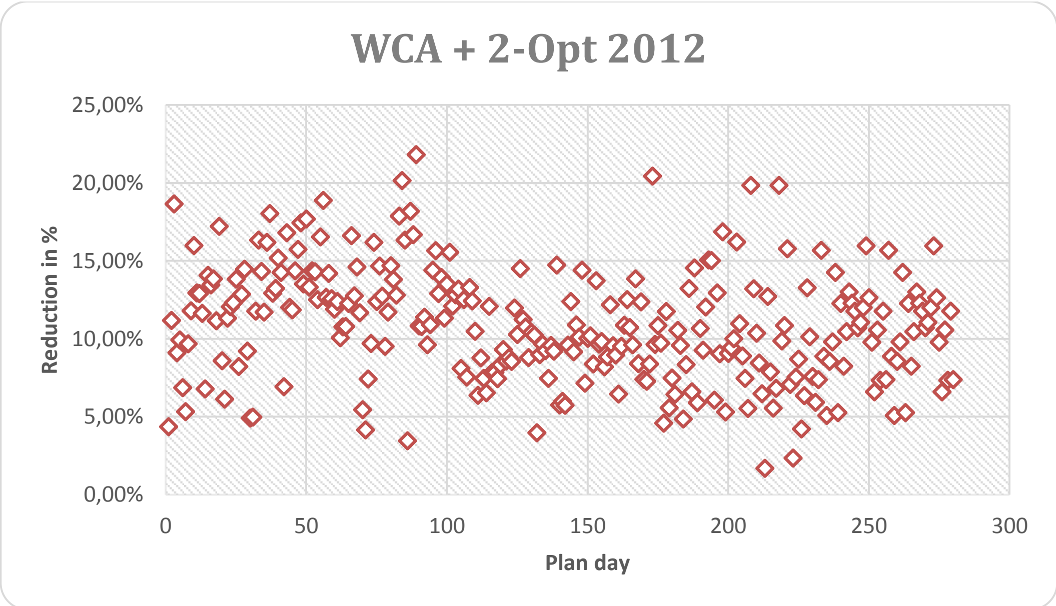


Figure 41: Improvement per day on WCA by 2-opt 2012

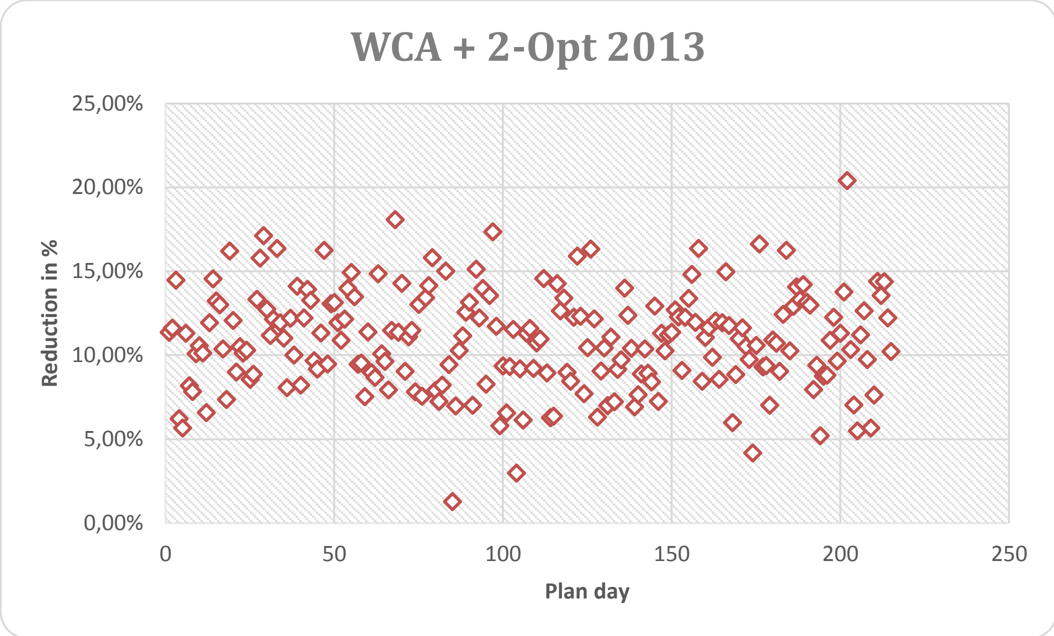


Figure 42: Improvement per day on WCA by 2-opt 2013

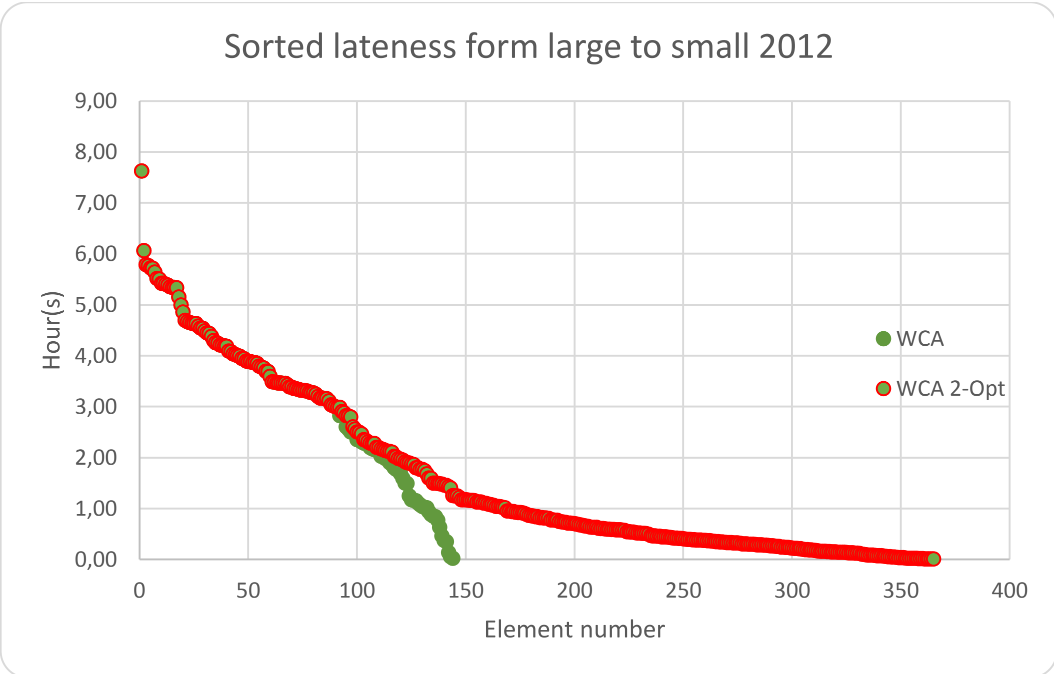


Figure 43: Improvement of lateness by 2-opt 2012

In the upcoming Table 10 and the Figures 44, 45 and 46 the same is shown, but for the improvement step simulated annealing. The simulated annealing showed slightly better results than the 2-opt.

Table 10: Results of WCA with consecutive simulated annealing

Appendix

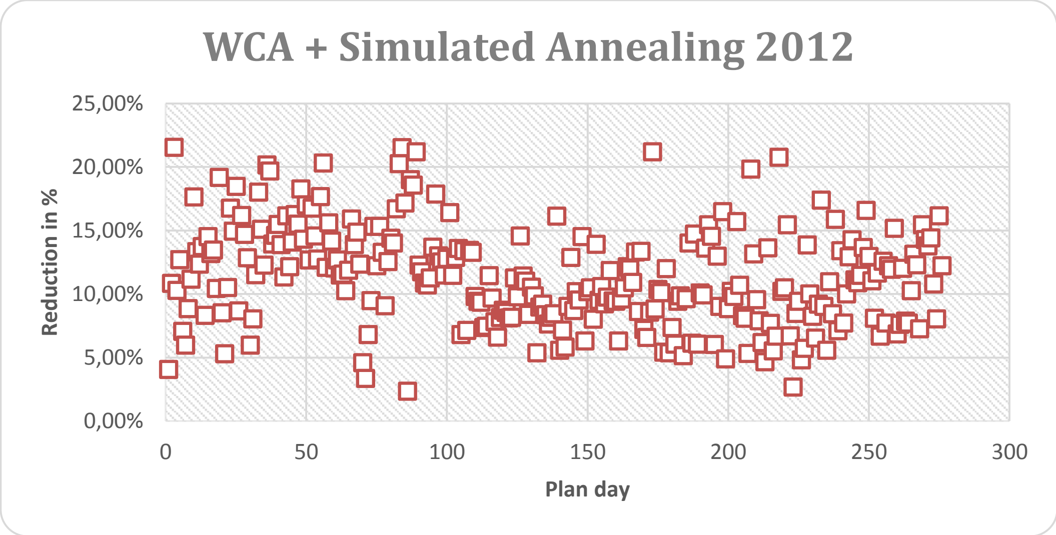


Figure 44: Improvement per day on WCA by simulated annealing 2012

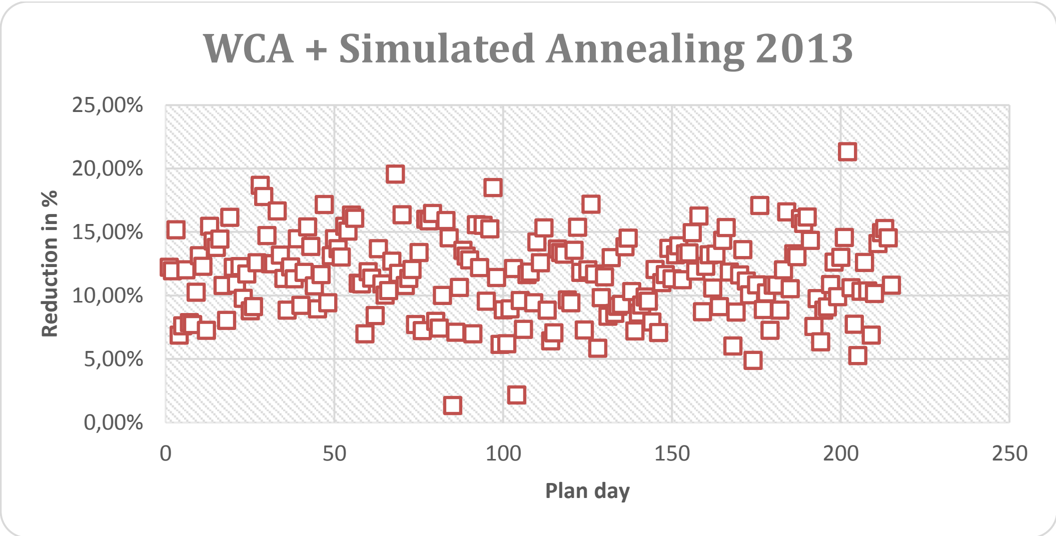


Figure 45: Improvement per day on WCA by simulated annealing 2013

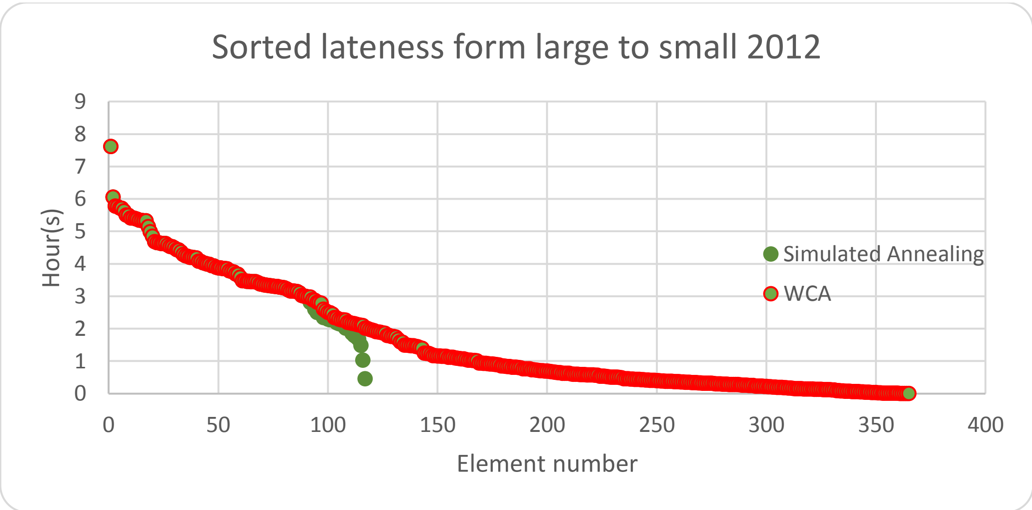


Figure 46: Improvement of lateness by simulated annealing 2012

Balance equal over vehicles

The results of Table 11 and 12, show the balance equal methodology with respectively the 2-opt and simulated annealing. Here the more detailed figures are omitted, because they show the same pattern as with the WCA with consecutive an improvement step. The tables show an improvement in reduction of kilometres and a deterioration of containers being late. Again the containers that were late were in all cases containers that had pickup locations outside of Venlo. This were as mentioned rush orders due to errors that occurred during the operation, caused by failure of a vehicle or errors from the preliminary modality. So the WCA was able to plan the rush orders better.

Table 11: Results of balance equal with consecutive 2-opt

Appendix

Table 12: Results of balance equal with consecutive simulated annealing

Appendix

Cost based savings

The cost based savings plan methodology performs a little better than the WCA planning methodology, as is shown by Table 13 and 14. What is rather noticeable is that the % from day to day is less with CBS, but once they are put in the light of the total reduction, the result is just a little better. This means that the CBS performs better on busy days but performs worse on days where relatively less containers than average. This means that being greedy on relatively busy days is a good strategy, while being greedy on days where there are relatively less containers is not a good strategy.

Table 13: Results of CBS with consecutive 2-opt

Appendix

Table 14: Results of CBS with consecutive simulated annealing

Appendix

Implications for the vehicles:

In Table 15, the different implications per vehicle are shown. The table gives all constructive methodologies and improvement steps. Based on Table 15, per indicator following is stated:

 # Vehicles: The building of the solution brings different usage of vehicles. The construction methodology is affects the usage of the vehicles, the improvement step is not. The cost based savings algorithm builds the solution with the least vehicles used, and logically the balancing of container-jobs leads to the most used vehicles. The last is because with this methodology all vehicles are used. If we steer the vehicles on first come first serve on availability time, the solution is build up with relatively a medium amount of vehicles used compared to the other constructive methodologies.

Var # vehicles: Regardless of the planning methodology, the variation of the number of trucks used on a day stays the same.

Start time: The balancing of container-jobs on the vehicles gives an average start time that is less than the other methodologies. Using the cost based savings leads to the earliest start time. The difference however is not that much. The WCA performs in-between.

End time: The vehicles are finished with their jobs the fastest with the balancing of the container-jobs. The CBS makes the vehicles makes the most hours. The WCA performs in-between. The total working time is directly affected by the start time and end time. The interesting note here however is that in 2013 the different methodologies converge to the same performance.

Variation working time: The variation in working time is the highest with the balancing methodology. The least variation is obtained with the CBS methodology, and again the WCA scores in-between.

Ratio empty vs total driven kilometres: The least ratio is obtained once we perform the balancing plan methodology. The biggest ratio is obtained with the CBS methodology. The WCA planning methodology scores in-between on the ratio.

Var Ratio: The least variation is obtained with the WCA planning methodology, and the biggest with the CBS planning methodology. The balancing of containers scores in-between.

Table 15: Implication for the vehicles from all constructive methods with consecutive the improvement methods

Appendix

Comparison optimization techniques

To make a statement about which improvement method is better, a graph for the years 2012 and 2013 is given in Figure 47 and 48. The figures represent the reduction per specific day of simulated annealing minus the reduction of the 2-opt on that day. A keen eye is able to spot the difference between the two years, but any observer is able to notice that on average for both years the simulated annealing performs better in the reduction of kilometres. To be more specific, on average simulated annealing reduces the WCA by 0,39% more for the year 2012 and 0,70% more for 2013 compared to the 2-Opt. Based on average simulated annealing is outperforming the 2-Opt. We made use of our sampling method to see significant differences between the improvement methods, see Section 6.4. In addition to the reduction, simulated annealing is able to plan the containers better according to their due date. For the year 2012 simulated annealing plans 27 containers more on time and for the year 2013 108 containers arrive according customer specifications. Over 44 thousand containers, this is rather small.

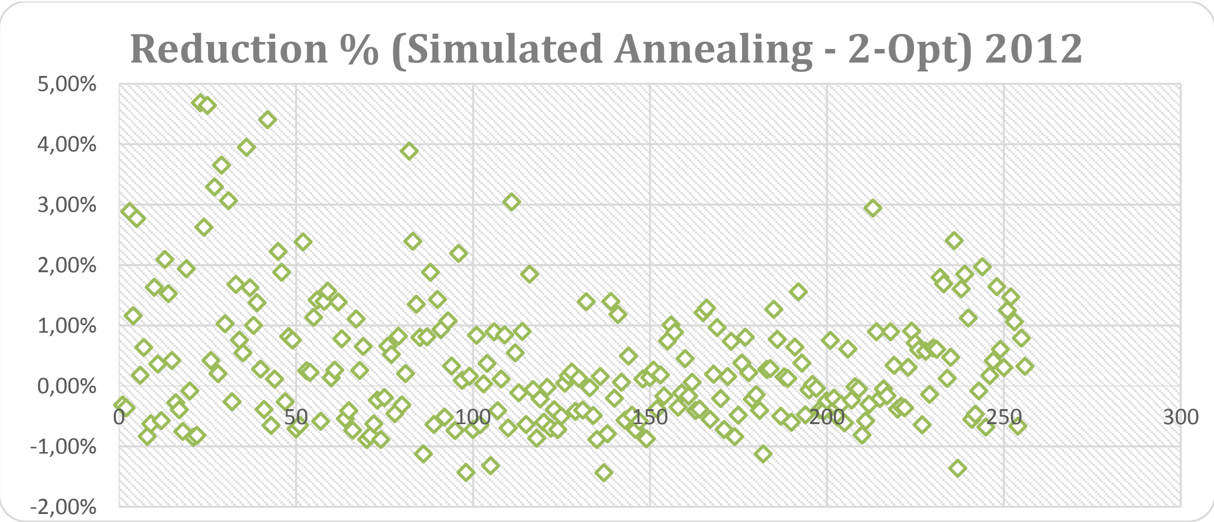


Figure 47: Reduction % simulated annealing minus reduction % 2-opt for 2012

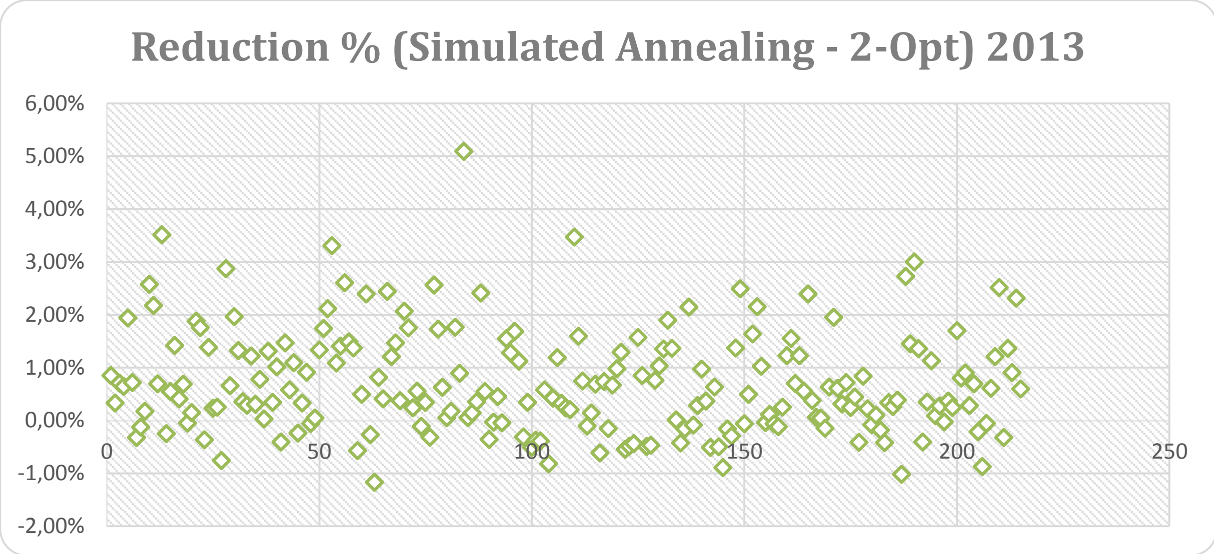


Figure 48: Reduction % simulated annealing minus reduction % 2-opt for 2013

6.3 Sensitively analysis

Effect of hard time windows

To monitor the effect of the use of hard time windows, different allowed lateness is set when optimising the schedule. Steps of 10 minutes are used. This implies results are generated for 10, 20, 30, 40, 50, and 60 minutes allowed lateness, see Table 16. In the table two different types of lateness are expressed. The lateness when setting the range around the due date and the effect if we allow the model to plan according to the due date plus time window, but evaluating according to the current practice (time window of 0). What we can see is that the use of the 10 minute time window gives us additional reduction of 1.78% for 2012 and 2.13% for 2013. The cause of this are the 2469 - 144 = 2325 containers that are better planned in the optimization procedure for 2012 and 2732 - 543 = 2189. Because this is 2325/44156 = 5.2% respectively 2189/50016 = 4.3%, approximately 10 containers per day are enabled to be planned better. This is rather large because 10 minutes is only 2.3% of the total working time of a vehicle.

Table 16: Time window results

Appendix

In total, if we would look at the original due date, between the 5%-5.5% of the containers is late, according to the time window, less than 1% is late. If we go any further, say 20 minute for the time windows, the solution becomes worse, now between the 8% and 9% containers is late according to the original due date and again below 1% of the containers is late according to the time window. This while only 0.2% additional reduction of kilometres is gained compared to the 10 minute time window. For the 30 minute time window, the same statements can be made, much more is late, and the reduction becomes smaller. How the reduction of kilometres behaves, see Figure 49. The figure shows that at first, some noticeable additional reduction are obtained, while the bigger the time window is set, more insignificant the additional reduction gets. The different time windows do however not incorporate the rush containers due to errors in the system. Which proves the statement once more that these containers cannot be planned right due to wrong specifications in the information system, which happened due to practical failure. The improvement and lateness of # containers shows the same pattern for both the years 2012 and 2013. Figure 49 **s**hows that the bigger the time window is set, the containers being late shows an increasing function. The rate of increasing reduces while increasing the time window. Figure 50 shows the number of containers being late compared to the original due date with a time window of 0 against the set time window. The difference between the points is the value that represents the number of containers that are re-planned by increasing the time window with 10 minutes.

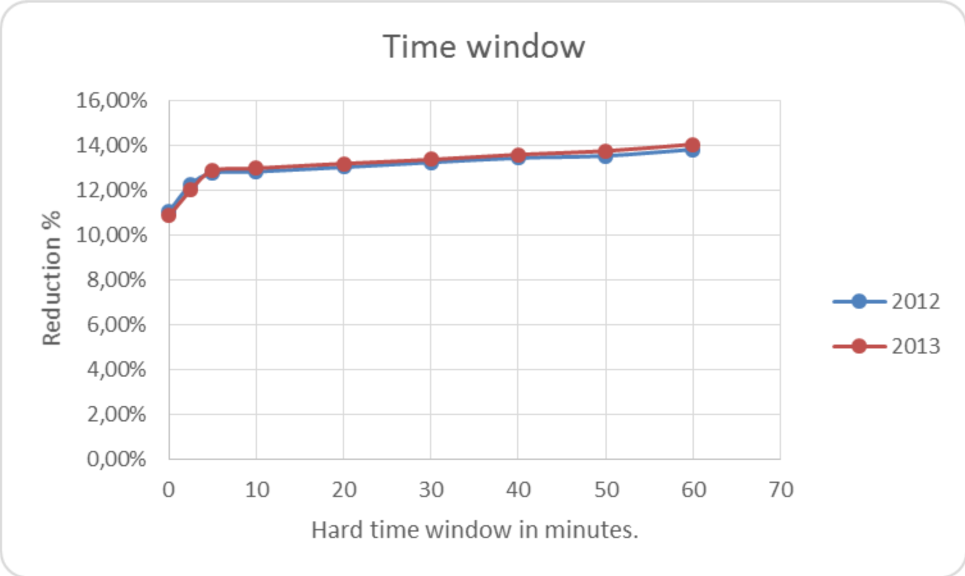


Figure 49: Average score of reduction against the set time window

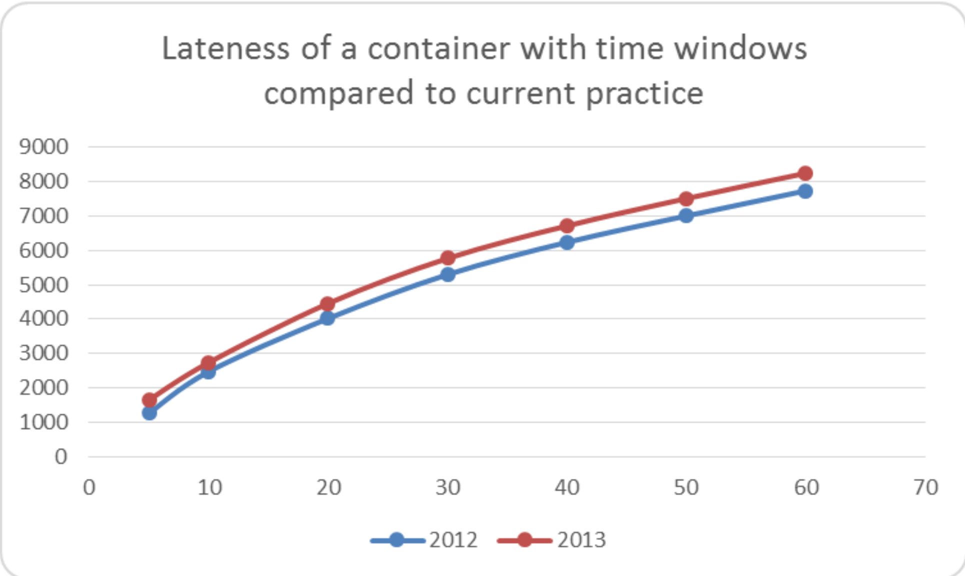


Figure 50: Number containers being late to the time window of 0 against the set time window

Table 17: Results for vehicles when using time windows

Appendix

In Table 17, the different implications per vehicle are shown. The table gives all time windows. Based on Table 17, per indicator the following is stated about the effect of the time windows:

 # Vehicles: Nothing noticeable about the current number of vehicles can be said.

Start time: Once containers are allowed to arrive before the due date plus the time window, the start time of the vehicles is shifted to a later time on that day.

End time: The vehicles are finished with their jobs a little later than without the time windows.

Working window: The total working time of a vehicle reduces with about 6 minutes at first, later it only reduces what seems to be linear, see Figure 51.

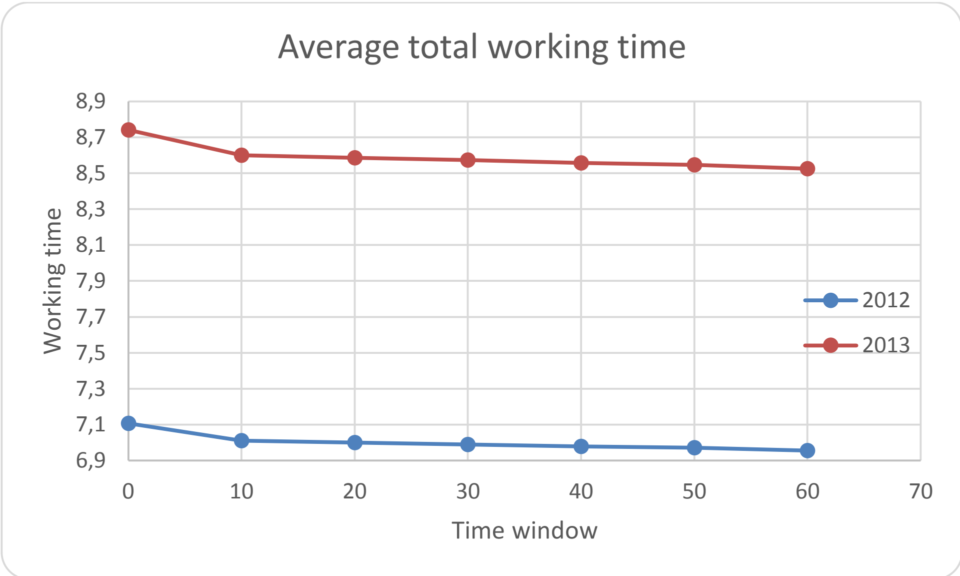


Figure 51: Effect of time windows on average working time

Variation working time: The variation in working time is reducing slightly with the time window.

Ratio empty vs total driven kilometres: The empty kilometre ratio is stagnating the bigger the time window.

Var Ratio: The time window is not affecting the variation of the ratio.

6.4 Scenario: future demand

As discussed in Section 5.2, a method to generate containers is described that can be used instead of the historical data. The method is based on the historical data pattern.

Validation: Approximating the behaviour of 2013

In Section 5.7, 43 weeks of 2013 were scheduled. The results were as in Table 18.

Table 18: Recap of the results of 2013

Appendix

If linear interpolation is used based upon the 43 weeks to say something about 52 weeks (a year), a total of 5773865 kilometres should be driven. A total of 60054 containers should be scheduled, and a total of 1264 containers should be late. If we look how our sampling procedure, results are close to what is expect with linear growth, however, the number of containers being late is a little off. The results of five sample years are shown in Table 19. Table 20 shows the 2-Opt on those five years. Table 21 shows the results from the perspective of a single driver. The method is giving good results for all indicators expect for the containers being late. We still using this method, but we have to keep in mind that the number of containers being late in this method is an overestimation of the number containers being late at the customer.

Table 19: Results of the WCA on the sampled data

Appendix

Table 20: Results of the WCA with consecutive 2-opt on the sampled data

Appendix

Table 21: Results of the vehicles by WCA with consecutive 2-opt on the sampled data

Appendix

Scenario growth

For the scenario growth the method described in Section 5.2 is used. The model contains a variable to set the percentage of growth of containers to the method of sampling. This is done for the scenarios 10%, 20% and 30%. This is done for three years. This is done by altering the seed of the model, which is another variable to change before running the model. Because the problem involves day optimisation, a year represents 52 replications of Monday, 52 replications of Tuesday, etc. So by setting three different seeds, 156 different Mondays, 156 different Tuesdays, etc. are obtained. All years use the same maximum vehicles to allocate the containers to.

The results are given on the next page in Table 22. The table shows that regardless of the increase in volume, the same reductions are obtained. This implies regardless of the volume, the methodologies used show the same behaviour. Simulated annealing still performs the same or better than the 2-Opt.

In total for the year 2013 by linear interpolation just below 5.8 million kilometres are driven for CTV, without optimisation. Table 22 shows that with an increase of 10% of container volume and an optimisation step, approximately the same amount of kilometres would be driven for CTV. With the plan model, CTV is able to cope with the 10% growth in container volume. Without the optimisation CTV would lose customers because in total 8% of the containers are late.

With an increase of 20% or 30% the total containers being late rise above a level that is just too much. The improvement step is no longer enough to cope with the containers. Additional drivers are needed for the logistical system.

What is interesting to notice is that the increase of container volume is the same for the logistical system as the increase in kilometres. This implies that if CTV would gain additional 10% of containers, the total driven kilometres on a yearly bases would increase by the same factor.

The keynote here is however that if the increase is due to for example one customer, the pattern of containers might change and adaptions to the model are required. If it involves multiple customers, the predictions are more reliable.

Table 22: Results of the sampled data

Appendix

6.5 Conclusion

In this chapter the results of the model are given. For the logistical system of CTV, the following can be concluded:

- The balancing between vehicles is recommended because it leads to the biggest reduction over a year. It shows more jobs are being late, however this will occur in practice with either methodology. This is because the containers that are being late were containers that were rush order. Moreover since the construction methodology is not affecting the end result of the schedule that much and balancing equally comes closest to the wish of equal benefits for the drivers, for the drivers there is a change that might be barely noticeable.
- The cost based savings leads to the least vehicles used. The savings are almost as good as with balancing equally, but the drivers' working time increases. Since CTV pays per container and does not own the vehicles, it is not beneficial to use less vehicles if it is resulting in the same performance.
- As improvement methodology simulated annealing is recommended. It is fast enough to be used for either offline or online purpose.
- With the usage of the construction and improvement step, the logistical system is able to cope with a growth of 10%. Going beyond the 10% growth means additional drivers must be hired.
- The percentage of growth in volume of containers leads to the same growth percentage of driven kilometres.

With Section 6.3 an answer can be given to sub-question VI. The company should discus with the customers about the possibility to arrive 15 minutes before and after the delivery time. 15 minutes is recommended due to practical feeling, people find it often easier to calculated with quarters of an hour than one-sixth(10) of an hour. But it is advised not to go to the 20 minute window or higher.

The model also tested with a max number of containers allowed on a vehicle, it showed promising results when building the solution, but once the model was finished optimizing, the results difference were insignificant. This claim is supported by the end results of Section 6.2 regardless of the number of vehicles used by the solution, and logically the number of container on a vehicle, the results in reduction of kilometres stayed the same.

The suspicion is that with only 24.5 percentage of decoupling, the fleet has the capacity to incorporate all smarter chooses. This because the results were relatively equal in Section 6.2.

Chapter 7

Implementation and evaluation

This chapter consists of two parts regarding the implementation: the strategic approach and the tactical design. The strategic approach determines the strategy involving the users that are affected by the usage of a planning system. The tactical design involves revealing a plan according to change management theory by Kotter and Schlesinger (2008), this is discussed in Section 7.1. The change management mentioned by the auteurs structures the change in eight steps to come to a successful implementation. In Section 7.2 the tactical design is discussed by the eight step model. In Section 7.3 the evaluation and timing of the implementation process is discussed.

7.1 Strategic approach

In the implementation process a strategic continuum arises according to Kotter and Schlesinger(Kotter & Schlesinger, 2008). In Figure 52 the strategic continuum is given.

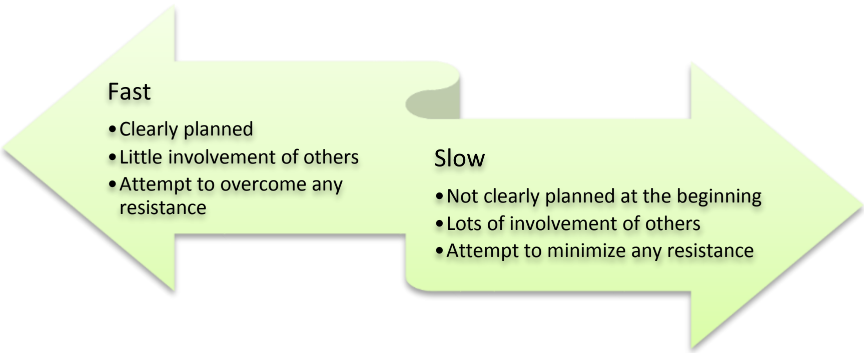


Figure 52: Strategic continuum (Kotter & Schlesinger, 2008)

The position on the continuum that is most appealing for CTV, was determined according to four situational factors. By positioning CTV on the strategic continuum, a change process can be developed to the specifics that fits CTV best. The four situational factors to determine the position on the strategic continuum according to Kotter et al are(Kotter & Schlesinger, 2008):

1. The amount and type of resistance that is anticipated;
2. The position of the initiators vis-à-vis the resisters (in terms of power, trust, and so forth);
3. The locus of relevant data for designing the change and needed energy for implementing it;
4. The stakes involved (for example, the presence or lack of a crisis, the consequences of resistance and lack of change.)

Kotter et al do not say anything about the continuum regarding the positioning on the horizontal axis. For simplicity, a distinguishing between the following three points on the horizontal axis are made, the left indicating the fast approach, the middle indicating a normal approach, and the right indicating the slow approach. The situational factors are now discussed applied to CTV.

1. **The amount and type of resistance that is anticipated:** Out of the office no resistance is anticipated. The planners were curious and optimistic about the possibilities of applying computerized techniques to construct a planning.
2. **The position of the initiators vis-à-vis the resisters:** The initiators of the project the green last mile are primarily Seacon Logistics and CTV. During the project, these two stakeholders kept taking the upper hand. Moreover the chief executive officer of CTV has to deal with possible resistance, so if any resistance occur, which we do not expect, the CEO can force any resisters to accept the initiated change.
3. **The locus of relevant data for designing the change and needed energy for implementing it:** Kotter et al. state that if the initiators need a relatively large amount of information and commitment from others, we move more to the right on the continuum. In our practical situation, all information is obtained from and by systems of CTV. The system is designed by BPA, which is the other relevant partner. Based upon this situational factor, we end up to the left part on the axis on the continuum.
4. **The stakes involved:** The stakes involved are explained by Kotter et al as follows: the greater the risks are on short term, the greater the stakes for the company. Given the fact that CTV is currently market leader, and the volume of the total containers to transport in the region is growing, CTV wants at least to grow as much as the market in percentage of container volume. This way the market share stays the same for CTV. However CTV feels the pressure growing on the planners at the office, so a growth in volume will result in a planning department that is overloaded. So if CTV wants to grow with the market something has to be done in the remaining of the year 2014. The alternative is to return a part of their market share. Returning a part of the market share due to the growth of the total market is not threating the survival of the company, therefore it is not necessary to set this situational factor to the left part of the strategic continuum.

Conclusion and discussion

First, according to Kotter et al. it is always better, regardless of what the continuum tells us, to be on the right side of the strategic continuum(Kotter & Schlesinger, 2008). This is due to economic and social reasons. The theory by Kotter et al. leaves room for judgement by the manager. If the practical situational demands that the company must change or else the company's survival is at risk, the change must be executed fast. This can however only be done if the first three situational factors allow the fast change. In our situation, we are able to change fast however, we do not need to. So even though three situational factors indicate that a fast change is possible, it is not recommended.

Out of this analyses, the judgement is made that it is desirable to have the project implemented by the end of 2014. For an overview of the steps to take, see Section 7.3. First the most common pitfalls are discussed in the form of the eight step model by Kotter et al in Section 7.2.

7.2 Tactical design on change management

Out of Section 7.1 it is known that there is not much resistance, the dominant stakeholders are at our side, and most required information is available. What is unknown however, if BPA is able to help us implement the plan model behind their system or what must be done if BPA is not capable of incorporating the plan model into the current system. While keeping the previously statements in mind, the remaining of this section is devoted to, briefly explain what Kotter et al intends by tactical design in eight steps and contiguous apply the tactical design model to CTV.

Tactical design: the 8 step model

According to the change management model of Kotter et al, there are eight common pitfalls we should at least cope with to make an implementation regarding organization change a success(Kotter, 1995). By this step-by-step method the biggest mistakes can be avoided. The model(Kotter, 1995), see Figure 53, is the framework that is used for the remaining of this section.

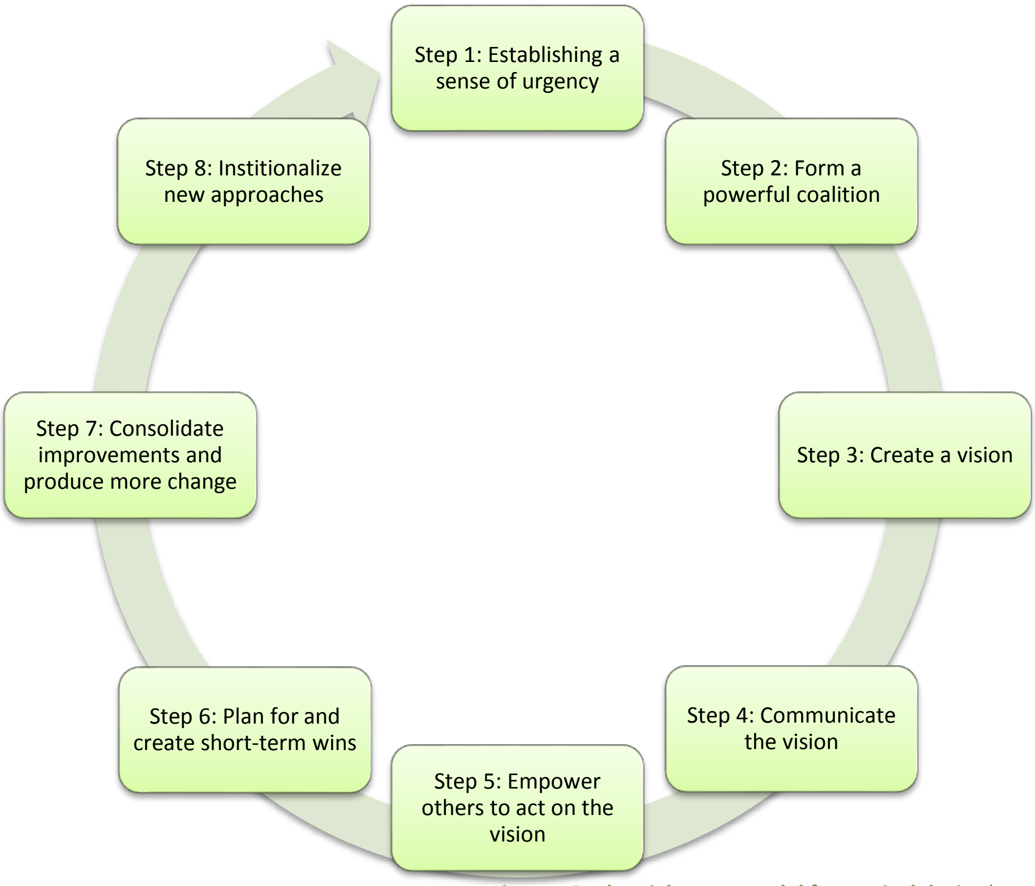


Figure 53: The eight step model for tactical design(Kotter, 1995)

Step 1: Establishing a sense of urgency

Given the fact that the CEO of CTV and the manager of business development department are involved in this project, the influential power is present and the sense of urgency can be created. This is however not necessary as stated in Section 7.1 this project. During the project, several drivers have been heard, they were flabbergasted about the situation where a colleague was driving empty to Venlo, while the driver spoken to was leaving Venlo empty in approximately the same time window. So the sense of urgency is present for this project.

Step 2: Forming a powerful guiding coalition

The Green last mile is as introduced in Chapter 1, more than this individual study. A powerful guiding coalition has been established at the start of the project. For the subject regarding a computerized system, additions need to be made.

For the management of the project, an internal project manager must be introduced to look after the interest of CTV. The manager of the project reports to the CEO of CTV and to the business development manager, and is involved within the implementation of the mathematics behind the system. Knowledge for the project manager regarding programming and mathematics is advice

Given the fact that the internal ITC department is not capable of coping with the mathematics behind the system, they feel uncomfortable developing such. Both CTV and Seacon are also comfortable with outsourcing such project. Involving an external partner is therefore a valid option. At first the developers of BPA should be approach. If they also feel uncomfortable with developing such smart systems behind their current container trucking tool, and the parties involved already feel that such systems should be introduced anyway, it is recommend that a bigger project than just adding a smart layer within the system should be introduced. In such case we strongly feel that CTV should let go of the BPA system and develop a new system or look within the market if such systems are present.

In the case BPA is willing and capable of developing the smarter system, we would advise to consider selling the piece of planning model to BPA, or request a free system for the two locations of CTV in exchange for the plan model.

Step 3: Creating a vision

The vision has already been created, for the vision recall Section 1.1 and 1.2.

Additionally, suggestions for adapting the structure at the office of CTV is made, and thereby introducing a new function. Also suggestions for future expansions of the plan model are made.

For the planner, the selection process of containers to vehicles lapses. A bigger weight must be allocated to the approval of a suggested planning by the plan model. Due to this, time is saved, and the workload on the planner becomes less since now he only has to approve or disapprove a planning and if necessary manually make minor changes to the schedule. We feel that there is a big possibility that the workforce of planners can be downsized in numbers. The magnitude of the downsizing should become clear during the implementation. The monitoring of the planning stays the same for the planner.

The new suggested function will be addressed by customer services for now. The customer services involves the information processing from and to the customer. By this information processing we mean for example: communicate to the customer in the situation of a vehicle is being late, the lateness of the vehicle, but also the proactive attitude by customer services of pressing the customers to give feedback about when a container is finished loading or unloading. This situation is only applicable to a container that is decoupled at the customer. This way, it is known when a container can be picked up at the customer and when not. By proactive pressing and making the customer clear that CTV is losing money once the trailer with container stay to long in the dock of the customer, the customer's sense about the urgency of feedback becomes clearer.

If the feedback about picking up containers at the customer becomes reliable, CTV should go to the shipping companies and request about the possibilities of reusing containers in the local logistical system, instead of first returning them to the shipping company and picking up a "new empty container" at the terminal. Within literature these problems are addressed as empty container repositioning problem. By this an expansion to the current model is made.

Step 4: Communicating the vision

To communicate the vision regarding the smarter scheduling system, the following is suggested:

- As long as the project duration, a two weekly returning progress meeting. The actors involved here are: CEO CTV (optional)), manager CTV (mandatory), appointed planner (mandatory), envoy(s) external developer (mandatory) and internal project manager.
- A weekly developers meeting. For the developers to plan on own discretion
- For the biggest customers, say the 40 most impactful, a visit to introduce the expectations of CTV from the customer regarding the internal change at CTV. These visits should start after the pilots.
- By an informative e-mail to all drivers, the drivers will be notified about the internal changes. The office of CTV will be informed by oral communication on a FriMiBo (Friday afternoon drink at the office) and for additional figures and numbers, see to the last point.
- As last, we want to give the actors involved from drivers to planners the opportunity to request a presentation about the impact on the organization and the expected results. The expected results are obtained by this study. Presentations for several actors such as CEO's and business managers have already been given, therefore this is state as a request. The project manager has to give such presentations. Presentations will be given within a time window of one week after request.

Step 5: Act on the vision

Before actors of the system will act to it, the attractiveness for the players must be made clear.

Drivers: The system is attractive for the drivers because the in-between legs are reduced. This is attractive for them because they drive as independent actor within the system. They get paid by per container delivered, so all kilometres made in-between containers are for the driver kilometres they do not want to drive. In an ideal world of the driver, these kilometres are nil. Because these kilometres are reduced by the plan model, the achievement of an ideal world for the driver comes one step closer.

Planners: Since the system assigns the containers to vehicles, and makes sure that the schedule is a fitting one, time for the planner is saved. The planner only has to give his or her approval of the suggested planning. The remaining tasks for the planner are the same. For the remaining set of activities of the planner we refer to Section 2.1. The plan model leads to less over utilized planners by time savings.

CTV: For CTV the system constructs a planning that involves less time in planning activities, reduced driven kilometres. Because the drivers drive less kilometres in total, less full is used and thereby less devaluation of the vehicle per driven kilometre is obtained. These factors in total gives CTV the position to approach the drivers to talk about sharing benefits of the reduced kilometres. As advertisement, CTV can use the reduced kilometres to state that their system is the greenest hinterland transportation system for container transportation. This can also attract new customers for CTV as explained in Section 1.1. Additionally due to the structured approach of the system, more containers can be processed on a day by the logistical system. The system is a little more future prove. Additionally, the system enables the possibility of future benefits of empty container repositioning. Another future possibility arises, once the terminal is willingly to work with the arrival times of the drivers from CTV at the terminal, the operation at the terminal can be smoothened and the operations of CTV become more reliable. The downside to all this is that CTV should watch that it does become too dependent on such a system. By this we mean that CTV should be able to cope with the operation if a system breakdown occurs.

Resistance form within is not expected. CTV should watch out for BPA, because if BPA is not able to come up with such a layer behind their current system, problems will arise. Arguments such as "Everyone in container trucking involving hinterland transport is using BPA" is an invalid argument, but nevertheless an argument that seems to have worked over the past centauries. This mainly involves stepping out of the current comfort zone for CTV. If this occurs additional discussions are avoidable in our opinion. The project leader should encourage the risk taking of CTV if it is struggling with the thoughts of stepping out of their comfort zone. Even if this means that CTV must abandon BPA and approach other software developers.

Step 6: Planning for and creating short term wins

To create a short term win, before the implementation of the plan model occurs, first two weeks of testing must occur. The tool used to simulate and analyses the logistical system is used for testing purpose. At the start of a day, a planner will sent the overall planning for that day to the project manager. Based upon that plan, predictions by the same mathematics as within the tool are made. Based upon those results a proper baseline is set. The real plan over the two weeks is analysed. The obtained data about those two weeks, is thereafter emptied in the sense of sequencing and allocation of containers to vehicles. The two weekly data is than processed by the tool. The real operation is than compared to the predictions of the model and compared by the possibilities of the plan model. The results will be presented by a progress meeting. The results of this are meaningful to cope with the pitfalls of one to five.

The generated schedules for the two weeks must be discussed by the project leader and the planner. On this point a "gate" can be set. If the results are satisfying, continue, else pull the plug on the project.

If the project continues, first a survey must be taken from the drivers. Once all surveys have returned, the system can be made operational. After the system has been operational 1.5 months, a new survey form the drivers must be taken. The difference is the effect of the change on the drivers. If no difference or only improvements occur, the system is implemented successfully from the perspective of the driver and no additional actions are required. Else, ask from the drivers what is causing the problems and eliminate those problems.

After the period of 1.5 months an end meeting between the CEO, managers, planners, and developers should be held to evaluate the project.

Step 7: Consolidating improvements and producing still more change

The magnitude of the time savings for the planner now should be measureable. At this point in time, the office should be open to setup the new suggested function of customer services. Additionally, suggestions from the planners to improve the logistical system of CTV further should be explored. We also feel that this might be a good moment of the marketers and the planners to discuss the possibilities of using the plan model in aiding the process of order acceptance.

Step 8: Institutionalizing new approaches

This involves the communication to the whole organization about the project, the success of the project, and the new adopted behaviour of the business unit. Within Seacon the possibility to do this is in the yearly Christmas drink where the most important points of the year within the organization are discusses by the management. If the magnitude of the project is big enough, this is the ideal moment to present such. Within CTV this is much easier planned, this can be done in an informal way on a Friday afternoon drink. From here the Change management model restarts the circle, so return to step 1 with a new idea. Additional ideas for CTV are covered by this study in Section 8.3.

7.3 Timeline and evaluation

The evaluation regarding the effect has partly been described in Section 7.2 as the survey before and after the implementation for the driver, additionally test are named for the first two weeks to evaluate the real performance improvement for the schedule. Indicators are directly adopted from the evaluation of the schedule of Chapter 6. For the planners, direct oral communication should be held on day to day bases during the implementation project.

Chapter 8

Conclusion, discussion and recommendations

This last chapter of this study is build up as follows: Section 8.1 shows the conclusions drawn from this study. In Section 8.2 the model is discussed briefly. Section 8.3 gives an answer to the research question. The research question is:

"How to create an optimal plan for container trucking by CTV in the region Venlo, taking into account sustainability for the region and equipment usage?"

In the last section, Section 8.4 suggestions for further research are given.

8.1 Conclusion

First, insides in the current practice were obtained and presented in Chapter 2. Currently a plan process according to gut feeling is used. This study suggests a structured way of planning the orders by an initial construction and improving that constructed plan by an optimisation step. In order to construct the initial plan, following data was used;

The three types of jobs

- Delivery job
- Return job
- Complete job

Important numbers:

- In the year 2012 44156 container-jobs were processed. In the year 2013 50016 container-jobs were processed. The year 2013 is analysed up to week 43.
- In total 24.5% of the containers are decoupled at the customer.
- The variability stayed stable from the year 2012 to 2013.
- Different means and standard deviations for the days were given. They showed a normal distributed pattern.
- Fractions/weights have been assigned to delivery times. Most containers are requested by the customer in the morning. The customer prefers full delivery hours. 17% of the containers are free to schedule over the day.

- Out of the 24.5% of containers that gets decoupled, 58% are picked up the same day. The remaining 42% stays at the customer between 1 and 28 days.
- 95% of the containers are picked up in Venlo at the barge or train terminal. The remaining pickups occur at terminals outside Venlo.
- In total there are five customers. Each contributes to more than 5% weight compared to the total.
- 82% of the containers are returned to Venlo. The remaining 18% gets returned to terminals outside Venlo.

The inflow of containers in Venlo is bigger than the outflow. There is an underling trade-off between service time, and additional empty kilometres and used trailers. The suspicion was that only the fraction of decoupling is influential on the trade-off. It is given that never decoupling a container at the customer leads to the least empty kilometres, remember the trade-off of Section 2.4. However, it is impossible to finish the day task of CTV without decoupling. This is due to long service time at the customer. Therefore, a method to improve the schedule of the current working practice was developed.

Model parameters were found in literature. However, these were not directly applicable. A unique model needed to be developed in order to fit the specifics of the current practice. The model development contains the following inputs:

- Capacity constrained (driving time)
- Stochastic service times at the customer
- Stochastic service times at the terminal
- Homogenous vehicles
- Homogenous loads
- Hard time windows
- Single truck loads
- Start and end at CTV
- Taking into account timing for trailers.
- Waiting times

In literature it was stated that no best method is available to solve our problem. We tested the model using four constructive planning methodologies. We tested a worst case scenario, an improvement of the worst case, a cost based savings approach, and the balance equal method. These four obtained model were improved by a 2-opt method or a simulated annealing.

Out of our experiments the following results were concluded:

- Simulated annealing is outperforming 2-opt in every experiment;. Table 23 versus Table 24. These optimisation techniques were fast enough in order to use them for both offline and online purposes.

Table 23: Results performance from 2-opt optimisation for three planning methodologies, i.e worst case scenario (WCS), balance equal and cost based savings (CBS).

Appendix

Table 24: Summarized results performance simulated annealing

Appendix

Out of the Tables 23, 24, and 15:

- WCA performs in-between in reduction of kilometres. It is best in # containers being late. This is the case with both improvement techniques. It uses in-between # vehicles.
- Balance equal with either improvement technique is best in reduction of kilometres. It shows more jobs being late than other construction methodology with improvement methodologies. It uses the most vehicles. Overall this methodology shows the best numbers from the perspective of the driver.
- Cost based savings shows the least reduction of the methodologies tested. It is in-between on # containers being late. The cost based savings leads to the least vehicles used, and logically the drivers make the most hours. Overall it shows the least potential for the driver.

The construction methodology did not affect the end reduction of the schedule. The construction of the solution between the equal balance, the cost based savings and the time steered worst case analyses was not significantly different for the total driven kilometres. The reduction was also not significantly different once an improvement heuristic was applied to one of the constructed solutions. Considering the total containers being late, the balanced container plan methodology is worse compared to any other construction methodology. The WCA performs best on lateness.

Simulated annealing performed better compared to the 2-opt in reduction of kilometres. Simulated annealing performed better when an increase in containers was evaluated. The sampled data with the increased in volume support this claim. Not only provided simulated annealing us with lesser driven kilometres, it also found better allocation of the containers since less containers are being late. The containers that are late are containers that were rush orders.

Balance equal came closest to equal benefits for the drivers. Planning according to the balance equal methodology made a barely noticeable change for the drivers. This is because CTV pays the driver per container and does not own the vehicles. It is not beneficial to use less vehicles if this is resulting in the same performance. Cost based savings is worst from the driver's perspective and the WCA performs in-between.

The suspicion was that with only 24.5% of decoupling, the fleet has the capacity to incorporate all smarter allocations of the sequencing of containers on a vehicle. Since the results were relatively close to each other in reduction. They showed a broadband of approximately 1%.

From a running time perspective it does not matter if the solution was fast steered to a better solution than the set benchmark. This is due to the fact that the solution converted to an optimal solution within minutes.

Scenario growth

- The method generated "random" containers equal to the historical data, except for the number of containers that are too late. The model overestimated these containers.

- With the usage of the construction and optimisation step, the logistical system is able to cope with a growth up to 10%. Going beyond the 10% growth means additional drivers must be hired.
- The percentage of growth in volume of containers leads to the same growth percentage of driven kilometres.

Sensitivity

- Restricting the model by setting a maximum on daily transported containers did not affect the end result of the schedule.
- The solution was also allowed to play a little with the delivery times. The odd finding here was that the reduction in kilometres compared to the worst case analysis was about 2%.

Once we realized where this reduction came from, the oddness disappeared. We already saw an average reduction of 11.5% with the simulated annealing where the 2-opt scored less than 11%. The main cause was because simulated annealing was able to plan the container better due to the possibility of devaluation of the solution at the beginning of the optimisation. The time window allowed the containers to be better planned without first escaping the local optimum due to the fact they were allowed in a wider range of delivery opportunity, and then the line shows a pattern that is close linear. The fact that this pattern occurred gave us the indication that the dataset is bounded by the delivery times. Since the delivery times were set by the customer - in collaboration with the order acceptance department - we stated that the order acceptance was doing a good job considering that this is done according to gut feeling.

8.2 Discussion

Important to keep in mind is the fact that the model is an approximation of the behaviour of real practice. If a model - like the one developed - is implemented in practice, the model can be made more accurate by feeding it with real time performance. The distance matrix should be slowly replaced by real time data. By this the following is intended:

Distance matrix: the distance matrix should be replaced after some time by the real time performance. So the plan layer should be able to evaluate the distance expected and the distance driven in practice. If enough data is available for the traverse from i to j in the matrix, the matrix should be updated by this real performance.

Time: The model is now determining time based on a straight weight walk over the earth and a correction factor and the average suspected speed of a vehicle. If the model becomes operational an additional matrix should be available to store the real driving time from i to j.

Both matrix mentioned should be updated automatically. The main problem here was the same as with the data of service times of the terminals. Currently the driver must administer the arrival at the customer or the TomTom. The driver is forgetting this in current practice too often. This suggested that this type of administration should be registered automatically. Setting points in the system for each customer can do this. If a vehicle is close to this point - say within 10 meters - the system gets feedback about the arrival of the vehicle at the customer. Best is to select points where a vehicle must past. For example the entrance of the area of a customer and the departure area/lane of a customer.

If for example, the centre point of the customer is picked and the customer has a warehouse that is to big, the system wrongly administrates the process of the driver.

Within CTV there should always be a backup plan to be able to still process todays planning once a system failure occurs. A short time suggestion is given in Section 8.3.

8.3 Recommendation

Using this study, it is recommended to start a pilot as suggested in Chapter 7. The project plan provided in Section 7.3 can be used as schedule for the process. The "gates" set in the project plan have to be used as evaluation points in the implementation process. If the gates give a go, it is recommended that the balance equal methodology with simulated annealing is programmed behind the system of BPA, or possible construct a whole new system containing such.

For the upcoming years, the logistical system of CTV should be able to cope with the containers. It is recommended however to monitor the real growth of containers compared to today. If the increase comes close to 10% growth, CTV should explore the market for additional vehicles to their current fleet.

Accepts orders up to three days of delivery. CTV can cope on short term with system breakdowns by having the planning three days from now ready and stored as backup. Therefore, the model must be run at the end of today for the planning three days from now.

8.4 Further research within CTV

For further research the following areas and their issues are recommended; dynamic planning, collaboration of information system of the company and external parties, and the pricing strategy per container-job.

The dynamic planning area is mentioned because we believe that after achieving the implementation of the current recommended plan methodology, dynamic planning is the next step. For dynamic planning to be evaluated properly, better data management by CTV should be achieved. Currently valuable information is lost due to the fact that the drivers are inconsistent with data registration. Due to this the database is contaminated with inaccurate data, which leads to less accurate predictions, and therefore the results can be deceiving.

The model developed for CTV is capable of predicting arrival times at the terminal. Ideally, CTV and (mainly) the terminals in Venlo should make use of this information. If CTV forwards the predicted arrival times to the terminal(s) and which container needs to be picked up, the terminal can anticipate by preparing the container that is picked up. How the architecture should look like of the systems to collaborate should be researched. With this research project additional problems arise, such as how do we break the barrier of trust when collaborating in the transportation industry?

CTV should explore the possibilities of using the plan model for accepting orders; some suggestions are given in Section 7.2.

The pricing strategy per container-job is mentioned because currently only two groups of containers are used: more than 100 km or 100 and less. If we look at the area of revenue management regarding the pricing strategy of seats in an airplane, we know once we construct the proper buckets regarding the pricing of a seat, additional revenues can be obtained. We are convinced if we would set the just buckets, based upon kilometres to drive per container that additional benefits can be obtained for CTV. To illustrate this, a day out of the planning of historical data is picked (Monday of week 5 2013), than the impact of Table 25 could be achieved by constructing a number of buckets. Since the step magnitude is based on linear pricing and just a sketch, a proper research should be conducted.

Table 25: Example of linear pricing strategy

Number of buckets	Revenues(arbitrary day)
2	€ 24.840,00
5	€ 27.045,00
10	€ 28.845,00

Bibliography

Altinkemer, K., & Gavish, B. (1991). Parallel savings based heuristics for the delivery problem. *Operations Research*, *39*(3), 456–469.

Assad, A. A., & Golden, B. L. (1995). Chapter 5 Arc routing methods and applications. In T. L. M. C. L. M. M.O. Ball & G. L. Nemhauser (Eds.), *Handbooks in Operations Research and Management Science* (Vol. Volume 8, pp. 375–483). Elsevier. doi:http://dx.doi.org/10.1016/S0927-0507(05)80109-4

Averill, M. (2007). Law. Simulation modeling and analysis. *Tata McGraw-Hill*.

Berbeglia, G., Cordeau, J.-F., Gribkovskaia, I., & Laporte, G. (2007). Static pickup and delivery problems: a classification scheme and survey. *TOP*, *15*(1), 1–31. doi:10.1007/s11750-007-0009-0

Caldas, A., Carpente, L., & Lorenzo-Freire, S. (n.d.). A reactive tabu search algorithm for the pickup and delivery routing problem with time windows.

Caris, A., & Janssens, G. K. (2009). A local search heuristic for the pre-and end-haulage of intermodal container terminals. *Computers & Operations Research*, *36*(10), 2763–2772.

Chao, I. M. (2002). A tabu search method for the truck and trailer routing problem. *Computers & Operations Research*, *29*(1), 33–51. doi:http://dx.doi.org/10.1016/S0305-0548(00)00056-3

Chopde, N. R., & Nichat, M. (2013). Landmark Based Shortest Path Detection by Using A* and Haversine Formula. *International Journal of Innovative Research in Computer and Communication Engineering*, *1*, 298–302.

Clarke, G. u, & Wright, J. W. (1964). Scheduling of vehicles from a central depot to a number of delivery points. *Operations Research*, *12*(4), 568–581.

Cordeau, J.-F., Laporte, G., Savelsbergh, M. W. P., & Vigo, D. (2007). Chapter 6 Vehicle Routing. In B. Cynthia & L. Gilbert (Eds.), *Handbooks in Operations Research and Management Science* (Vol. Volume 14, pp. 367–428). Elsevier. doi:http://dx.doi.org/10.1016/S0927-0507(06)14006-2

Dantzig, G. B., & Ramser, J. H. (1959). THE TRUCK DISPATCHING PROBLEM. *Management Science*, *6*(1), 80–91. doi:10.1287/mnsc.6.1.80

Desrosiers, J., Dumas, Y., Solomon, M. M., & Soumis, F. (1995). Chapter 2 Time constrained routing and scheduling. In T. L. M. C. L. M. M.O. Ball & G. L. Nemhauser (Eds.), *Handbooks in Operations Research and Management Science* (Vol. Volume 8, pp. 35–139). Elsevier. doi:http://dx.doi.org/10.1016/S0927-0507(05)80106-9

Fisher, M. (1995). Chapter 1 Vehicle routing. In T. L. M. C. L. M. M.O. Ball & G. L. Nemhauser (Eds.), *Handbooks in Operations Research and Management Science* (Vol. Volume 8, pp. 1–33). Elsevier. doi:http://dx.doi.org/10.1016/S0927-0507(05)80105-7

Kotter, J. P. (1995). Leading change: Why transformation efforts fail. *Harvard Business Review*, *73*(2), 59–67.

Kotter, J. P., & Schlesinger, L. A. (2008). Choosing strategies for change. *Harvard Business Review*, *86*(7/8), 130.

Laporte, G. (2009). Fifty Years of Vehicle Routing. *Transportation Science*, *43*(4), 408–416. doi:doi:10.1287/trsc.1090.0301

Lawler, E. L., Lenstra, J. K., Kan, A. H. G. R., & Shmoys, D. B. (1985). *The traveling salesman problem: a guided tour of combinatorial optimization* (Vol. 3). Wiley Chichester.

Levinson, D., & El-Geneidy, A. (2009). The minimum circuity frontier and the journey to work. *Regional Science and Urban Economics*, *39*(6), 732–738. doi:http://dx.doi.org/10.1016/j.regsciurbeco.2009.07.003

Lin, S.-W., Yu, V. F., & Lu, C.-C. (2011). A simulated annealing heuristic for the truck and trailer routing problem with time windows. *Expert Systems with Applications*, *38*(12), 15244–15252. doi:http://dx.doi.org/10.1016/j.eswa.2011.05.075

Little, J. D. C., & Graves, S. C. (2008). Little's law. In *Building Intuition* (pp. 81–100). Springer.

Nagy, G., & Salhi, S. (2005). Heuristic algorithms for single and multiple depot Vehicle Routing Problems with Pickups and Deliveries. *European Journal of Operational Research*, *162*(1), 126–141. doi:10.1016/j.ejor.2002.11.003

Parragh, S. N., Doerner, K. F., & Hartl, R. F. (2008). A survey on pickup and delivery problems: Part II: Transportation between pickup and delivery locations. *Journal Fur Betriebswirtschaft*, *58*(2), 81–117. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-44349186058&partnerID=40&md5=e2f4ce9843675e9787eef2cef411527d

Pillac, V., Gendreau, M., Guéret, C., & Medaglia, A. L. (2013). A review of dynamic vehicle routing problems. *European Journal of Operational Research*, *225*(1), 1–11. doi:http://dx.doi.org/10.1016/j.ejor.2012.08.015

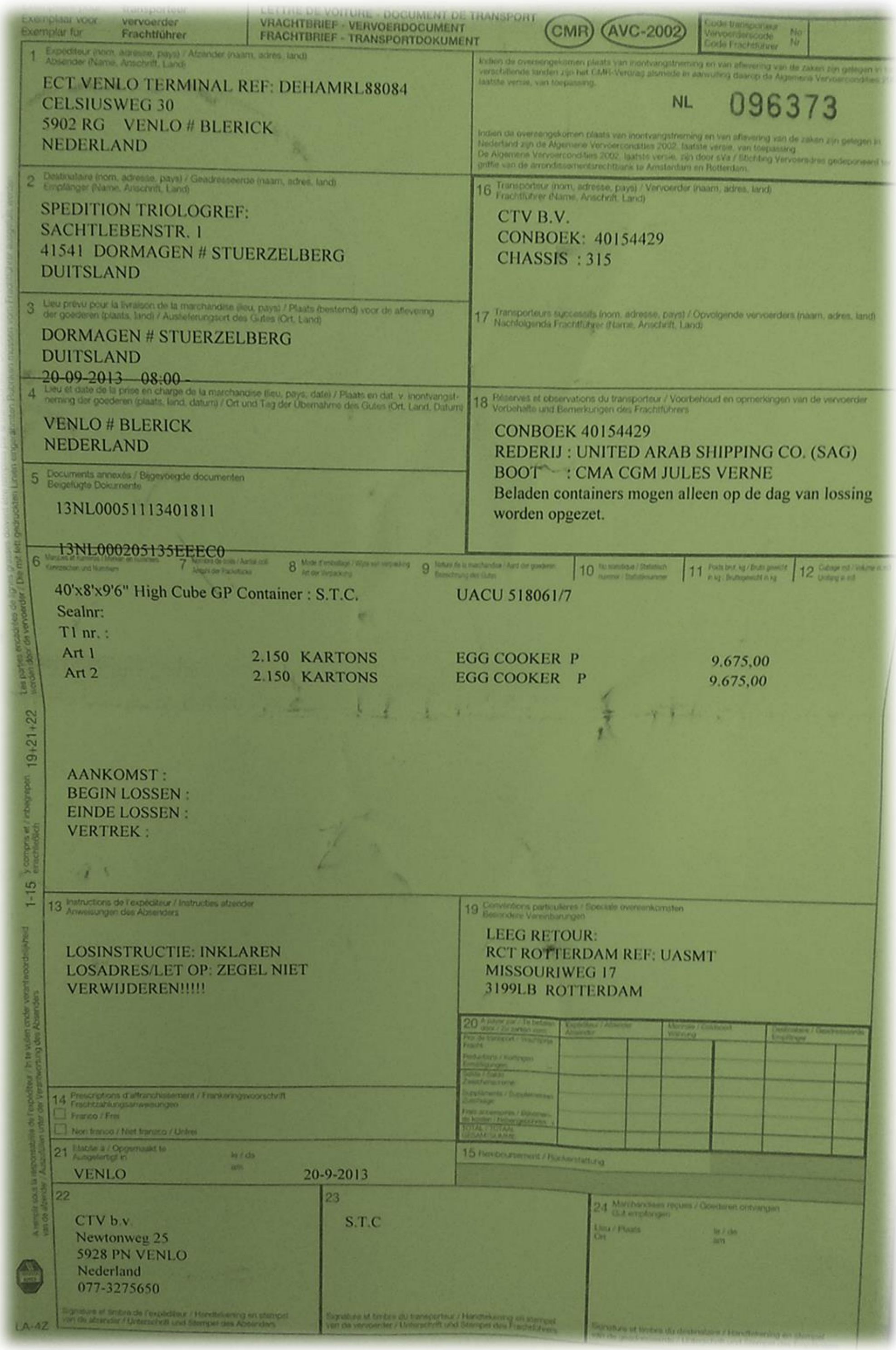
Pinedo, M. (2005). *Planning and scheduling in manufacturing and services* (Vol. 24). Springer.

Poot, A., Kant, G., & Wagelmans, A. P. M. (2002). A savings based method for real-life vehicle routing problems. *Journal of the Operational Research Society*, 57–68.

Tan, K. C., Chew, Y. H., & Lee, L. H. (2006). A hybrid multi-objective evolutionary algorithm for solving truck and trailer vehicle routing problems. *European Journal of Operational Research*, *172*(3), 855–885. doi:http://dx.doi.org/10.1016/j.ejor.2004.11.019

Thangiah, S. R., Osman, I. H., & Sun, T. (1994). Hybrid genetic algorithm, simulated annealing and tabu search methods for vehicle routing problems with time windows. *Computer Science Department, Slippery Rock University, Technical Report SRU CpSc-TR-94-27*, *69*.

Appendix A: Example of CMR document



VRACHTBRIEF - VERVOERDOCUMENT
FRACHTBRIEF - TRANSPORTDOKUMENT
CMR AVC-2002

1 Expéditeur (nom, adresse, pays) / Afzender (naam, adres, land) / Absender (Name, Anschrift, Land)
ECT VENLO TERMINAL REF: DEHAMRL88084
CELSIUSWEG 30
5902 RG VENLO # BLERICK
NEDERLAND

NL 096373

2 Destinataire (nom, adresse, pays) / Geadresseerde (naam, adres, land) / Empfänger (Name, Anschrift, Land)
SPEDITION TRIOLOGREF:
SACHTLEBENSTR. 1
41541 DORMAGEN # STUERZELBERG
DUITSLAND

16 Transporteur (nom, adresse, pays) / Vervoerder (naam, adres, land) / Frachtführer (Name, Anschrift, Land)
CTV B.V.
CONBOEK: 40154429
CHASSIS : 315

3
DORMAGEN # STUERZELBERG
DUITSLAND
20-09-2013 08:00

17 Transporteurs successifs (nom, adresse, pays) / Opvolgende vervoerders (naam, adres, land) / Nachfolgende Frachtführer (Name, Anschrift, Land)

4
VENLO # BLERICK
NEDERLAND

18 Réserves et observations du transporteur / Voorbehoud en opmerkingen van de vervoerder / Vorbehalte und Bemerkungen des Frachtführers
CONBOEK 40154429
REDERIJ : UNITED ARAB SHIPPING CO. (SAG)
BOOT : CMA CGM JULES VERNE
Beladen containers mogen alleen op de dag van lossing worden opgezet.

5 Documents annexés / Bijgevoegde documenten / Beigefügte Dokumente
13NL00051113401811
13NL000205135EEEC0

6 7 8 9 10 11 12
40'x8'x9'6" High Cube GP Container : S.T.C. UACU 518061/7
Sealnr:
T1 nr. :
Art 1 2.150 KARTONS EGG COOKER P 9.675,00
Art 2 2.150 KARTONS EGG COOKER P 9.675,00

AANKOMST :
BEGIN LOSSEN :
EINDE LOSSEN :
VERTREK :

13 Instructions de l'expéditeur / Instructies afzender / Anweisungen des Absenders
LOSINSTRUCTIE: INKLAREN
LOSADRES/LET OP: ZEGEL NIET
VERWIJDEREN!!!!!

19 Conventions particulières / Speciale overeenkomsten / Besondere Vereinbarungen
LEEG RETOUR:
RCT ROTTERDAM REF: UASMT
MISSOURIWEG 17
3199LB ROTTERDAM

20

14 Prescriptions d'affranchissement / Frankeringsvoorschrift / Frachtzahlungsanweisungen
Franco / Frei
Non franco / Niet franco / Unfrei

15 Remboursement / Rembours / Rückerstattung

21 Etablie à / Opgemaakt te / Ausgefertigt in VENLO le / de / am 20-9-2013

22
CTV b.v.
Newtonweg 25
5928 PN VENLO
Nederland
077-3275650

23
S.T.C

24 Marchandises reçues / Goederen ontvangen / Gut empfangen

Appendix B: Steps in the terminal

HANDLEIDING INMELDEN VOLLE CONTAINERS VIA DOE HET ZELF BALIE

Stap 1 Cargocard op lezer leggen en handscan maken (tab)

Stap 2 Kenteken invullen (tab)

Stap 3 F1 Container brengen (tab)

Stap 4 Containernummer inbrengen en type container (tab)
20 ft DV = 22G1
40 ft DV = 42G1
40 ft HC = 45G1

Stap 5 Container schadevrij Ja Vol/Leeg (tab)

Stap 6 Referentie inbrengen = boekingsnummer rederij (tab)

Stap 7 Zegelnummer / Nettogewicht (tab)

Stap 8 Inhoud (bijvoorbeeld 225 colli Trespa platen) (tab)

Stap 9 Documenttype: T1, T2L, VO = Verordening, INV = Invoice, GEE = Geen, EX, EU, CO (tab)

Documentnummer: 13NL......... (tab)

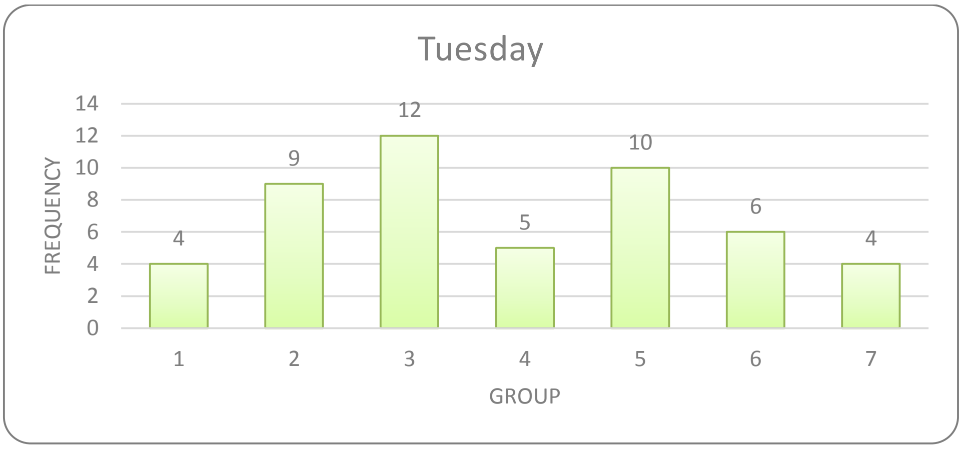
Stap 10 Gevaargoed N (enter) (enter)

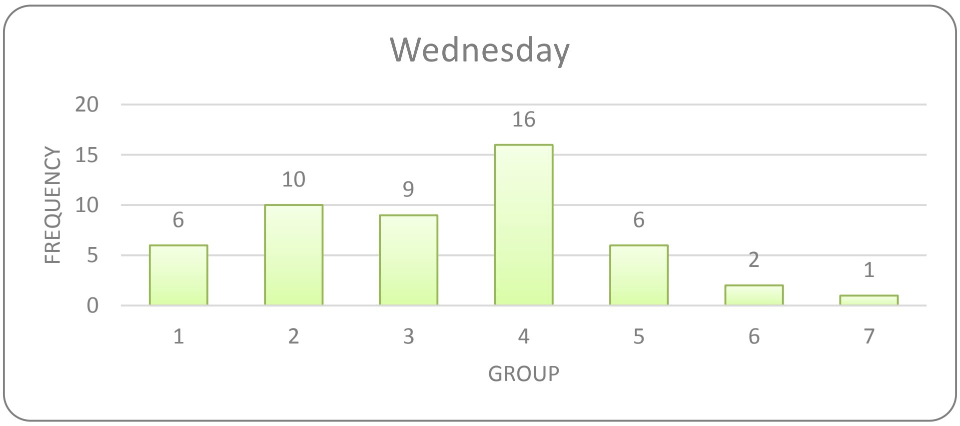
Document + CMR in Kluis 4 (Export Doc CTV) (code = dezelfde als voor kluis Import Documenten)

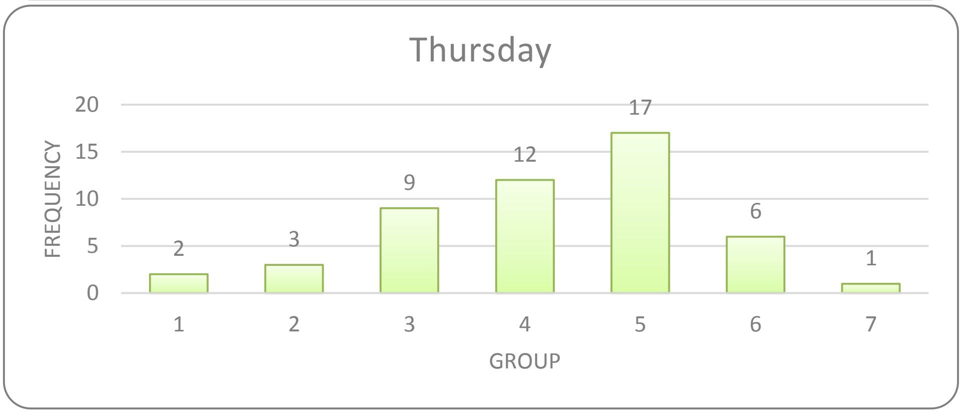
Appendix C.1: Data tables number containers 2012

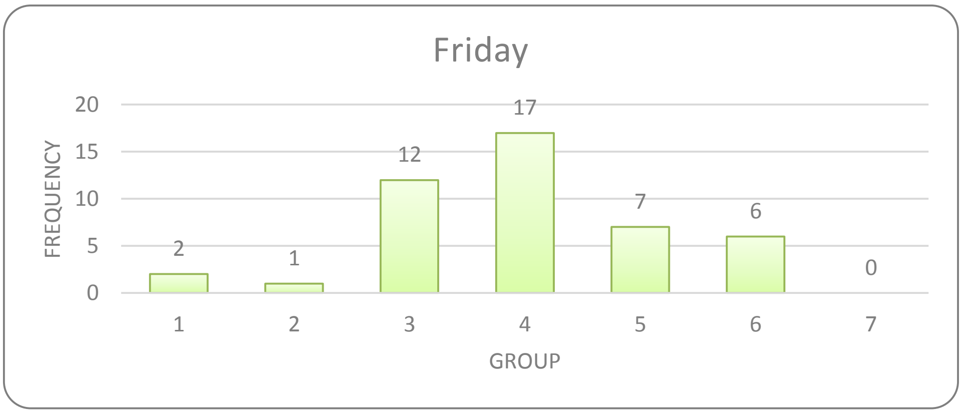
Tuesday	max	min	range	step
	247	152	95	13,57143
Group	low	high	n<high	n in bin
1	152	165,5714	4	4
2	165,5714	179,1429	13	9
3	179,1429	192,7143	25	12
4	192,7143	206,2857	30	5
5	206,2857	219,8571	40	10
6	219,8571	233,4286	46	6
7	233,4286	247	50	4
Wednesday	max	min	range	step
	286	152	134	19,14286
Group	low	high	n<high	n in bin
1	152	171,1429	6	6
2	171,1429	190,2857	16	10
3	190,2857	209,4286	25	9
4	209,4286	228,5714	41	16
5	228,5714	247,7143	47	6
6	247,7143	266,8571	49	2
7	266,8571	286	50	1
Thursday	max	min	range	step
	267	115	152	21,71429
Group	low	high	n<high	n in bin
1	115	136,7143	2	2
2	136,7143	158,4286	5	3
3	158,4286	180,1429	14	9
4	180,1429	201,8571	26	12
5	201,8571	223,5714	43	17
6	223,5714	245,2857	49	6
7	245,2857	267	50	1
Friday	max	min	range	step
	231	104	127	18,14286
Group	low	high	n<high	n in bin
1	104	122,1429	2	2
2	122,1429	140,2857	3	1
3	140,2857	158,4286	15	12
4	158,4286	176,5714	32	17
5	176,5714	194,7143	39	7
6	194,7143	212,8571	45	6
7	212,8571	231	50	0

Appendix C.2:Histogram on number containers 2012







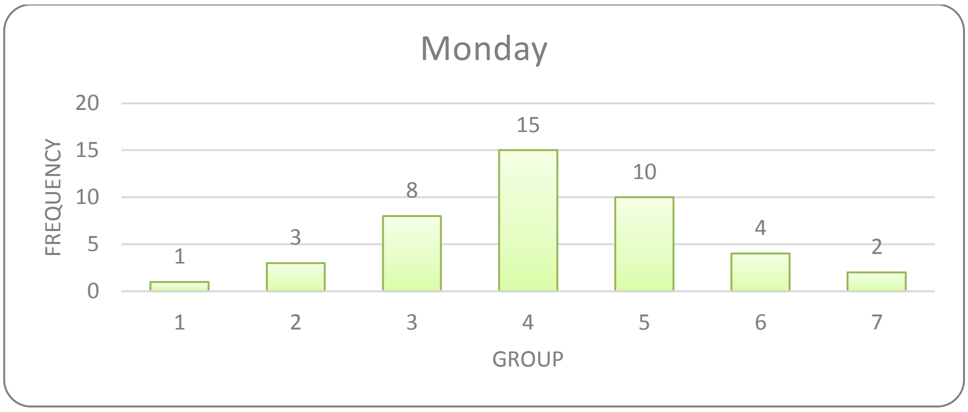


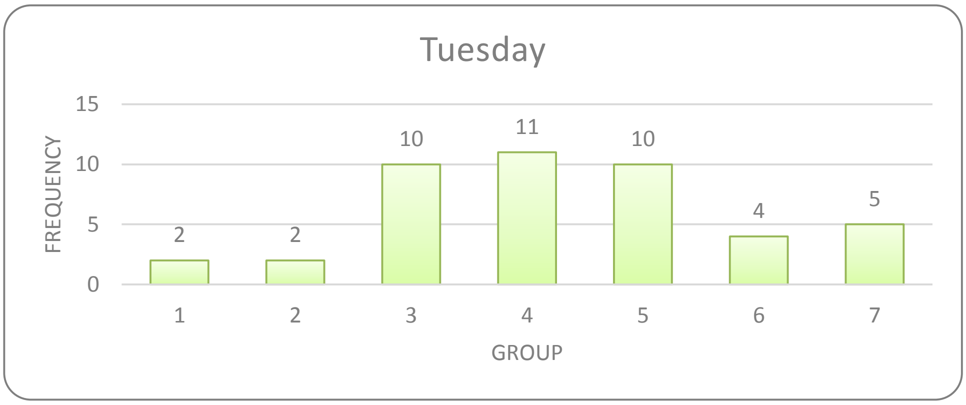
Appendix D.1: Data tables number containers 2013

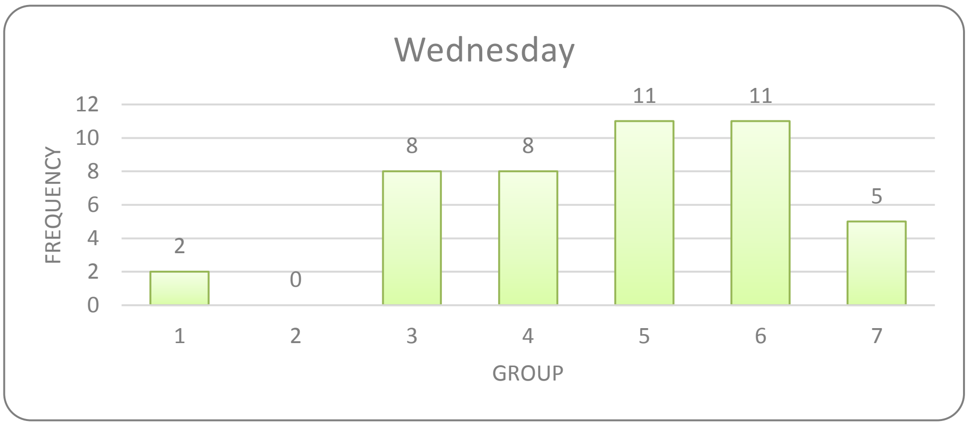
Monday	max	min	range	step
	303	158	145	20,71429
	low	high	n<high	n in bin
1	158	178,7143	1	1
2	178,7143	199,4286	4	3
3	199,4286	220,1429	12	8
4	220,1429	240,8571	27	15
5	240,8571	261,5714	37	10
6	261,5714	282,2857	41	4
7	282,2857	304	43	2
Tuesday	max	min	range	step
	305	166	139	19,85714
	low	high	n<high	n in bin
1	166	185,8571	2	2
2	185,8571	205,7143	4	2
3	205,7143	225,5714	14	10
4	225,5714	245,4286	25	11
5	245,4286	265,2857	35	10
6	265,2857	285,1429	39	4
7	285,1429	305	44	5
Wednesday	max	min	range	step
	279	172	107	15,28571
	low	high	n<high	n in bin
1	172	187,2857	2	2
2	187,2857	202,5714	2	0
3	202,5714	217,8571	10	8
4	217,8571	233,1429	18	8
5	233,1429	248,4286	29	11
6	248,4286	263,7143	40	11
7	263,7143	279	45	5
Thursday	max	min	range	step
	301	143	158	22,57143
	low	high	n<high	n in bin
1	143	165,5714	3	3
2	165,5714	188,1429	7	4
3	188,1429	210,7143	11	4
4	210,7143	233,2857	23	12
5	233,2857	255,8571	32	9
6	255,8571	278,4286	42	10
7	278,4286	301	45	3
Friday	max	min	range	step

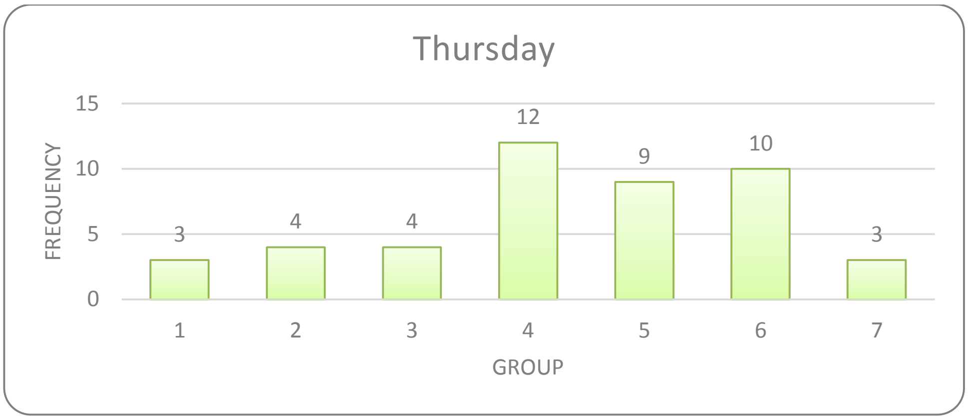
	274	114	160	22,85714
	low	high	n<high	n in bin
1	114	136,8571	1	3
2	136,8571	159,7143	2	1
3	159,7143	182,5714	10	8
4	182,5714	205,4286	19	9
5	205,4286	228,2857	28	9
6	228,2857	251,1429	38	10
7	251,1429	274	46	8

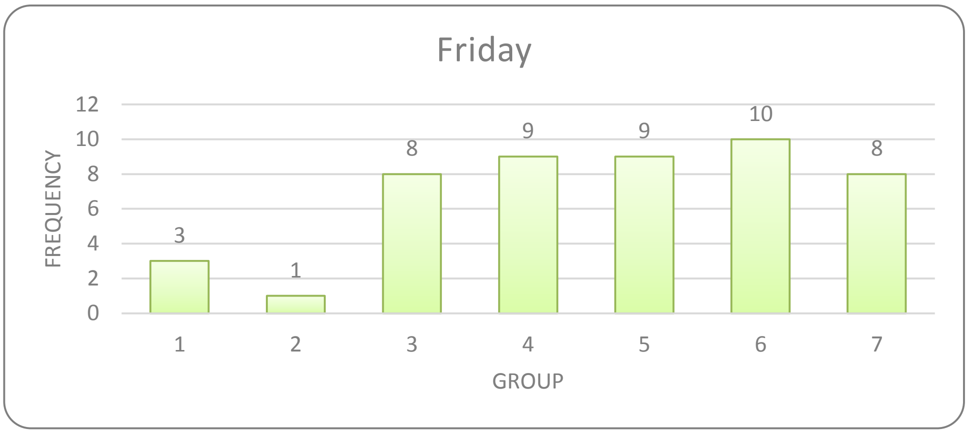
Appendix D.2: Histogram on number containers 2013








Thursday
15
10
5
0
FREQUENCY
3
4
4
12
9
10
3
1
2
3
4
5
6
7
GROUP


Friday
12
10
8
6
4
2
0
FREQUENCY
3
1
8
9
9
10
8
1
2
3
4
5
6
7
GROUP

Appendix E: Mathematical model

This was our first rough model. Possibilities such as taking a container home was possible in this model, in our end model this was omitted.

Indices:

- Day d in the planning horizon, $d = \{1,2,\ldots,D\}, where\ 1,7,13\ldots,D-5\ is\ Monday\ and\ 6,12,18,\ldots,D\ is\ Saturday;$
- Vehicle v of the fleet, $v = \{1,2,\ldots,V\};$
- Container c/ γ of the containers to plan on "planday" d, $c,\gamma = \{1,2,\ldots,C_d\};$
- Customer location i/j which represents a possible loading/unloading location in the network, i,j$\in Locationslist$
- $Sequence\ of\ the\ container\ on\ vehicle\ v\ on\ day\ d\ r = \{1,2,\ldots,R_d^v\}$

Parameters:

- $C_d = number\ of\ container\ to\ be\ served\ on\ day\ d,\ where\ d = \{1,2,\ldots,D\}$
  $c \in C_d \in Locations, where\ locations\ represent\ all\ know\ load\ and\ unload\ locations\ within\ the\ constrained\ area$
- $\delta_{c,d}\ delivery\ location\ of\ container\ c, on\ day\ d, location\ is\ a\ unique\ duo\ of\ geographical\ coordinates$
- $\varphi_{c,d}\ pickup\ location\ of\ container\ c, on\ day\ d, location\ is\ a\ unique\ duo\ of\ geographical\ coordinates$
- $V = number\ of\ (optional) vehicles\ availible$
- $T = number\ of\ diffrent\ vehicles\ availible$(can be used to expand)
- $D = number\ of\ transportationdays$
- $R_d^v = total\ \#\ of\ routes\ on\ day\ d\ on\ vehicle\ v, where\ d = \{1,2,\ldots,D\}, v = \{1,2,\ldots,V\}$
- $X_{c,\gamma,d}^v = \begin{cases} 1: if\ container\ \gamma\ is\ visited\ by\ vehicle\ v\ on\ day\ d, after\ container\ c \\ 0: else \end{cases}$
  $where\ c,\gamma = \delta_{c,d} \in \{1,2,\ldots,I\}, v = \{1,2,\ldots,V\}, d = \{1,2,\ldots,D\}$
- $f_{DISTANCE}(\varphi_{c,d}, \delta_{c,d}): a\ formula\ used\ to\ calculate\ the\ distance\ between\ node\ i,j\ based\ upon\ a\ duo\ of\ coordinates\ longitude\ and\ latitude\ of\ i,j$[4]$, where\ i = \{1,2,\ldots,I\}, j` = \{1,2,\ldots,J\}.\ Also\ coordinates\ of\ f.e.home\ to\ first\ pickup\ or\ delivery\ container\ c\ to\ container\ \gamma\ can\ be\ plugged\ in.$
- $t_{i,j}(f_{distance}(i,j)) = time\ to\ travel\ forme\ node\ i\ to\ node\ j, where\ i = \{1,2,\ldots,I\},\ j = \{1,2,\ldots,J\}$
- $\tau_i = \ stochastic\ service\ time\ at\ node\ i,\ where\ \ i = \delta_{c,d} \in \{1,2,\ldots,I\}$
  $\tau_i\ follow\ a\ \ldots distribution$
- $a_i = start\ time\ of\ container\ i\ , where\ i = \delta_{c,d} \in \{1,2,\ldots,I\}$
- $w_i = waitingtime\ of\ container\ i\ , where\ i = \delta_{c,d} \in \{1,2,\ldots,I\}$
- $e_i = start\ of\ lower\ soft\ time\ windown\ of\ containerlocation\ i\ , where\ i = \delta_{c,d} \in \{1,2,\ldots,I\}$
- $l_i = end\ of\ uppersoft\ time\ windown\ of\ containerlocation\ i\ , where\ i = \delta_{c,d} \in \{1,2,\ldots,I\}$

---

[4] In our model we used the haversine formula, to estimate the distance between two points, we did this because this formula is effective when distances are not that large. 100 km on a diameter of 6875 is not assumed to be large

- $L_{max} = hard\ timeconstraint$
- $\lambda_i = actual\ lateness\ of\ containerlocation\ i\ , where\ i = \delta_{c,d} \in \{1,2,\dots,I\}$
- $T^0_{d,v} = starttime(from\ home\ of\ the\ driver)\ of\ vehicle\ v\ on\ day\ d\ v = \{1,2,\dots,V\},\ d = \{1,2,\dots,D\}$
- $T^F_{v,d} = Endtime(at\ home\ of\ the\ driver)\ of\ vehicle\ v\ on\ day\ d\ v = \{1,2,\dots,V\},\ d = \{1,2,\dots,D\}$
- $DC = driving\ capacty\ of\ a\ driver;$
- $CCF = crowcorrectionfactor\ to\ come\ to\ more\ realistic\ distances$
- $SP = Average\ speed\ of\ a\ driving\ truck;$

Decision variables:

$$Y^{v,r}_{c,d} = \begin{cases} 1, if\ vehicle\ v\ transports\ container\ c\ on\ day\ d\ as\ rth\ container\ of\ his\ trip \\ 0, \quad else \end{cases}$$

$$where\ \ c = \{1,2,\dots,C_d\}, \quad r = \{1,2,\dots,R^v_d\}, \quad v = \{1,2,\dots,V\}, \quad d = \{1,2,\dots,D\}$$

$U^v_d = \begin{cases} 1, if\ vehicle\ v\ is\ used\ on\ day\ d \\ 0,\ else \end{cases}$ $where\ \ v = \{1,2,\dots,V\},\ d = \{1,2,\dots,D\}$ (optional to use, similar formulations regarding vehicle selection, can also be used for the usage of chassis).

Objective function:

$$\min_{X^v_{i,j,d}} \sum_d^D \sum_c^{C_d} \sum_{\gamma>c}^{C_d} \sum_v^V X^v_{c,\gamma,d} \cdot (F_{distance}(\delta_{c,d}\ , \varphi_{\gamma,d})) + \sum_d^D \sum_c^{C_d} \sum_v^V X^{\ \ v}_{c,H_v,d} \cdot ((F_{distance}(\varphi_{c,d}\ , H_v) + (F_{distance}(\delta_{c,d}\ , H_v))$$

Subjected to:

1. $\sum_{v=1}^{V} Y^{v,r}_{c,d} = 1 \quad \forall c\ \forall d \forall R^v_d$ Container to vehicle allocation constraint; only one vehicle for each container, and each container can only have a unique sequence on the vehicle.

2. $\sum_{c=1}^{C_d} Y^{v,r}_{c,d} \geq 2 \cdot U^v_d \quad \forall v\ \forall d$ When we use a vehicle we must at least schedule two containers on it on day d.

3. $\sum_{c=1}^{C_d} Y^{v,r}_{c,d} \leq \lceil (U^v_d \cdot C_d) / \sum_{v=1}^{V} (U^v_d \rceil \cdot 2\ \forall v\ \forall d$ When we use a vehicle v we must at most schedule 2 times the number containers divided by the number of vehicles used on day d.

4. $R^v_d = \sum_c^{C_d} Y^{v,r}_{c,d} \quad \forall v\ \forall d$ Number of containers on day d on vehicle v

5. $R^v_d + 1 = \sum_{c=1}^{C_d} \sum_{\gamma>c}^{C_d} X^v_{c,\gamma,d} \quad \forall v\ \forall d$ Number connections +1 is the number of containers (auxerially var)

6. $\sum_{r=1}^{R^v_d-1} \sum_{c=1}^{C_d} \sum_{\gamma>c}^{C_d} \left(Y^{v,r}_{c,d} + Y^{v,r+1}_{\gamma,d} \right) - 1 \leq X^v_{c,\gamma,d} \quad \forall v\ \forall d$ Force a connection between two containers on the same day, if and only if they are on the same vehicle and follow each other up in the planning.

7. $Y_{c,d}^{v,r} \geq \sum_{\gamma}^{C_d} X_{c,\gamma,d}^{v}$ $\forall v\ \forall d\ \forall R_d^v$ aux (help for 6.)

8. $Y_{\gamma,d}^{v,r} \geq \sum_{c}^{C_d} X_{c,\gamma,d}^{v}$ $\forall v\ \forall d\ \forall R_d^v$aux(help for 6.)

9. $\sum_{c=1}^{C_d} \sum_{r>c}^{C_d} X_{c,\gamma,d}^{v} \cdot (a_{\delta_{c,d}} + \left(\frac{CCF}{SP}\right) * (F_{distance}(\delta_{c,d}, \varphi_{\gamma,d}) + F_{distance}(\varphi_{\gamma,d}, \delta_{\gamma,d})) + w_{\delta_{c,d}} + \tau_{\delta_{c,d}} + \tau_{\varphi_{\gamma,d}}) \leq a_{\delta_{c,d}}$ $\forall v\ \forall d$

10. $e_{\delta_{c,d}} \leq (a_{\delta_{c,d}} + w_{\delta_{c,d}}) \leq l_{\delta_{c,d}}$ $\forall c \forall d$ Time window const.

11. $\lambda_{\delta_{c,d}} = \max\{0, (a_{\delta_{c,d}} - l_{\delta_{c,d}})\} \leq L_{max}$ $\forall \delta_{c,d}$ lateness of container c on day d, a delivery may never exceed more than the maximum allowed lateness(L_{max})

12. $w_{\delta_{c,d}} = \max\{0, e_{\delta_{c,d}} - a_{\delta_{c,d}}\}$ $\forall \delta_{c,d}$ waiting time of container c on day d

13. $X_{c,H_v,d}^{v} \cdot (a_{\delta_{c,d}} + \left(\frac{CCF}{SP}\right) * (F_{distance}(\delta_{c,d}, H_v)) + w_{\delta_{c,d}} + \tau_{\delta_{c,d}}) = T_{v.d}^{F}$ $\forall v\ \forall d$ finalize

14. $X_{H_v,c,d}^{v} \cdot (a_{\delta_{c,d}} - \left(\frac{CCF}{SP}\right) * (F_{distance}(H_v, \delta_{c,d}))) = T_{v.d}^{0}$ $\forall v\ \forall d$ Initialize all vehicles for all days;

15. $\sum_{c=1}^{C_d} X_{H_v,\delta_{c,d},d}^{v} \leq 1$ $\forall v\ \forall d \in \{2,3,\dots,D-1\}$ only one possible delivery in the morning

16. $\sum_{c=1}^{C_d} X_{\varphi_{c,d+1},H_v,d}^{v} \leq 1$ $\forall v \forall d \in \{1,2,\dots,D-1\}$ may pick 1 container to take home

17. $X_{H_v,\delta_{c,d},d}^{v} = X_{\varphi_{c,(d+1)},H_v,d}^{v}$ $\forall v\ \forall d \in \{1,2,\dots,D-1\}$ if we pick 1 container to take home, we must deliver it the next day as first container

18. $T_{v.d}^{F}$-$T_{v,d}^{0} \leq DC$ $\forall v \forall d$ Driver capacity of day i

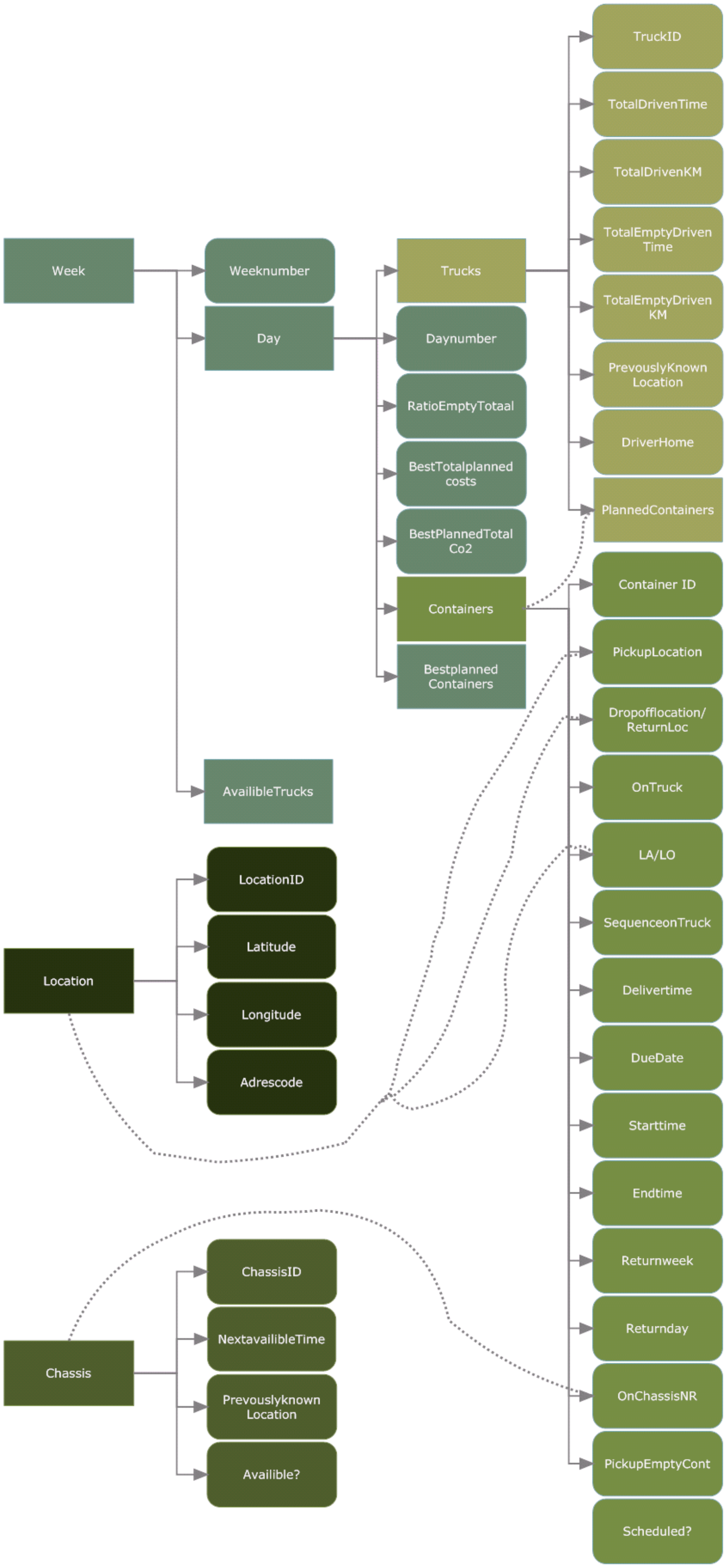
19. $Y_{c,d}^{v,r}$ ∈{0,1} $\forall r\ \forall c \forall v\ \forall d$ binary variable

20. $X_{c,\gamma,d}^{v}$ ∈{0,1} $\forall c\ \forall \gamma\ \forall v\ \forall d$ binary

21. $U_d^v \in \{0,1\}$ $\forall v \forall d$ binary variable

22. all variables and parameters none negative

Appendix F: Structrue of the model and the communication inside



Appendix G: correction factor of Crow Flight (=Euclidean distance)

Network Distance = *f*(Euclidean Distance) models for the Twin Cities region.

Case	Description	Circuity coefficient	R^2	Average network distance (m)	Average Euclidean distance (m)
1	Home–work	1.18	0.99	17,845	14,746
3	Euclidean distance matched	1.22	0.99	18,134	14,357
4	Network distance matched	1.25	0.98	19,473	14,987
2	Euclidean distance				
2–1	≤ 5 km	1.58	0.85	5250	3295
2–2	> 5 km and ≤ 10 km	1.42	0.94	11,021	7731
2–3	> 10 km and ≤ 15 km	1.34	0.97	16,986	12,639
2–4	> 15 km and ≤ 20 km	1.30	0.98	22,845	17,549
2–5	> 20 km and ≤ 25 km	1.27	0.98	28,660	22,558
2–6	> 25 km and ≤ 30 km	1.25	0.99	34,376	27,539
2–7	> 30 km and ≤ 35 km	1.23	0.99	40,072	32,536
2–8	> 35 km and ≤ 40 km	1.22	0.99	45,762	37,554
2–9	> 40 km and ≤ 45 km	1.21	0.99	51,267	42,519
2–10	> 45 km and ≤ 50 km	1.2	0.99	56,745	47,457

N = 5000

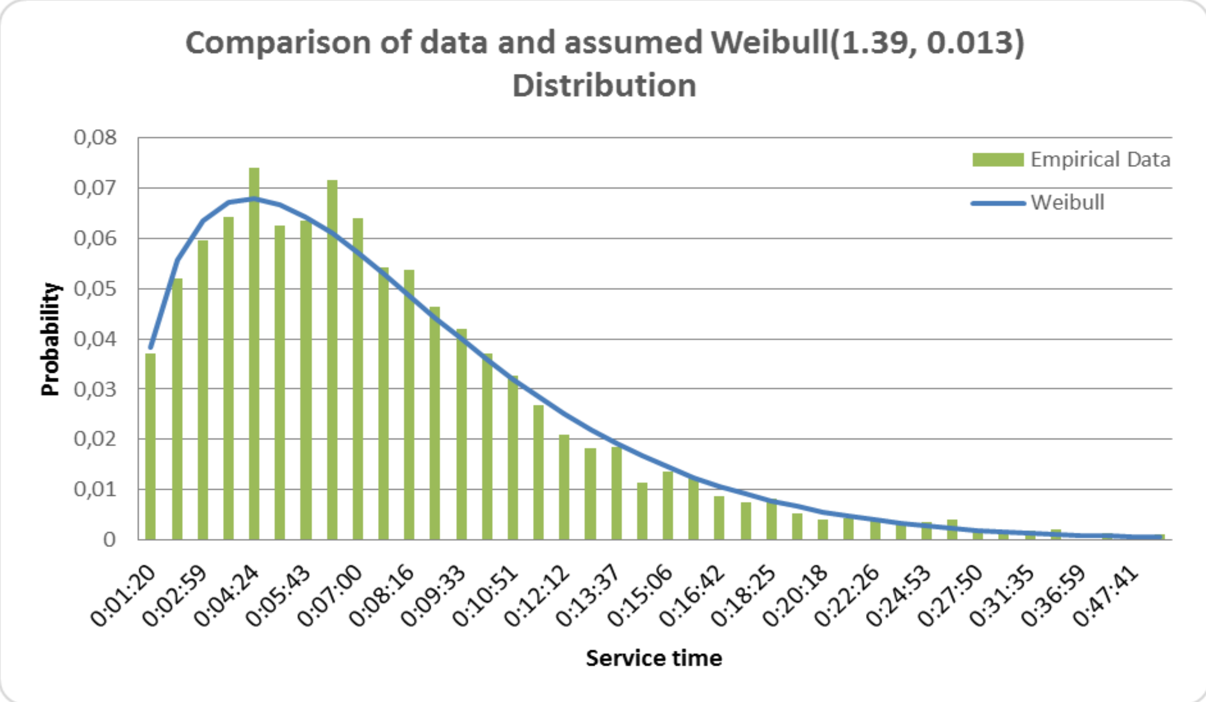
Appendix H: Weibull fitting

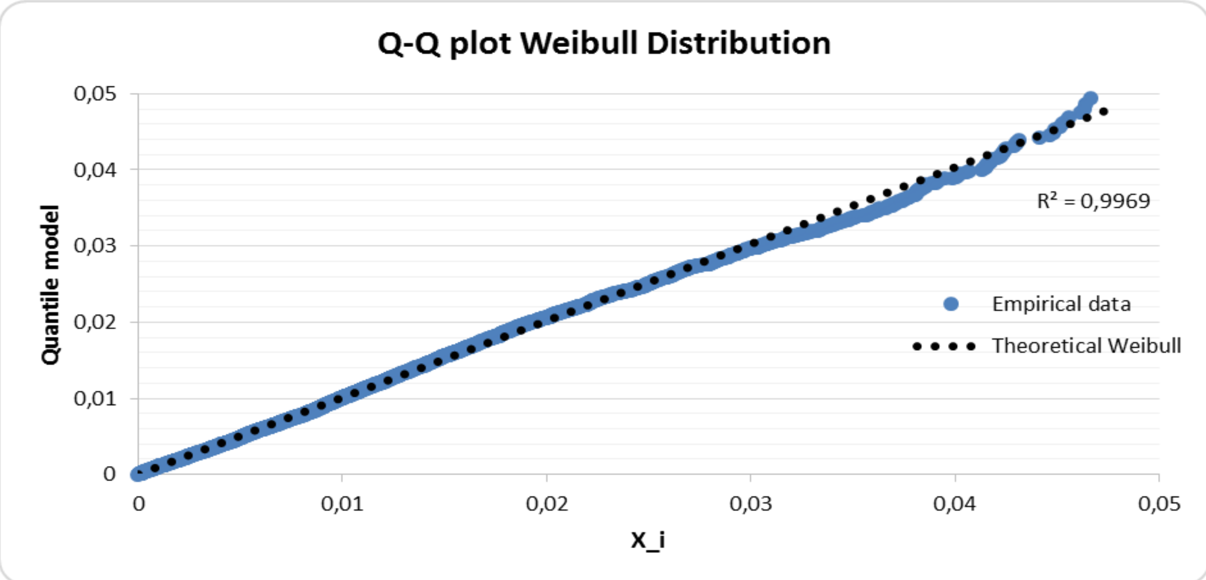
H0: we assume a Weibull distribution

α	β
1,392310554	0,0129655855

$$F^{-1}(p) = \beta(In(\frac{1}{1-p}))^{\frac{1}{\alpha}}$$

	Critical value				
Chi square value	α =0,25	α =0,10	α =0,05	α =0,025	α =0,01
46,97888841	44,5344	54,5595	54,5595	58,1057	62,4111
reject?	Yes	No	No	No	No





Appendix I: Dagum

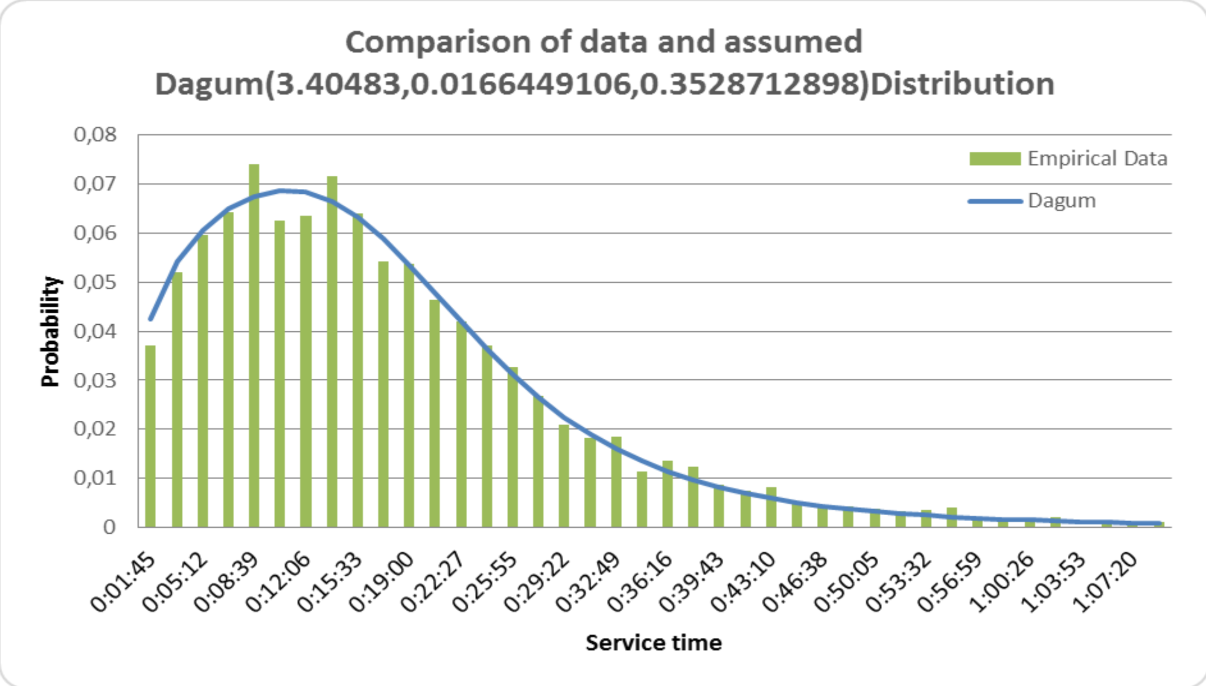
H0: we assume a Dagum distribution

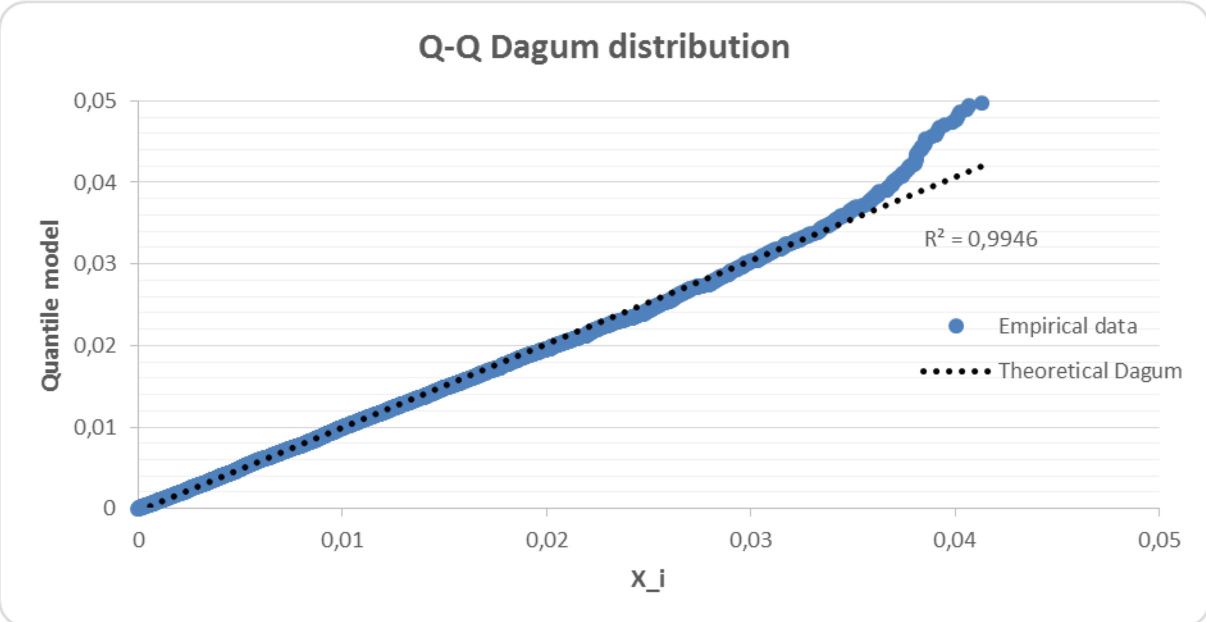
A	β	k
3,406050631	0,0165111636	0,3600244237

$$F^{-1}(p) = \beta\left(p^{-\frac{1}{k}} - 1\right)^{-\frac{1}{\alpha}}$$

	Critical value					
H0 critical value	α =0,5	α =0,25	α =0,10	α =0,05	α =0,025	α =0,01
33,65704438	38,3351	44,5344	54,5595	54,5595	58,1057	62,4111

reject?	No	No	No	No	No	No





Appendix J: Burr

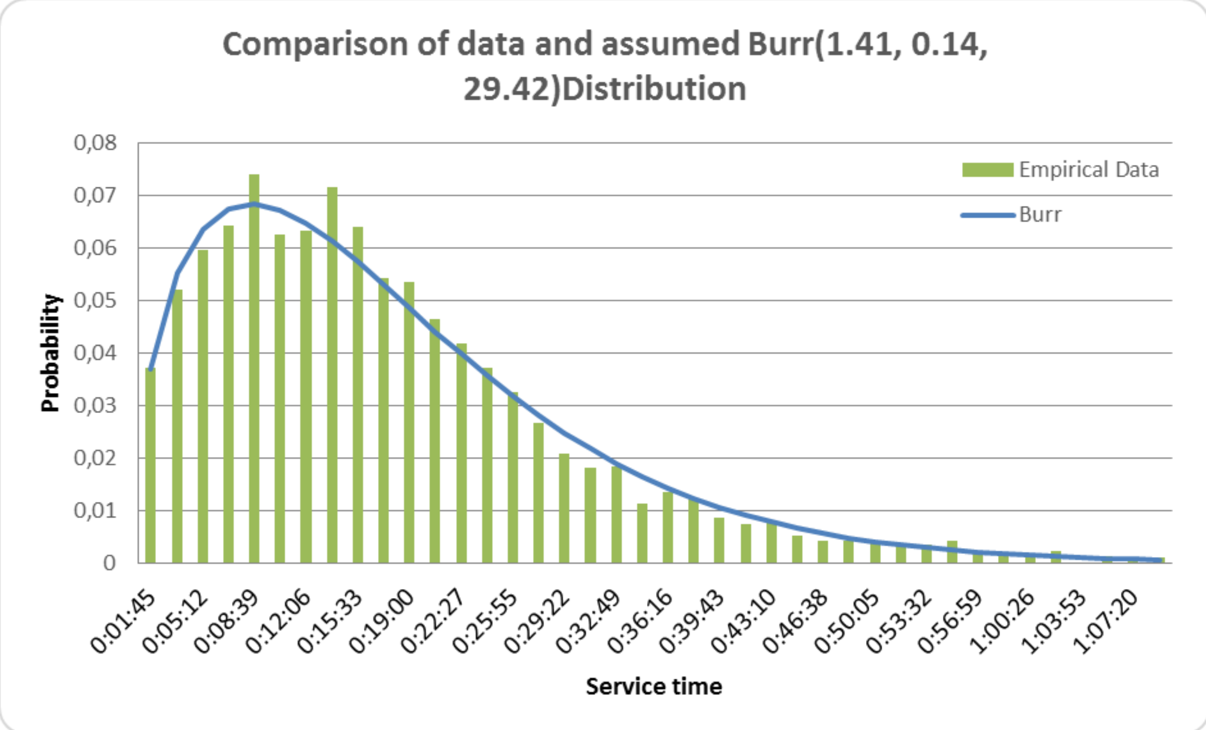
H0: we assume a Burr distribution

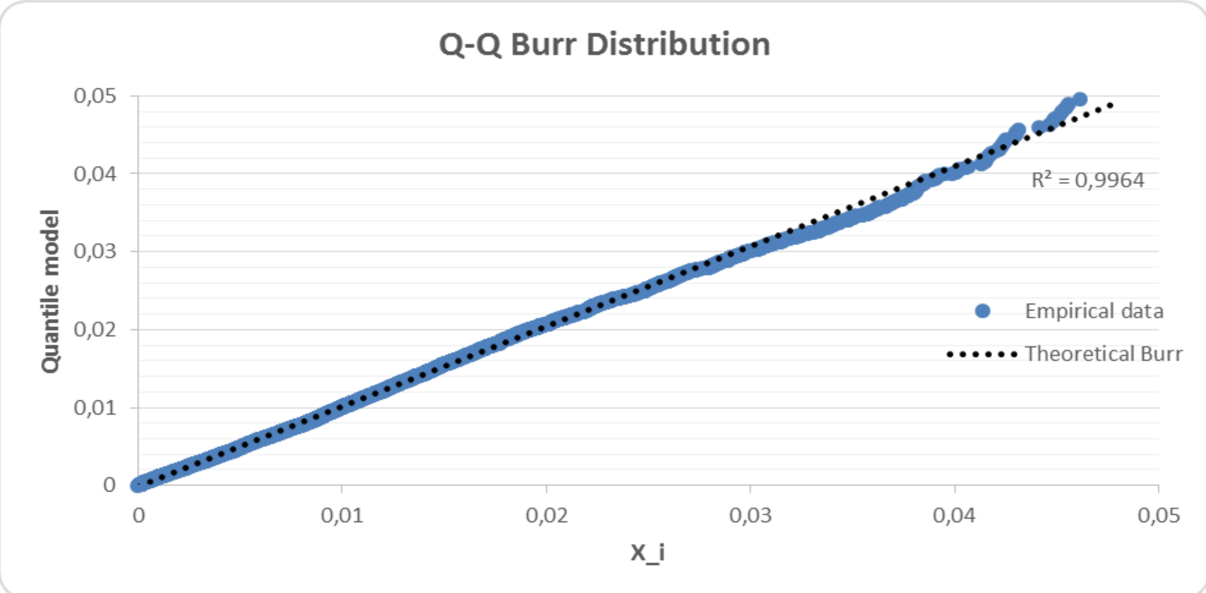
α	β	k
1,411669043	0,1404413213	29,4182772842

$$F^{-1}(p) = \beta\left((1-p)^{-\frac{1}{k}} - 1\right)^{\frac{1}{\alpha}}$$

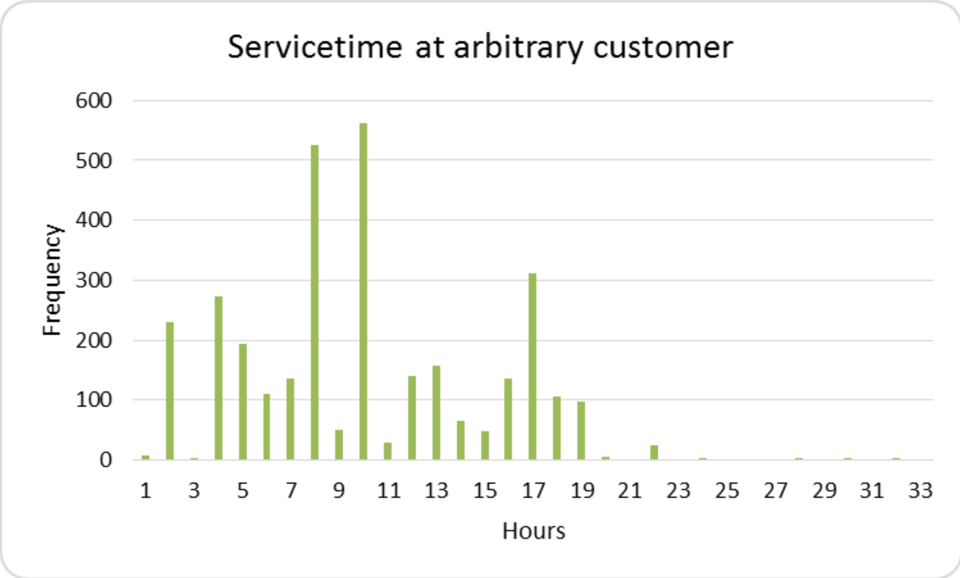
	Critical value					
H0 critical value	α =0,5	α =0,25	α =0,10	α =0,05	α =0,025	α =0,01

42,99784576	38,3351	44,5344	54,5595	54,5595	58,1057	62,4111
reject?	Yes	No	No	No	No	No

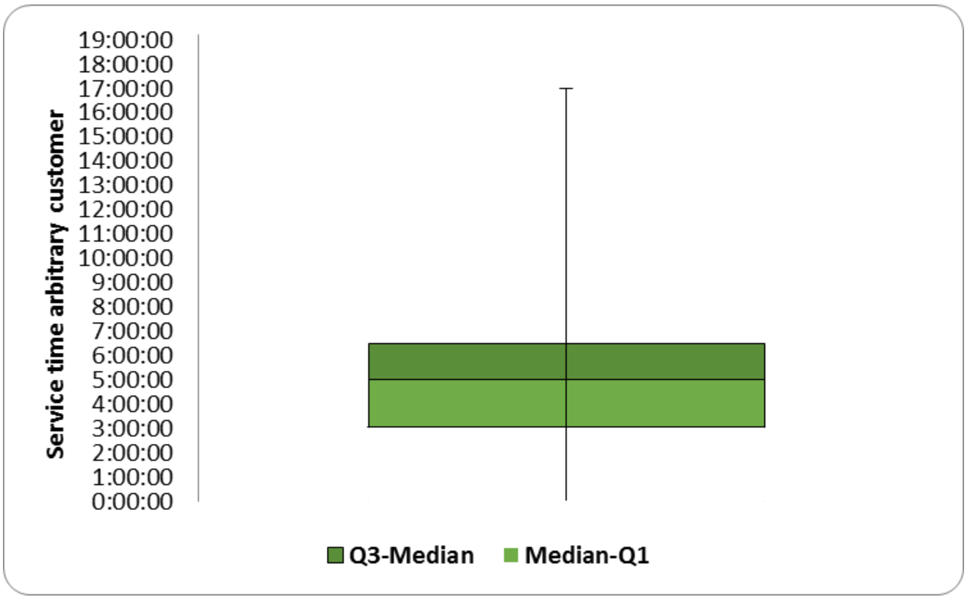




Appendix K: Service time at a customer



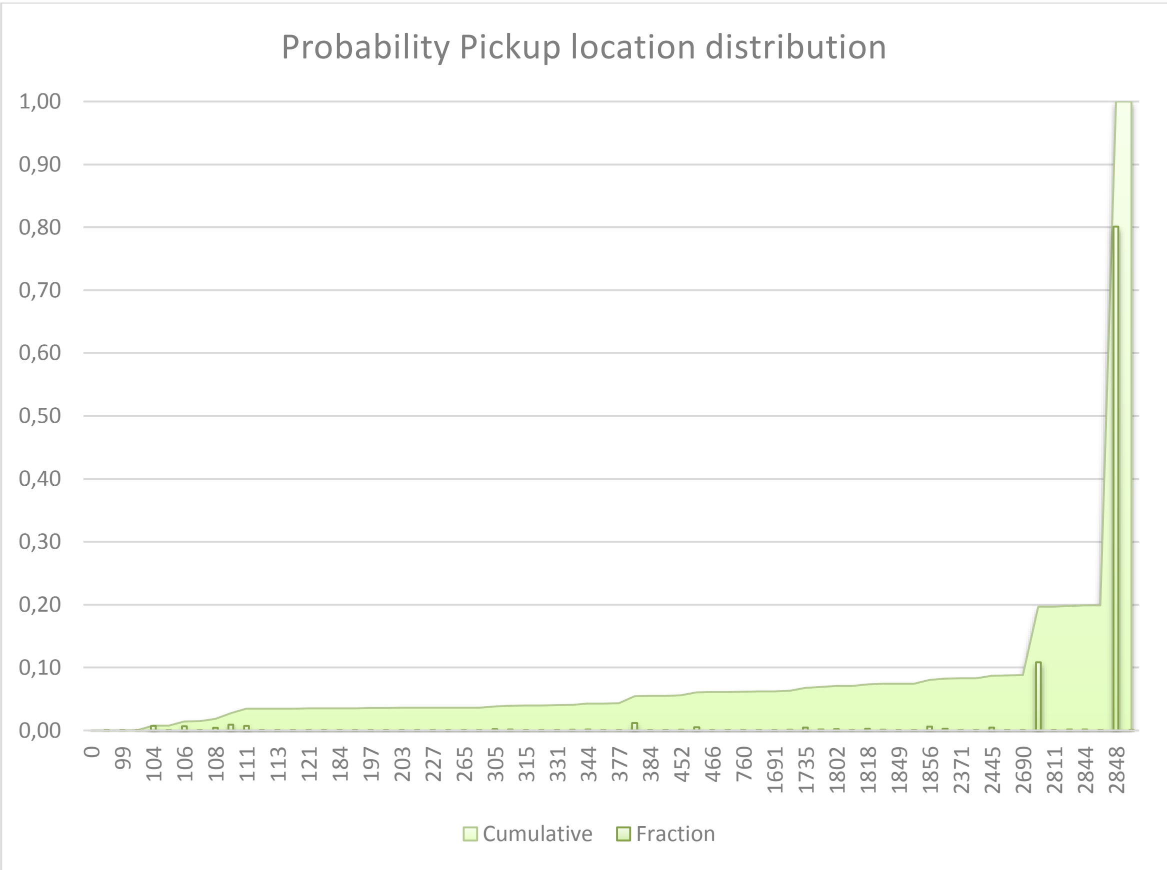
Boxplot

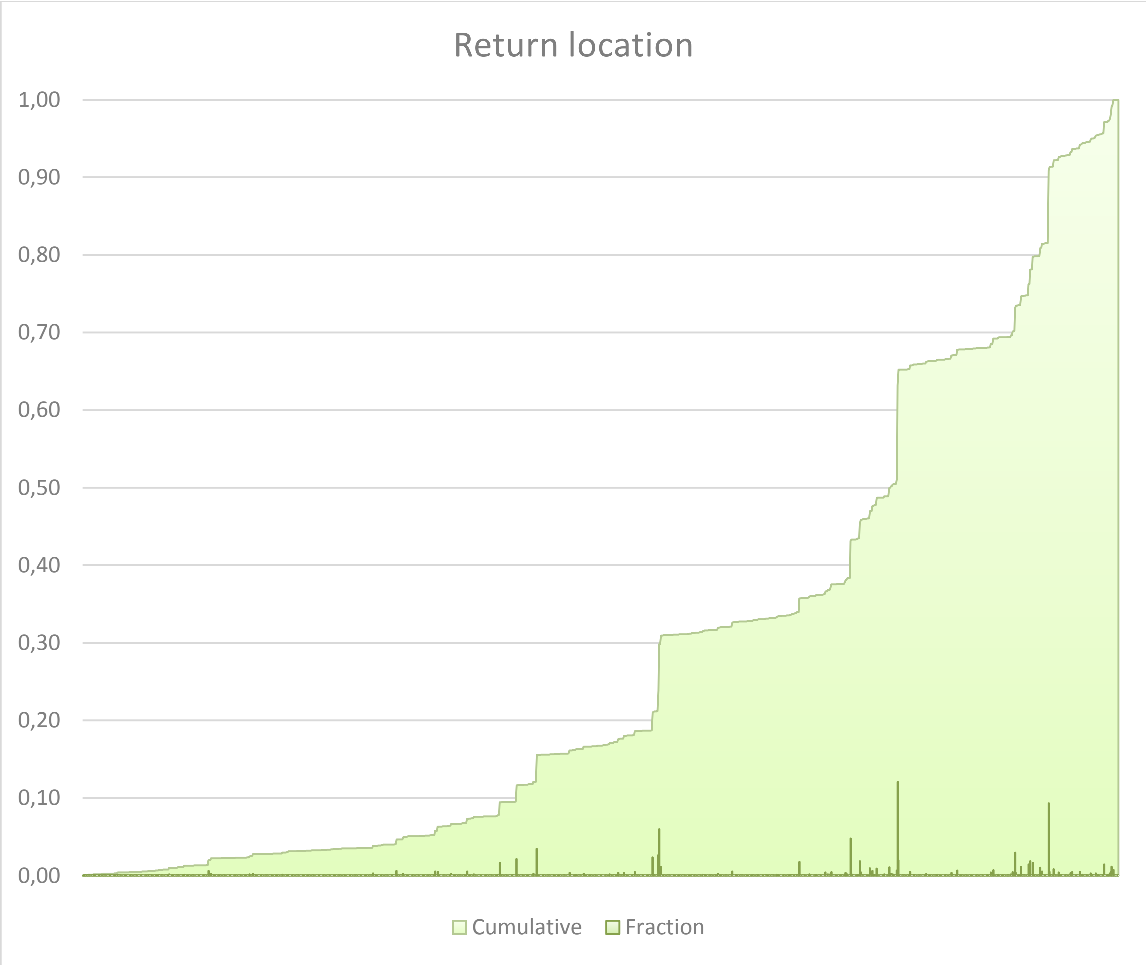


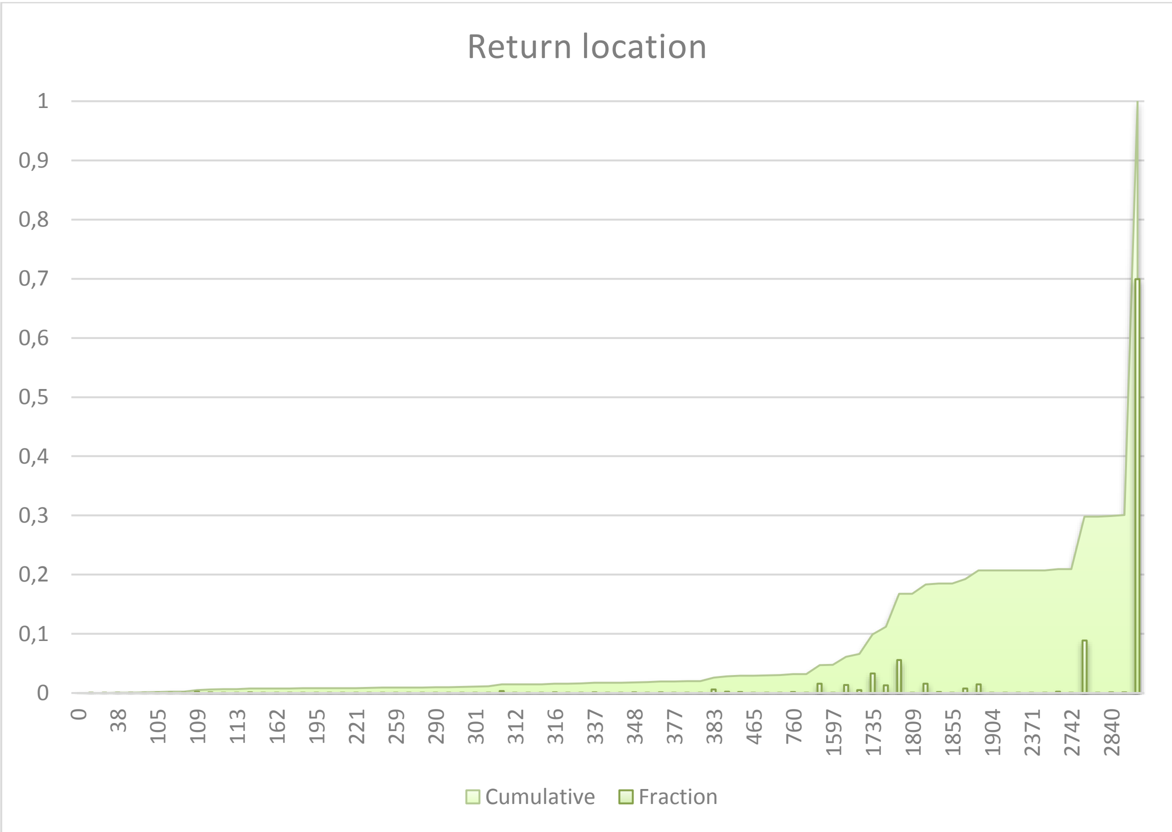
Appendix L: Transition diagram

Transition matrix		To state											
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
From state	**0**	0	p_i,j	0	0	0	p_i,j	0	p_i,j	0	0	0	0
	1	0	0	0	0	0	0	0	0	1	0	0	0
	2	0	0	0	0	0	0	0	0	1	0	0	0
	3	0	0	0	0	p_i,j	0	0	0	0	p_i,j	0	0
	4	0	0	0	0	0	0	0	0	1	0	0	0
	5	0	0	0	0	0	0	0	0	1	0	0	0
	6	0	0	p_i,j	0	0	0	0	0	0	p_i,j	0	0
	7	0	0	0	p_i,j	0	0	p_i,j	0	0	0	0	0
	8	0	0	0	p_i,j	0	0	p_i,j	0	0	0	p_i,j	0
	9	0	p_i,j	0	0	0	p_i,j	0	p_i,j	0	0	0	p_i,j
	10	0	p_i,j	0	0	0	p_i,j	0	0	0	0	0	p_i,j
	11	1	0	0	0	0	0	0	0	0	0	0	0

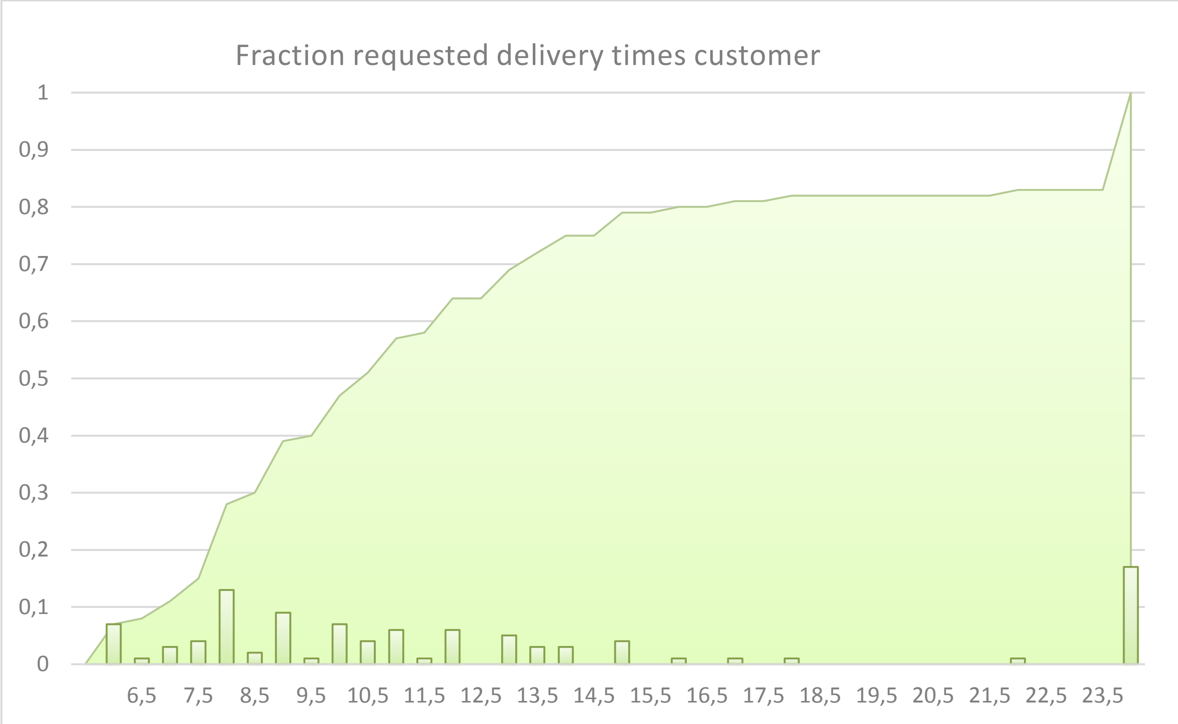
Appendix M.1: Locations (pickup, customer, and return)




Return location
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
Cumulative
Fraction


Return location
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
38
105
109
113
162
195
221
259
290
301
312
316
337
348
377
383
465
760
1597
1735
1809
1855
1904
2371
2742
2840
Cumulative
Fraction

Appendix M.2: Delivery times



Appendix M.3: Forward-job

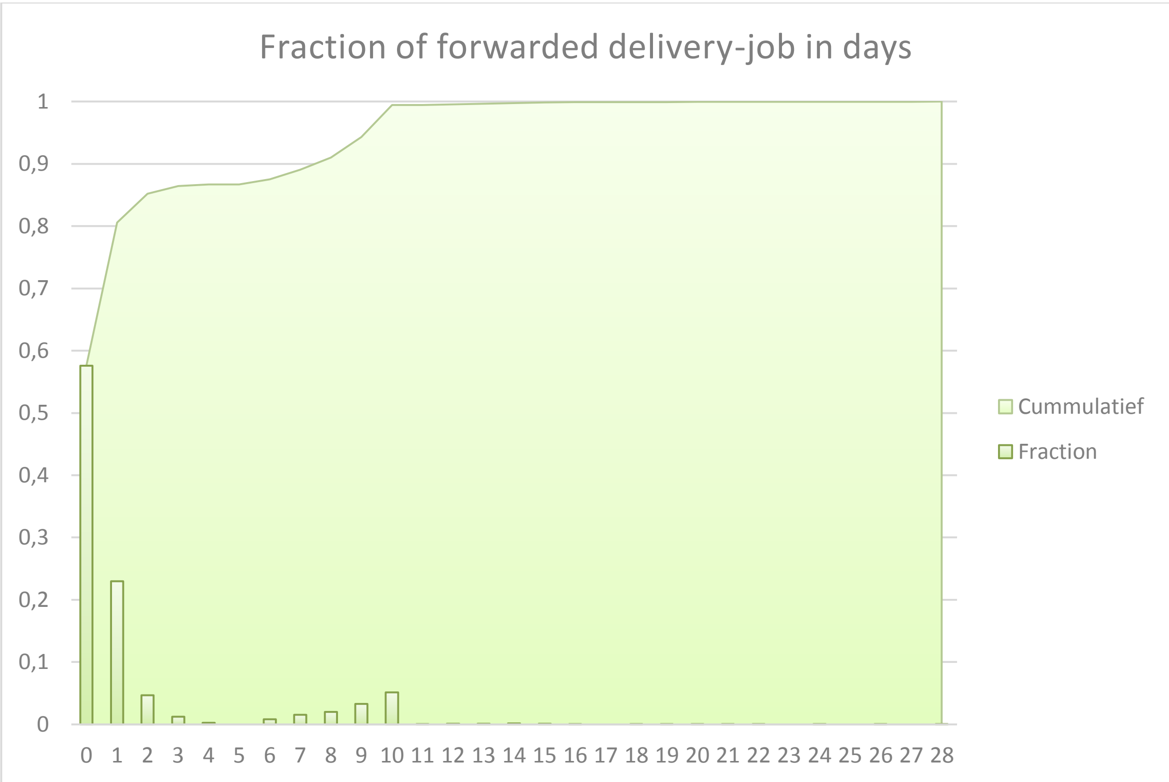


Table 1

	Day	Monday(0)	Thursday(1)	Wednesday(2)	Thursday(3)	Friday(4)	Saturday(5)
2012	Mean	187,38	198,06	205,64	195,00	171,80	1,50
	Std Dev.	29,84	22,66	26,50	25,66	23,75	3,58
2013	mean	232,98	243,78	236,98	228,66	213,58	2,13
	Std Dev.	28,43	44,22	28,58	39,61	35,04	4,46
Delta	*Mean*	*45,60*	*45,72*	*31,34*	*33,66*	*41,78*	*0,63*
	Std Dev.	*-1,41*	*21,56*	*2,08*	*13,95*	*11,29*	*0,88*

Table 2 Table 3

2012	max	min	range	step
	267	115	152	9,5
Group	low	high	n<high(i)	n in group
1	115	124,5	3	3
2	124,5	134	4	1
3	134	143,5	9	5
4	143,5	153	23	14
5	153	162,5	40	17
6	162,5	172	67	27
7	172	181,5	92	25
8	181,5	191	124	32
9	191	200,5	146	22
10	200,5	210	170	24
11	210	219,5	202	32
12	219,5	229	224	22
13	229	238,5	235	11
14	238,5	248	242	7
15	248	257,5	243	1
16	257,5	267	245	2

2013	max	min	range	step
	311	148	163	10,87
Group	low	high	n<high(i)	n in group
1	148	158,9	2	2
2	158,9	169,7	6	4
3	169,7	180,6	11	5
4	180,6	191,5	21	10
5	191,5	202,3	32	11
6	202,3	213,2	57	25
7	213,2	224	79	22
8	224	234,9	105	26
9	234,9	245,8	139	34
10	245,8	256,7	166	27
11	256,7	267,5	191	25
12	267,5	278,4	201	10
13	278,4	289,3	210	9
14	289,3	300,1	214	4
15	300,1	311	218	4

Table 4

Table 5

Monday		Tuesday		Wednesday		Thursday		Friday	
Mean	233,72	Mean	243,78	Mean	237,89	Mean	229,53	Mean	214,10
Standard Deviation	28,67	Standard Deviation	44,72	Standard Deviation	29,24	Standard Deviation	40,04	Standard Deviation	35,23

Table 6

Table 7

WCA					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	4096796	-	-	365	1,61
2013	4774542	-	-	1045	1,85

Table 8

Balance					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	4087466,64	-	-	2054	1,82295
2013	4747874,95	-	-	4054	2,24817

Table 9

WCA + 2-Opt					
	Total KM	% per day	% of total	# too late	Average time per late container
2012	3643914	10,91%	11,05%	144	3,23
2013	4256311,33	10,89%	10,85%	543	2,9

Table 10

WCA + simulated annealing					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	3627102,60	11,30%	11,46%	117	3,71
2013	4223557,68	11,59%	11,54%	435	3,26

Table 11

Balance + 2-opt					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	3609244,50	11,41%	11,70%	650	3,235589
2013	4192077,50	12,15%	11,71%	1481	3,49

Table 12

Balance + simulated annealing					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	3585852,38	11,95%	12,27%	444	3,81
2013	4159066,60	12,79%	12,40%	1088	3,82

Table 13

CBS + 2-opt					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	3640262,8	9,75%	11,14%	2280	0,91
2013	4251276,4	9,19%	10,96%	2772	2,5

Table 14

CBS + simulated annealing					
	Total KM	% per day	% of total	# to late	Average time per late container
2012	3633440,7	9,89%	11,31%	412	0,36
2013	4207068,1	10,44%	11,89%	497	1,69

Table 15

	year	days	# vehicles	Var # vehicles	Start time	End time	Working window	Var time working	Ratio	Ratio Var
WCA + LS	2012	313	51,60	11,10	6,363	13,469	7,106	1,011	0,227	0,045
	2013	264	54,58	11,42	6,185	14,927	8,742	1,929	0,224	0,047
WCA + SA	2012	313	51,60	11,10	6,363	13,495	7,131	1,013	0,229	0,044
	2013	264	54,58	11,42	6,185	14,931	8,746	1,907	0,225	0,047
CBS+ LS	2012	313	42,97	8,82	5,851	14,327	8,475	1,167	0,250	0,049
	2013	264	49,12	12,04	5,777	15,450	9,673	1,566	0,232	0,050
CBS+ SA	2012	313	42,97	8,82	5,845	14,272	8,427	1,160	0,242	0,048
	2013	264	49,12	12,04	5,775	15,383	9,607	1,543	0,225	0,049
Bal + LS	2012	313	58,12	8,90	6,585	12,745	6,160	1,293	0,210	0,049
	2013	264	57,64	10,18	6,379	14,448	8,069	2,313	0,202	0,042
Bal + SA	2012	313	58,12	8,90	6,576	12,727	6,150	1,291	0,208	0,049
	2013	264	57,64	10,18	6,376	14,422	8,046	2,295	0,200	0,041

Table 16

TW 10	Total KM	% reduction ave. day	% reduction year	# late	# late no TW
2012	3571297,36	12,68%	12,83%	29	2469
2013	4154910,59	13,08%	12,98%	181	2732
TW 20					
2012	3563242,88	12,87%	13,02%	32	4016
2013	4145207,26	13,29%	13,18%	150	4455
TW 30					
2012	3554528,70	13,08%	13,24%	25	5297
2013	4136598,48	13,46%	13,36%	110	5768
TW 40					
2012	3546399,52	13,27%	13,43%	24	6238
2013	4125907,48	13,68%	13,59%	97	6716
TW 50					
2012	3542477,45	13,36%	13,53%	19	7007
2013	4118267,24	13,83%	13,75%	72	7513
TW 60					
2012	3530866,89	13,64%	13,81%	18	7740
2013	4104004,23	14,13%	14,04%	61	8251

Table 17

TW	year	days	#trucks	var	Start time	End time	Working window	var time working	Ratio	Ratio var
10	2012	313	51,597	11,095	6,266	13,277	7,011	0,994	0,210	0,044
	2013	264	54,580	11,420	6,051	14,652	8,601	1,891	0,203	0,048
20	2012	313	51,597	11,095	6,301	13,301	7,000	0,992	0,207	0,043
	2013	264	54,580	11,420	6,092	14,678	8,586	1,888	0,201	0,047
30	2012	313	51,597	11,095	6,374	13,363	6,989	0,993	0,204	0,043

	2013	264	54,580	11,420	6,139	14,711	8,573	1,882	0,198	0,048
40	2012	313	51,597	11,095	6,410	13,388	6,978	0,986	0,203	0,043
	2013	264	54,580	11,420	6,172	14,730	8,558	1,878	0,196	0,048
50	2012	313	51,597	11,095	6,466	13,437	6,971	0,984	0,201	0,044
	2013	264	54,580	11,420	6,214	14,760	8,546	1,873	0,195	0,048
60	2012	313	51,597	11,095	6,525	13,480	6,955	0,982	0,198	0,043
	2013	264	54,580	11,420	6,268	14,794	8,526	1,869	0,191	0,048

Table 18

Run	Total KM	# containers	Ave. KM per day	# too late	Ave. time per late container
2013	4774542	49660	18223,44	1045	1,85

Table 19

Sample baseline					
Run	**Total KM**	**# containers**	**Ave. KM per day**	**# too late**	**Ave. time per late container**
0	5985210,3	59321	18880,79	2650	1,67
1	5938355,2	59081	18732,98	2541	1,66
2	5940058,5	59150	18738,35	2401	1,7
3	5912427	59024	18651,19	2519	1,67
4	5955296	59440	18786,42	2527	1,63

Table 20

Sampled data + 2 opt						
Run	**Total KM**	**# containers**	**Ave. KM p/d**	**reduction**	**# late**	**ave. Late time**
0	5299859,19	59321	16666,22	11,45%	1363	2,58
1	5256308,20	59081	16529,27	11,49%	1268	2,58
2	5251045,02	59150	16512,72	11,60%	1147	2,72
3	5245404,42	59024	16494,98	11,28%	1202	2,71
4	5289004,33	59440	16632,09	11,19%	1278	2,54

Table 21

Run	days	#vehicles	Var.	Start time	End time	Working window	Var. time working	Ratio	Ratio var.
1	291	58,178	6,961	6,255	14,979	8,724	0,859	0,215	0,043
2	289	57,703	8,215	6,268	14,960	8,692	1,027	0,218	0,057
3	288	58,000	8,115	6,362	15,033	8,672	1,100	0,225	0,071
4	289	57,970	8,153	6,262	14,865	8,602	0,990	0,219	0,053
5	288	58,958	3,931	6,242	14,900	8,659	0,953	0,216	0,037

Table 22

Seed	container growth	Methodology	Total KM	# containers	reduction	# late	% to late	average late	Increase KM
111	1,1	Const	6563284,73	52299	0%	4081	8%	1,65	1,10
111	1,1	2-opt	5807539,49	52299	12%	2189	4%	2,49	

111	1,1	SA	5769663,78	52299	12%	1765	3%	2,84	
111	1,2	Const	7159652,91	56934	0%	6944	12%	1,46	1,20
111	1,2	2-opt	6357344,24	56934	11%	4141	7%	2,05	
111	1,2	SA	6311592,19	56934	12%	3481	6%	2,28	
111	1,3	Const	7788257,05	61901	0%	10317	17%	1,36	1,31
111	1,3	2-opt	6977756,35	61901	10%	7383	12%	1,79	
111	1,3	SA	6932458,63	61901	11%	6576	11%	1,68	
211	1,1	Const	6505504,28	51737	0%	4031	8%	1,54	1,09
211	1,1	2-opt	5749274,45	51737	12%	2050	4%	2,4	
211	1,1	SA	5702645,01	51737	12%	1571	3%	2,83	
211	1,2	Const	7100187,34	56540	0%	7947	14%	1,3	1,19
211	1,2	2-opt	6305292,42	56540	11%	5218	9%	1,69	
211	1,2	SA	6263830,11	56540	12%	3884	7%	2,1	
211	1,3	Const	7661575,14	61106	0%	10817	18%	1,33	1,29
211	1,3	2-opt	6842395,97	61106	11%	7587	12%	1,67	
211	1,3	SA	6798176,98	61106	11%	6744	11%	1,79	

Table 23

2-Opt			
	2012		
	WCA	Balance equal	CBS
Total km	3643914	3609245	3640263
% per day	10,91%	11,41%	9,75%
% of total	11,05%	11,70%	11,14%
# to late	144	650	2280
Average time per late container	3,23	3,235589	0,91
	2013		
	WCA	Balance equal	CBS
Total km	4256311	4192078	4251276
% per day	10,89%	12,15%	9,19%
% of total	10,85%	11,71%	10,96%

# to late	543	1481	2772
Average time per late container	2,9	3,49	2,5

Table 24

Simulated annealing			
	2012		
	WCA	Balance equal	CBS
Total km	3627103	3585852	3633441
% per day	11,30%	11,95%	9,89%
% of total	11,46%	12,27%	11,31%
# to late	117	444	412
Average time per late container	3,71	3,81	0,36
	2013		
	WCA	Balance equal	CBS
Total km	4223558	4159067	4207068
% per day	11,59%	12,79%	10,44%
% of total	11,54%	12,40%	11,89%
# to late	435	1088	497
Average time per late container	3,26	3,82	1,69