

MASTER

Hinterland container supply chain optimization from an export consignee perspective

van der Pluijm, P.

Award date:
2014

[Link to publication](#)

Disclaimer

This document contains a student thesis (bachelor's or master's), as authored by a student at Eindhoven University of Technology. Student theses are made available in the TU/e repository upon obtaining the required degree. The grade received is not published on the document as presented in the repository. The required complexity or quality of research of student theses may vary by program, and the required minimum study period may vary in duration.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain

Eindhoven, June 2014

**Hinterland container supply
chain optimization from an
export consignee perspective**

by
Patrick van der Pluijm

BSc Industrial Engineering – TU/e

Student identity number 0682668

in partial fulfillment of the requirements for the degree of

Master of Science

in Operations Management and Logistics

University supervisors:

Dr. Ir. H.P.G. van Ooijen, TU/e, OPAC

Dr. Y. Bouchery, TU/e, OPAC

Company supervisor:

Ton van den Oetelaar, VION Food Group

Abstract

This master thesis develops a set of guidelines for hinterland supply chain optimization from an export consignee perspective. Hinterland optimization is proposed in threefold. First, considering a long term perspective, the (intermodal) transport network should be designed by selecting hubs. This is done by developing a qualitative p-hub problem. Second, the short term perspective consists of optimizing the planning schedule. We developed an intermodal vehicle routing problem with extensions to detention and demurrage (IVRPDD) to plan the transportation towards a port. A simple solution method is developed based on insights gained by solving the IVRPDD problem. Third, synchronization of import and export flows is proposed as a novel idea to reduce empty containers distances. The concept of synchronization is presented and a method for allocating benefits and convincing other consignees to collaborate is proposed. The set of guidelines is validated by a case study at VION Food Group to show the applicability of the guidelines and the benefits which arise from using the guidelines.

Keywords: Transport, containers, export, optimization, collaboration, detention and demurrage.

Management summary

In this thesis, we developed a set of guidelines for hinterland supply chain optimization from an export consignee perspective. We developed:

- A qualitative p-hub problem for the long term perspective of selecting hubs;
- An intermodal vehicle routing problem extended with detention and demurrage (IVRPDD) for the short term perspective of planning cargo flows;
- A solution method for this planning problem, referred to as the “Forward Earliest Detention Date” method to minimize detention and demurrage cost;
- The concept of synchronization which leads to a reduction in empty container distance (ECD) which is even greater than using empty depots.

We developed a qualitative p-hub problem which selects hubs from a set of potential hubs. The qualitative p-hub problem integrates quantitative measures and qualitative measures in order to create a better solution. Using the qualitative p-hub problem is shown to be:

- A straightforward way to select partners for the hinterland supply chain;
- Time-consuming. The process should not be underestimated since a long-term solution is created.
- A useful tool to create savings in terms of cost (~6%) , emissions (~19%), complexity and risk.

An intermodal vehicle routing problem was extended with detention and demurrage (D&D) to plan cargo flows. Detention refers to the amount of days a consignee can hold on to a container without additional charges. Demurrage refers to the amount of days a container can arrive at the port before the departure of the sea vessel without additional charges. This results into a penalty-free period, as shown in Figure 1.

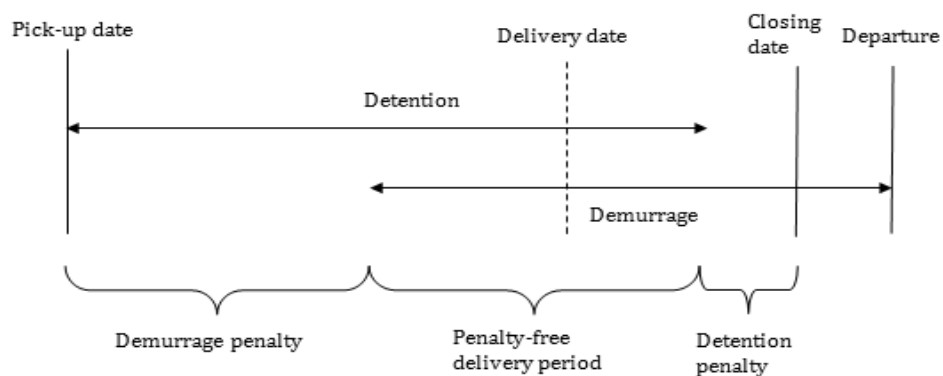


Figure 1: Detention and demurrage (D&D)

D&D cost can range up to €100,- per day per container and to 10% of total cost. Therefore, it is very important to include detention and demurrage in the planning decision. The developed intermodal vehicle routing problem with detention and demurrage (IVRPDD) showed that:

- The height of the D&D charges influences the decision whether to use intermodal transport or direct shipments;
- The amount of D&D days influences the decision whether to use intermodal transport or direct shipments;
- If inventory cost > inventory in transit cost, D&D influence the timing of transporting the containers.

Intermodal transportation is considered to be beneficial for consignees with at least 5 free detention days and 3 demurrage days due to the longer transit time of intermodal transport and the limited amount of departures of modes towards a port. D&D cost can be reduced by a smart way of planning. We developed a “Forward Earliest Detention Date” method to plan the cargo flows.

A new concept, referred to as synchronization was developed. Synchronization bundles import and export flows directly between consignees to minimize empty container distances, resulting in a round trip. Empty container distance is seen as an indicator for empty container transportation cost, which is perceived unnecessary cost. Synchronization is considered in the situation where consignees use intermodal transportation and where consignees use direct shipment. Figure 2 shows the situation where an importer and an exporter use the same terminal.

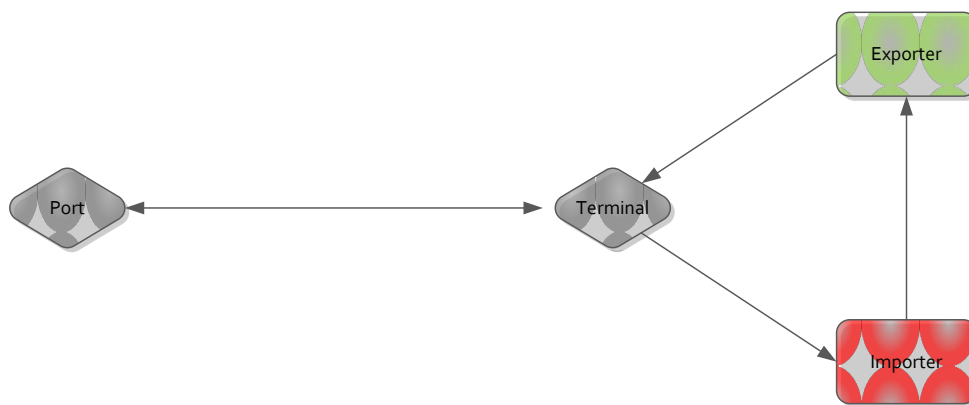


Figure 2: Synchronization

Synchronization proves more beneficial when:

- Hubs are used which don't provide empty depot services;
- Import/export flows are of a similar amount;
- Distances between importers and exporters are small.

Preface

The master thesis is the result of my graduation project for the Master of Science program in Operations Management and Logistics at the University of Technology, Eindhoven. The project has been performed at VION Food Group.

From the University, I would like to thank my first supervisor, Henny van Ooijen, for his help and guidance. He really helped in structuring the project, making it a scientific master thesis. Also, my second supervisor Yann Bouchery helped me a lot by discussing different modeling issues and the structure of the thesis.

From VION Food Group, I would like to thank my supervisor, Ton van den Oetelaar, for giving me consignee specific insights and making me familiar with VION. He also accompanied me in trips towards different inland hubs. Discussions and comments gave me a better view on practical issues. This helped me in combining theory and practice. Also, Susan van Donselaar and Jordy van de Korput helped me in my day-to-day work and made it pleasant to work at VION Food Group.

During this project I got a lot of support from my girlfriend, for which I'm very grateful.

Patrick van der Pluijm

June 2014

Content

Management summary	iii
Preface.....	vi
1. Introduction.....	1
2. Assignment.....	3
2.1 Literature review	3
2.2 Literature gaps.....	4
2.3 Research questions	5
3. Hub selection.....	6
3.1 p-hub problem.....	7
3.1.1 Solving the p-hub problem.....	8
3.1.2 Shortcomings.....	11
3.2 Qualitative measurements	11
3.2.1 Relevant factors.....	11
3.2.2 Consensus based selection.....	13
3.2.3 Shortcomings.....	15
3.3 New Approach: Qualitative p-hub problem	16
3.4 Pareto Efficiency.....	17
3.5 Summary	18
4. Planning schedule.....	19
4.1 Set-up Model	20
4.1.1 Routing	20
4.1.2 Scheduled services	20
4.1.3 Cost.....	22
4.2 Model formulation	26
4.3 Solution methods	28
4.3.1 Alternative methods.....	29
4.4 Influence detention and demurrage	30
4.5 Summary	31
5. Synchronization	32
5.1 Description	33
5.1.1 - 1 Exporter, 1 Importer, 1 hub	33
5.1.2 - N Importers, M Exporters, P hubs.....	34
5.2 Convincing potential partners	36
5.2.1 Benefits.....	36
5.2.2 Allocation.....	37
5.2.3 Collaboration plan	40
5.3 Challenges	40

5.4	Summary	41
6.	Case study – Vion Food Group	42
6.1	Hub selection	42
6.1.1	Qualitative p-hub problem	43
6.1.2.	Initial solution	46
6.1.3.	Sensitivity analysis	47
6.1.4.	End Result	48
6.2	Planning schedule	49
6.2.1	Situation VION Food Group	49
6.2.2	Solution method	49
6.3	Synchronization	51
6.4	Summary	51
7.	Conclusions and recommendations	52
7.1.	Conclusions	52
7.2.	Recommendations	53
7.2.1	Consignees	53
7.2.2.	Future research	54
	Bibliography	56
	Appendix A	60
	Appendix B	61
	Appendix C	62
	Appendix D	64
	Figure 1: Detention and demurrage (D&D)	iv
	Figure 2: Synchronization	v
	Figure 3: Detention and demurrage	1
	Figure 4: Intermodal transport (Veenstra & Zuidwijk, 2011)	2
	Figure 5: Genetic algorithm (Lin, Lee, & Hong, 2003)	9
	Figure 6: Relevant factors	13
	Figure 7: Two-criteria consensus model (Vannieuwenhuysse, Gelders, & Pintelon, 2003)	13
	Figure 8: Pareto Efficiency	18
	Figure 9: Synchronization import/export flows	33
	Figure 10: D&D Synchronization	41
	Figure 11: Relevant selection factors - VION Food Group	45
	Figure 12: Overall Solution	47
	Figure 13: Risk-Cost-Emissions-Complexity scenarios	47
	Figure 14: Weak - Strong scenarios	48
	Figure 15: End Result – Selected hubs	48
	Figure 16: Forward Detention Date method	50

Table 1: Verification model	28
Table 2: Example characteristic function	37
Table 3: Glove game example	39
Table 4: Marginal contributions	39
Table 5: Proposed parameter values	46
Table 6: Earliest Detention Day Example	50
Table 7: Example Shipping day	64

1. Introduction

VION Food Group is one of the larger food companies in the Netherlands and is represented all over the world (VION Food Group, 2014). VION Food Group is a consignee: an owner of goods, who leases empty containers (or reefers) from a carrier and subcontracts a hub operating company to transport them between the location of the consignee and the final destination of freight within the predefined time interval (Sharypova, 2014). This thesis will consider the pork division of VION Food Group. Pork is frozen and stored at several cold stores across the Netherlands, resulting into the fact that the pork meat has to travel via these cold stores. Certifications for exporting pork drives the allocation of product to these stores. From the colds stores, the meat is transported to the port of Rotterdam with the use of 40 ft. reefer containers. Yearly, 4500 40 ft. reefer containers containing frozen pork are exported to all over the world. Since reefers are very expensive, VION Food Group leases them from carriers. In negotiations with such carriers, detention and demurrage lengths are set. Detention refers to the amount of time containers can be held on to by the consignee. Demurrage refers to the amount of time that is available to store a container at a port before departure. The combination of detention and demurrage results into a penalty-free delivery time-window when the pick-up date is set. Detention and demurrage can result into high additional costs.

VION Food Group triggered this project by stating that their transport towards the port of Rotterdam is both expensive as non-insightful. Additional detention and demurrage costs arise from planning problems. Detention refers to the amount of days a consignee can hold on to a container without additional charges. Demurrage refers to the amount of days a container can arrive at the port before the departure of the sea vessel without additional charges. This result into a penalty free delivery period, as can be seen in Figure 3.

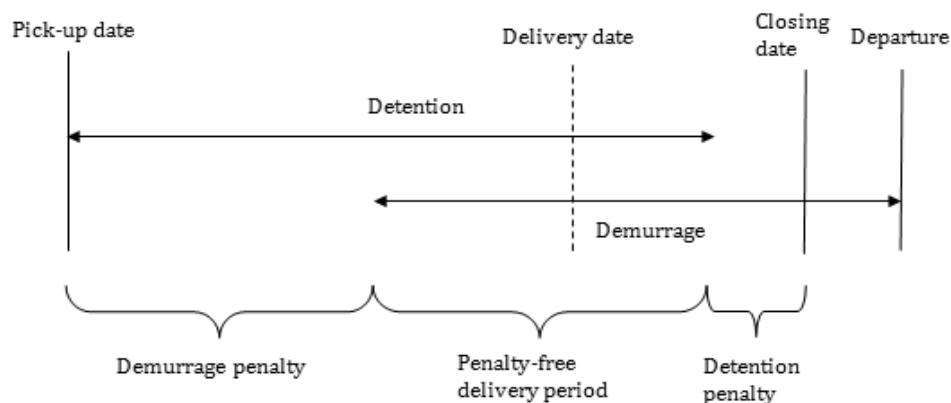


Figure 3: Detention and demurrage

The transportation is also considered expensive due to the high amount of empty-container kilometers.

VION Food Group is aware of possibilities regarding intermodal transportation (Figure 4). Intermodal transport is defined as: “Movement of containerized (unitized) cargo over air, land, or sea through the use of different transport modes (aircraft, truck, rail, boats, ships, barges, etc.) capable of handling containers” (BusinessDictionary, 2014).

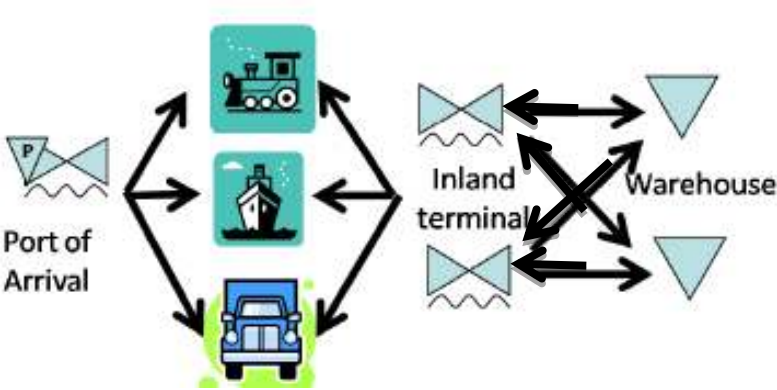


Figure 4: Intermodal transport (Veenstra & Zuidwijk, 2011)

Intermodal container-based transportation has grown very fast over the last decades, driven by a general expansion in intercontinental transport resulting from the growth in world trade (Sharypova, 2014). Research has concentrated on port operations and maritime transportation (Horst & Langen, 2008). Network development has been studied significantly, but using this network to optimize the network from a consignee perspective has received less attention (Konings, Kreuzberg, & Maras, 2013).

Inland terminals (or hubs) are part of the intermodal hinterland network since these are used to transfer containers from a truck to another mode. Transport modes (other than truck) transport a large amount of containers at once, resulting into economies of scale. Economies of scale reduce cost and emissions. However, especially on short distances, it is uncertain whether the economies of scale cost reduction outweighs the additional handling charges and increase in inventory in transit cost (Sharypova, 2014). Intermodal transportation increases throughput times and thus risk in terms of time and quality. Container transportation deals with high-value loadings, which incur high risk whenever not transported properly due to the nature of the product.

The problem of VION Food Group is defined as: “an export consignee optimization of the hinterland supply chain problem”. A consignee isn’t able to change the network by setting up inland hubs, but has to use the current network. Usually, in a container freight transportation system, consignees are not located in the vicinity of a container hub, so trucking is required to move containers between the hub and a consignee (Sharypova, 2014). From the hub, high-volume, low-emissions modes can be used to travel the cargo to the final destination, which in this thesis will be a port.

2. Assignment

VION Food Group triggered this project by stating that their transport towards the port of Rotterdam is both expensive as non-insightful. Additional costs arise due to the lack of insight in operations at external parties. External parties include cold stores which are used by VION for storing frozen meat and have capacity restrictions regarding the filling of reefers. This results into planning problems and a lot of detention and demurrage cost, ranging up to €100.000,- a year. The transportation towards the port of Rotterdam is also considered expensive due to the high amount of empty-container kilometers. Reefers are mostly stored at the port of Rotterdam and transported empty to the cold stores. This is perceived to be a costly operation and the main cause of the high cost. Transporting containers towards a port is referred to as the export hinterland supply chain.

2.1 Literature review

In literature, export hinterland supply chain optimization from a consignee perspective has received less attention than the port perspective (Veenstra & Zuidwijk, 2011). Although optimizing the hinterland supply chain from a port perspective benefits consignees as well, deciding on how to use the network from a consignee perspective is a different problem. Consignees don't design the network, they use it.

From a strategic, long-term perspective, hubs should be selected for a multiple year collaboration. In practice, changing hub use can't be done regularly due to the need of agreements and commitment. In literature, selecting which hubs to use is mostly done by setting up a p-hub median problem. P-hub median problems have gained quite some attention in literature due to the increasing amount of intermodal transportation (Campbell & O'Kelly, 2012). Most p-hub median problems use average demand flows and cost to differentiate transportation modes and propose a discount factor for cargo transported via hubs, making it a more efficient way of transportation.

From an operational, short term perspective, planning intermodal container transport is relevant regarding the optimization of the export hinterland supply chain. In a dynamic situation, a decision on whether to use intermodal transport or direct shipments is based on several factors, such as the amount of orders and detention and demurrage. Intermodal vehicle routing problems have received a considerable amount of attention in literature. For example, Ayar & Yaman (2012) propose a model using scheduled services to plan intermodal transport at an operational level (Ayar & Yaman, 2012).

Another challenge in hinterland supply chain management is the management of empty-container transportation (Kelleher, El-Rhalibi, & Arshad, 2003). Empty-container transportation results into high costs, which is perceived unnecessary. Empty-container depots and extended gates are proposed in literature to handle empty-containers more efficiently.

Empty-container depots store empty containers to position them closer to the consignees. They often use intermodal transportation for more efficient transport of empty containers towards and from a port by using economies of scale (Veenstra, Zuidwijk, & Asperen, 2012). Extended gates are defined as “an inland intermodal hub directly connected to seaport hub(s) with high capacity transport mean(s), where customers can leave or pick up their containers as if directly to a seaport, and where the seaport hub can choose to control the flow of containers to and from the inland hub” (Veenstra, Zuidwijk, & Asperen, 2012). Extended gates manage the flow between hubs and ports, which ultimately leads to more efficient handling of empty-containers by increasing the load degree of the used modes (Mittal, Boile, Baveja, & Theofanis, 2013).

2.2 Literature gaps

As mentioned before, hinterland supply chain optimization from an export consignee perspective has received less attention than the port perspective (Veenstra & Zuidwijk, 2011). Selecting which hubs to use is, in literature, mostly done by setting up a p-hub median problem. However, this problem often doesn't incur qualitative issues. In most supply chains, cost isn't the only relevant factor, especially when considering the long term perspective. Integrating qualitative measures such as risk and complexity in the p-hub median problem could make the problem more applicable for a consignee and result into better solutions.

Container specific issues like detention and demurrage are often not incorporated in intermodal vehicle routing problems in literature. Detention and demurrage penalties can result into a lot of additional cost which could make an existing intermodal transport model result into non-optimal solutions for container transport.

Empty-container depots and extended gates are proposed in literature to deal with empty-containers more efficiently. However, consignees could also collaborate with each other directly in order to minimize empty container kilometers.

The literature gaps can be summarized as follows:

- Long term consignee perspective on hub selection lacks qualitative criteria;
- Detention and demurrage are not included intermodal vehicle routing problems;
- Direct consignee collaborations regarding empty container kilometer minimization is missing.

2.3 Research questions

The assignment of this thesis is to guide a consignee in the optimization process of their hinterland supply chain. The goal of this thesis is to develop applicable guidelines based on theory. The assignment is defined as follows:

- Develop guidelines which an export consignee can use to optimize their hinterland supply chain.

The assignment is translated into the following main question:

- How can an export consignee optimize their hinterland container supply chain?

From the literature gaps, it is shown that there is need for integrating qualitative measures into the long term hub selection from an export consignee perspective. Extending the planning of cargo flows with detention and demurrage will benefit the consignees short term planning processes. Regarding direct collaboration between consignees, we develop the concept of synchronization. Synchronization refers to a novel concept which consists of transporting empty containers from an importing consignee towards an exporting consignee directly resulting in a round trip in order to minimize empty containers distances.

These problems are not independent but will be treated sequentially. This is due to the time perspective of the decisions. Selecting hubs is a strategic, long term decision, since changing hubs can't be done regularly in reality. Planning cargo flows is an operational, short term decision. The concept of synchronizing import-and export flows is developed third, since it is a novel concept which should first be explained and investigated before implemented into the planning process.

The related sub questions are:

- How can a consignee select hubs based on quantitative and qualitative measures?
- Given a set of hubs, how can a consignee optimize their planning schedule?
- What benefits arise from synchronization and how can a consignee use it?

These questions will be answered in a dedicated chapter. Chapter 3 will consider hub selection. Chapter 4 consists of a vehicle routing problem which can be used to optimize the planning schedule. Chapter 5 will look at synchronizing import and export flows. Together, chapter 3,4 and 5 will answer the main question and form the solution to the assignment. Chapter 6 will consist of a case study at VION Food Group to show the applicability of the developed guidelines. Chapter 7 will summarize the results, conclude how the guidelines should be used by an export consignee and will look at future research directions.

3. Hub selection

This chapter will address the long term decision in optimizing the intermodal hinterland supply chain from an export consignee perspective; hub selection. Hubs are used in an intermodal network to transfer containers between different modes. In this case, hubs transfer containers from a truck to another mode and use this mode to transport the cargo to the final destination.

Hub selection from a consignee perspective can be seen as network design. This decision is perceived to be a long term decision since agreements with hub operators normally last for at least 1 or 2 years. Given a set of possible locations, a consignee needs to “design” their network by selecting which hubs to use. This decision should be reviewed at the end of the agreement and the guidelines developed in this chapter can also be used for this review.

Optimizing an intermodal transport network from a consignee perspective is a different issue than from a port perspective. Ports will try to locate inland hubs on strategic locations. Consignees can only “design” their network by selecting existing hubs which can assist in the transportation towards the final destination. Consignees use the hinterland network which ports and hub operating companies have designed. It is assumed that the network is sufficiently developed to use it independently from volumes.

The question which will be answered in this chapter is:

- How can an export consignee select hubs based on quantitative and qualitative measures?

Literature proposes to use a p-hub median problem for network design. The p-hub median problem addresses a class of hub location problems in which all hubs are interconnected and each non-hub node is assigned to a single hub (Abdinnour-Helm, 2000). A p-hub median problem routes demand flows between origin-destination (OD) pairs potentially via hubs, assuming there is a benefit of routing flows via hubs. Minimization of transportation cost is the goal of most p-hub problems (Campbell & O'Kelly, 2012).

A p-hub problem which alters the p-hub median problem such that it is more applicable for the considered situation is set up in section 3.1. Section 3.1.1. will propose a solution algorithm and 3.1.2 will discuss shortcomings of this model. Section 3.2 will look at a qualitative consensus based model to mitigate the shortcomings of the original p-hub problem regarding hub selection from a consignee perspective. Section 3.3 will integrate the qualitative part and the p-hub problem into a “qualitative p-hub problem”. Combining the quantitative model of section 3.1 and the qualitative section of 3.2. will mitigate the shortcomings of the both approaches. Section 3.4 will discuss creating different scenarios based on Pareto Efficiency and section 3.5 will summarize the chapter.

3.1 p-hub problem

This section will alter the original p-hub median problem in order to create a problem which can be used by an export consignee. The original p-hub median problem is defined as: “given a set of demands (flows for origin-destination pairs), locate p-hub facilities at candidate sites to minimize the total transportation cost to serve the demand” (Campbell & O’Kelly, 2012). This problem assumes the following (Abdinnour-Helm, 2000):

- The number of hubs (p) is set a priori;
- There is no limit on the number of origins assigned to a hub;
- Each origin is assigned to a single hub;
- All hubs are interconnected.

Assuming the number of hubs is set a priori is done to make the problem smaller (Campbell & O’Kelly, 2012). However, using “at most” p hubs constraints will result into an equal or better solution, since the solution space would contain of the same and more solutions. If for example, $p \leq 4$, a solution with three hubs is still considered and could be better solution. Therefore, it is proposed to relax the assumption of setting the number of hubs is a priori. Also, In reality, not all hubs are interconnected. Most of the time, all hubs are connected with the final destination directly. This is assumed instead of the interconnectivity of all hubs. Assuming that there is no limit on the number of origins assigned to a hub and that each origin is assigned to a single hub is proposed to be done for the p-hub problem too. Empty container transportation is not considered, since it is assumed to have no effect on the decision. The following assumptions are made:

- There is no limit on the number of origins assigned to a hub;
- Each origin is assigned to a single hub;
- All hubs are connected with the final destination;
- Empty containers transportation doesn’t affect the long term hub selection decision.

To set up the p-hub problem, the following variables are defined. s_w is defined as the supply of origin w . z_{wt} denotes 1 if origin w uses hub t . Note that deciding which hub to use (or none by selecting $t=0$) per origin is the only decision in this problem. z_t denotes 1 if hub t is used by at least one origin. c_{wt} is defined as the cost for transporting one unit from origin w to hub t . c_{tp} is defined as the cost for transporting one unit from hub t to port p . α is defined as the discount factor for traveling via hubs. This discount factor gives a economies of scale benefit to intermodal transportation, which models the benefit of using hubs. The goal is to minimize the total transportation cost, with a limited amount of hubs.

The p-hub problem is as follows:

Minimize

$$\sum_{w,t,p} s_w (z_{wt} * (c_{wt} + \alpha c_{tp})) \quad (3.1)$$

Subject to

$$\sum_t z_{wt} = 1 \quad \forall w \in W \quad (3.2)$$

$$z_{wt} \leq z_t \quad \forall w \in W, \forall t \in T \quad (3.3)$$

$$\sum_t z_t \leq p \quad (3.4)$$

$$z_t, z_{wt} \in \{0,1\} \quad \forall w \in W, \forall t \in T \quad (3.5)$$

$$p \geq 1 \quad (3.6)$$

$$s_w, c_{wt}, c_{tp}, \alpha \geq 0 \quad (3.7)$$

Objective function (3.1) denotes the total cost, in which the supply of origin w travels via hub t to port p . Note that it is also possible to use direct shipments by inserting that $t = 0$ denotes a direct shipment. Constraints (3.2) make sure that each origin has a hub or a direct shipment allocated to it, making sure that the supply reaches the port. Constraint (3.3) make sure that a hub can only be allocated to an origin when it is used and constraints (3.4) make sure that at most p hubs are used. Note that when inserting direct shipments, this is also seen as a hub. This result into the fact that $p \geq 1$, as shown in constraint (3.6). Constraints (3.7) result into non-negative parameters.

The original p-hub median problem is proved to be NP-hard (Campbell & O'Kelly, 2012). Since it is proposed to use a “maximum” constraint instead of an “exact” constraint for the amount of hubs, the p-hub problem is considered to be even harder. Therefore, it is assumed that the p-hub problem stated in (3.1)-(3.7) is also NP-hard. For this reason, an approximate algorithm to solve the p-hub problem is proposed in section 3.1.1.

3.1.1 Solving the p-hub problem

Different solution algorithms for solving the p-hub median problem are proposed in literature. Sangsawang & Chanta (2012) consider an “Artificial Bee Colony” algorithm for solving the p-hub median problem (Sangsawang & Chanta, 2012). They propose to create neighborhood solutions by swapping nodes using random keys. This swapping doesn't contain the decision of the amount of hubs to use, making it not applicable to the developed p-hub problem, since the amount of hubs which can be used is not fixed in the p-hub problem. This issue arises when looking at a lot of algorithms. Therefore, another approach has to be found.

Using genetic algorithms to solve the p-hub median problem is proposed by Stanimirovic (2010) (Stanimirovic, 2010). Genetic algorithms start with a solution set (population) and uses a “fitness” function (selection) and different operators (cross-over and mutation) to create a new population, as shown in Figure 5 (Lin, Lee, & Hong, 2003). A more elaborate explanation can be found in Appendix A.

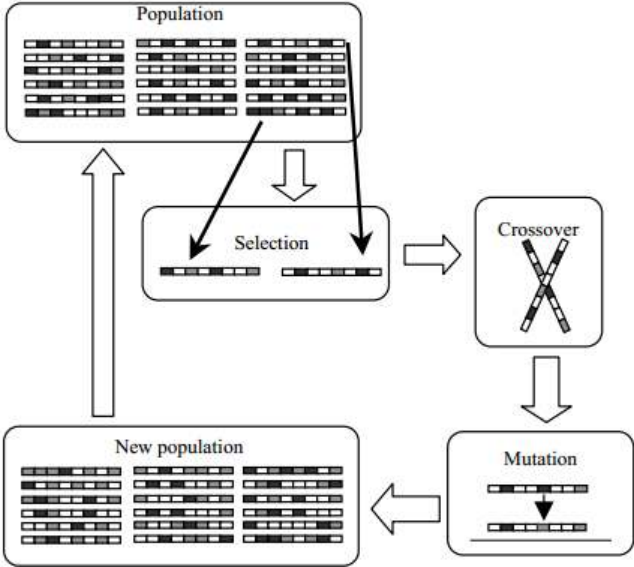


Figure 5: Genetic algorithm (Lin, Lee, & Hong, 2003)

Genetic algorithms are also applicable to the p-hub problem. Relaxing the assumptions will not create problems for the applicability of the genetic algorithms. Interconnectivity is not an issue in this problem and using a bit array doesn't need the assumption of a fixed amount of hubs. Encoding possible solutions into a bit array (or chromosome) is relatively easy, since the decision which hubs to use is the only issue in the problem. Consider the situation where locations 1-4 are origins and 5-8 are hubs. The only decision is to decide which hubs the origins will use. This can be done by having 4 bits per origin. For example, 0001 denotes that an origin uses hub 8 and 0010 denotes that the origin uses hub 7. When only 4 origins and 4 hubs are considered, this leads to a $4 \times 4 = 16$ bit array. For example, 0100|1000|0001|0001 denotes the solution where origin 1 uses hub 6, origin 2 uses hub 5 and origin 3 and 4 use hub 8. Note that hub 7 is not allocated. Therefore, genetic algorithms can also provide a solution for the situation where the maximum amount of hubs is fixed and thus make it applicable to the developed p-hub problem.

For this example, enumerating on all possibilities is not too hard, but adding an origin would lead to an addition of 4 bits, and adding a hub would lead to an additional bit for each origin. Generally, when M hubs and N origins are considered, a bit array of $M \times N$ bits is needed to evaluate the possibilities.

To start the algorithm, the fitness function consists of the relative cost of the solution compared to the average cost of the genetic representation. TC_s is defined as the total cost of solution s , the fitness of solution s is denoted by F_s and L denotes the set of solutions in the genetic representation (population) of the solution domain, consisting of N solutions. The genetic representation consists of a subset of the possible solutions. The fitness of solution s (F_s) is then calculated as follows (Stanimirovic, 2010):

$$F_s = \frac{TC_s}{\sum_{s \in L} TC_s / N}$$

This fitness function results into an evaluation of the genetic representation. The fitness function denotes the probability that a solution is selected (i.e. stays in the representation). This results into the fact that “weak” solutions are more likely to disappear from the representation.

After selecting solutions, mutations and cross-overs operations are proposed to occur on a fairly random basis. This is to create new solutions which may be better than the selected solutions. Mutation and cross-over rules can be altered to look at the effect of different settings. For cross-over operations, the cross-over point has a large impact. Magalhaes-Mendes (2013) showed that also the type of cross-over operators is relevant (Magalhaes-Mendes, 2013). Single cross-over, uniform cross-over and flat cross-over result in different type of solutions. Magalhaes-Mendes tested these crossover operators on a set of 50 standard instances taken from the literature and concluded that the single-crossover has the best results, followed by the uniform crossover operator (Magalhaes-Mendes, 2013). Therefore, it is proposed to use the single cross over. Typical cross-over points are at the middle.

Mutation-probabilities also have a large impact on the process. Greenwell et al (1995) investigated the optimal mutation probabilities to maximize the probability that the genetic algorithm end up with the optimal solution (Greenwell, Angus, & Finck, 1995). The optimal mutation probability is shown to depend on the length of the chromosome and the size of the population. Too high mutation rates reduce the search ability of genetic algorithms to a random walk while a too small mutation probability almost always gets stuck in a local optimum (ResearchGate, 2014).

After cross-over an mutation operations are carried out, a new genetic representation (generation) is created. The fitness function will again lead to a selection, which will delete “weak” solutions. The operations are carried out again and this process starts over, as shown in Figure 5. The trade-off in the setting the amount of generations is choosing between the computation time and the performance of the solution.

It is proposed to use the settings suggested by De Jong & Spears (DeJong & Spears, 1990). These settings are the de facto standard for most genetic algorithms (Scholand, 2014). De Jong & Spears have shown that this combination of parameters works better than many other parameter combinations for function optimization.

3.1.2 Shortcomings

An important limitation of the original p-hub median problems is the separation between the cost-oriented and service-oriented hub problems (Campbell & O'Kelly, 2012). The p-hub problem altered the p-hub median problem, but this limitation still occurs. The p-hub problem is cost-oriented. However, cost is not leading in hinterland transportation. Due to the long term decision and the high value of the cargo, service is as least as important. Only considering service however also results into problems. High service solutions could result into too high cost. A trade-off is needed in this type of transportation. Due to this shortcoming of the cost-oriented p-hub problem, relevant qualitative factors are identified to guide the qualitative process of optimizing the intermodal transportation network.

3.2 Qualitative measurements

Using qualitative measures is needed to mitigate the shortcomings of the p-hub problem as discussed in section 3.1.2. First, relevant selection factors are proposed in section 3.2.1 to guide the qualitative measure selection for selecting hubs from a consignee perspective. In 3.2.2, a consensus based model is proposed to translate the qualitative nature of the factors into a more quantitative nature.

The p-hub problem shown in section 3.1 is a quantitative model. This section regards the proposed factors as qualitative measures since objective, accurate information is hard to obtain regarding these issues. Cost information is not obtained easily from potential partners and emission information needs a lot of assumptions. A simulation could address the effect of risk, but this needs to assume information on break-downs and quality aspects. Qualitative measures are needed to estimate the amount of risk. Complexity is also considered a qualitative issue since no accurate, precise definition is at hand.

3.2.1 Relevant factors

To cope with the lack of qualitative measures in the cost-oriented p-hub problem presented in section 3.1, relevant factors are identified. Risk, emissions, cost and complexity are seen as important when considering hinterland supply chain transportation. Although these factors are very general, they can guide the decision process in ensuring which factors have to be addressed.

Risk is the dominant factor in the hub selection process. Risk is divided into time-related and quality related risk. Time-related risk concerns missing the closing date of a vessel at a port, which is very costly. Quality-related risk concerns the decrease in quality, which is costly due to the high value of the cargo. These risks should be identified for each mode of transportation and hub. Risk could also arise from a certain route a mode takes. The performance on these indicators should drive the decision process.

Emissions within a supply chain are becoming more and more relevant due to consumer pressure (The Guardian, 2011). Intermodal transportation is considered to be more sustainable due to efficient transportation by low-emission modes. In an intermodal transportation network, emission problems can be translated to transport-related emissions and handling-related emissions. Using different modes on different distances can alter the emissions, but also efficient handling at a hub reduces emissions of the network.

Cost is proposed to be a less dominant factor. Cost is divided into transport-related cost and time-related cost. Transport-related cost concerns the costs which are incurred for shipping a container from an origin to a port. Mostly, hub operating companies provide “total transportation cost”, by offering a price per container for the transportation via their hub. It could be possible that they also distinguish transport by using intermodal transport or by truck whenever intermodal transport is not possible due to time restrictions. Time-related cost arise due to detention and demurrage and inventory cost. Inventory cost arise due to possible earlier transshipments due to longer throughput times while using intermodal transportation.

An important trend regarding hinterland supply chain is that hubs make arrangements with carriers that lead to benefits regarding detention/demurrage cost. Some hubs already store a limited amount of containers (empty container depot) and/or have arrangements such that the detention period starts at the release at the hub instead of the port. This can have benefits regarding detention cost.

Complexity should receive attention since it interferes with the insight within the supply chain.. Decreasing complexity will make the solution more insightful, which benefits the supply chain (Martin, 2004).

Figure 6 shows the four relevant factors separately, but these can be related. Cost savings could for example lead to an increase in risk. The factors can be used to address important issues regarding hinterland transport separately. It can be seen that the amount of risk, emissions, cost and complexity should be minimized.



Figure 6: Relevant factors

To make a selection of hubs based on these qualitative measures, a consensus has to be made. A consensus model assigns weights to the qualitative measures and can deal with conflicting issues, making it a general applicable method. It can also be used for sensitivity analysis relatively easy.

3.2.2 Consensus based selection

Whenever the relevant factors are addressed, a consensus model is proposed to quantify the results in order to make a decision. These factors should be addressed to show which criteria will be used and what weights are assigned to these criteria. A consensus should be made between risk, emission, cost and complexity minimization (Figure 6). Vannieuwenhuysse et al (2003) propose a consensus model which measures the distance between an alternative and the ideal point (Vannieuwenhuysse, Gelders, & Pintelon, 2003). As an input, it is proposed to use criteria with weights to calculate this distance. The scores should be scored in a [0;1] range, with 0 being the worst score and 1 being the best score. Figure 7 shows a two-criteria example. This idea forms the basis for the consensus model.

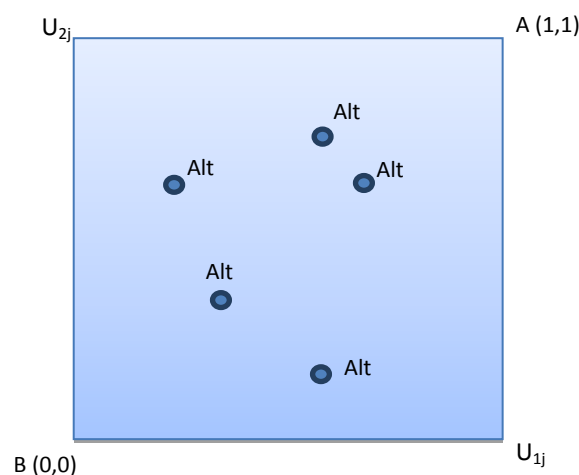


Figure 7: Two-criteria consensus model (Vannieuwenhuysse, Gelders, & Pintelon, 2003)

In Figure 7, it can't easily be seen which alternative performs best. Alternative 1 scores better on criteria 2, but worse than Alternative 2 on criteria 1. When using more criteria, drawing a similar figure is problematic. Therefore, the idea of the distance between a best point (A) is used. It is proposed to maximize an utility function. For this, the following variables are defined.

$$\begin{aligned}
 m &= \text{number of criteria} \\
 \lambda_i &= \text{normalized weight criteria } i \\
 u_{wti} &= \text{score on criteria } i \text{ for allocating hub } t \text{ to origin } w \\
 x &= \text{distance power}
 \end{aligned}$$

It is proposed to score the four factors (risk, cost, emissions and complexity) using different sub-topics on a [0,1) scale in order to achieve a total utility per option. Scoring should be done by someone who understands the procedure of calculating the utility in order to be able to understand what effect different scores have. After assigning weights to the criteria, the utility $U_{wt}(x)$ can be calculated by using formula (3.8) (Vannieuwenhuysse, Gelders, & Pintelon, 2003).

$$U_{wt}(x) = 1 - \left[\sum_{i=1}^m \lambda_i (1 - u_{wti})^x \right]^{\frac{1}{x}} \quad (3.8)$$

Since it is proposed to maximize the utility, the problem becomes:

Maximize

$$U_{wt}(x) = 1 - \left[\sum_{i=1}^m \lambda_i (1 - u_{wti})^x \right]^{\frac{1}{x}} \quad (3.9)$$

Subject to

$$\sum_{i=1}^m \lambda_i = 1 \quad (3.10)$$

$$m, \lambda_i \geq 0 \quad (3.11)$$

$$0 \leq u_{wti} < 1 \quad (3.12)$$

$$x \neq 0 \quad (3.13)$$

Objective function (3.9) maximizes the utility function. Constraint (3.10) makes sure that the sum of the weights is equal to 1. Constraints (3.11)-(3.13) make sure that only viable values are inserted. Using $x = 0$ in (3.9) will make the score be the same for each option, since $\lambda_i (1 - u_{wti})^x$ will be equal to λ_i and thus independent of the score u_{wti} . This would also lead to dividing problems due to $\frac{1}{x}$. Therefore, this value for x should not be used. Also, using $u_{wti} = 1$ is not appropriate since $1 - u_{wti}$ will lead to $\sum_{i=1}^m \lambda_i (1 - u_{wti})^x = 0$ and leads to dividing problems in $0^{1/x}$ when x is negative.

Including the distance power (x) creates additional options for comparing alternatives. $x = 1$ will reflect a compensatory attitude, where low scores on a criteria can be fully compensated by high scores on other criteria (Vannieuwenhuysse, Gelders, & Pintelon, 2003). Increasing $x (> 1)$ will lead towards more relevance of weak points. Low values decrease faster than higher scores when they are raised to a higher power. A high score will return into a low value of $1 - u_{wti}$ and thus loses its relevance more quickly. Low scores will become more relevant since $1 - u_{wti}$ results into a higher number. When raised to a high power, this will not decrease as fast, making it more dominant. Similarly, decreasing $x (< 0)$ will lead towards more relevance of strong points. Note that using a negative distance power will faster increase the dominance of the strong points than a positive distance power will on weak points. An extreme example is given to show the effect of the distance power. Consider the situation with one origin where $m = 3, \lambda_1 = \lambda_2 = \lambda_3 = 1/3, u_{11} = 0, u_{21} = 0,999, u_{31} = 0,5$. Then:

- Using an extreme high distance power ($x = 100$) will make the emphasis lie on the weak score, resulting into a utility of 0,011;
- Using an extreme low distance power ($x = -100$) will make the emphasis on the strong score resulting in a utility of 0,9989;
- Using a compensatory attitude ($x = 1$) will lead into a utility of 0,4997. This is due to the fact that $1/3 * 0 + 1/3 * 0,999 + 1/3 * 0,5 = 0,4997$.

As can be seen, the value of the distance power is important when calculating the utility. Vannieuwenhuysse et al (2003) suggest $|x| = 4$ when a dominant view is selected (Vannieuwenhuysse, Gelders, & Pintelon, 2003). The utility should be calculated for every origin since hub selection is also be done per origin.

3.2.3 Shortcomings

The previous extreme example of using different values for the distance power in section 3.2.2 reveals the main shortcoming of using qualitative measures. Giving values for the different parameters is a subjective method, which is inevitable when trying to score qualitative measures. In this case, not only the scores are subjective. Also parameters, such as distance power and weights of the criteria, can have a great impact on the outcome.

To mitigate the effect of the subjectivity regarding parameter values, the consensus based model is combined with the p-hub problem. This results into a more objective problem which can be used for sensitivity analysis relatively simple. The combined problem will be referred to as the qualitative p-hub problem and elaborated in section 3.3.

3.3 New Approach: Qualitative p-hub problem

In this section, we develop a new approach regarding selecting hubs. The quantitative nature of the p-hub problem shown in section 3.1 is combined with the qualitative part of section 3.2. The consensus model translated the relevant factors proposed in section 3.2.1. into a quantitative measure by using an utility function ($U_{wt}(x)$). This utility is implemented in the p-hub problem, so that the resulting problem consists of quantitative and qualitative issues.

For the p-hub problem it is proposed to use distances instead of cost, since this information is relatively easy to obtain and gives an objective indication on some of the factors of the utility (i.e. cost and emissions). Since the p-hub problem is a minimization problem, it is proposed to minimize ($1-U_{wt}(x)$). Weights should be assigned to the original problem (based on distances) and the utility (based on qualitative measures). For this, γ is defined as the relative importance of qualitative measurements compared with distance/cost issues. Since the distances are much greater than the utility, which were scaled in a range of [0,1] per origin, the relative distance compared to the direct shipping solution is used. This will make sure that the distance factor ranges from 0 to a number around 1. Note that in this case, the relative distance could still become higher than 1 and result into a good solution if the utility is sufficiently high. To make sure the amount of origins doesn't affect the utility factor, it is proposed to use a weighted average for the utility. The problem becomes:

Minimize

$$(1 - \gamma) \frac{\sum_{w,t,p} s_w (z_{wt} * (c_{wt} + \alpha c_{tp}))}{\sum_{w,p} s_w * c_{op}} + \gamma \frac{\sum_{w,t} s_w (1 - U_{wt}(x))}{\sum_w s_w} \quad (3.14)$$

Subject to

$$\sum_t z_{wt} = 1 \quad (3.15)$$

$$z_{wt} \leq z_t \quad (3.16)$$

$$\sum_t z_t \leq p \quad (3.17)$$

$$U_{wt}(x) = 1 - \left[\sum_{i=1}^m \lambda_i (1 - u_{wti})^x \right]^{\frac{1}{x}} \quad (3.18)$$

$$\sum_{i=1}^m \lambda_i = 1 \quad (3.19)$$

$$0 \leq u_{wti} < 1 \quad (3.20)$$

$$0 \leq \gamma \leq 1 \quad (3.21)$$

$$x \neq 0 \quad (3.22)$$

$$p \geq 1 \quad (3.23)$$

$$z_t, z_{wt} \in \{0,1\} \quad (3.24)$$

$$m, \lambda_i, s_w, c_{wt}, c_{tp}, \alpha \geq 0 \quad (3.25)$$

The model presented in (3.14)-(3.25) is developed to select at most p partners for the hinterland supply chain. It has implemented qualitative measures, through $U_{wt}(x)$. A more objective factor, relative distance, is used since it is a good indicator for cost and emissions. Also, distance information is easy to obtain in reality by using for example Google Maps (Google, 2014).

An advantage of stating the problem in this way is that a sensitivity analysis can be done in a straight forward way. This is to mitigate the subjectivity of the method. The parameters which definitely should receive attention during the sensitivity analysis are:

- Relative importance of qualitative measures, γ ;
- Discount factor for intermodal transport, α ;
- Distance power, x ;
- Amount of partners, p ;
- Normalized weights of criteria i , λ_i .

Also, the scores on the criteria can be altered to see what influence a slightly different score would have. A sensitivity analysis can only be done easily for relatively small problems. For bigger problems, an algorithm is needed. Genetic algorithms, proposed to use for the p -hub problem, can also be used to solve the qualitative p -hub problem. The qualitative p -hub median problem also needs $M \times N$ (M hubs and N origins) bits, equal to the p -hub problem stated in section 3.1 since the only decision which has to be made is which hub to use for each origin. However, calculating values for the objective function could take more time, making the computing time larger than for the p -hub problem. It is proposed to use the same values for the parameters for the genetic algorithm as proposed to solve the p -hub problem, as shown in section 3.1.1.

3.4 Pareto Efficiency

By using a sensitivity analysis, it should be tried to state Pareto efficient solutions. A solution is said to be Pareto efficient if it is impossible to make any one criteria better without making at least one criteria worse. Such solutions provide different scenarios from which a final solution can be selected.

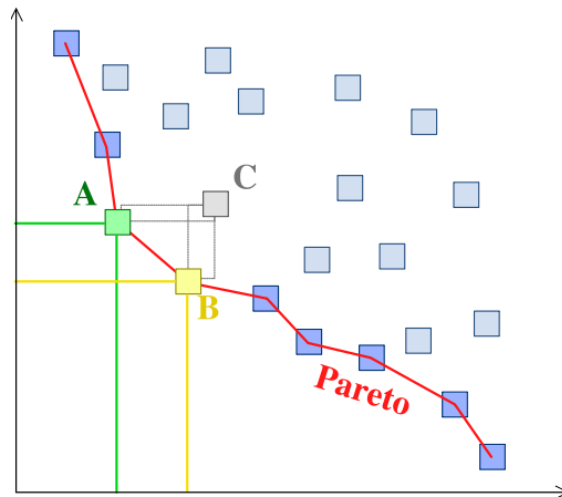


Figure 8: Pareto Efficiency

Figure 8 shows an two-criteria example. It can be seen that solutions A and B are Pareto efficient and solution C is not. Solution C is dominated by solution A and B since these points perform better on both minimization criteria. The line drawn in Figure 8 is referred to as the Pareto efficient frontier. A and B are both on the Pareto frontier since they aren't strictly dominated by other solutions (including each other). All the solutions which are on this line are not dominated by any other solution.

Using different values for the parameters, Pareto efficient solutions can be derived. Weights could be altered to see which situations lead to which solutions. Scenario's should be created based on this analysis in order to led the decision maker choose between these solutions. For example, adjusting the weights such that cost are more relevant could create a "cost" scenario. It is proposed to make scenarios where each criteria is leading. This results into a risk-, emissions-, cost- and complexity scenario. Note that the other factors still play a role in the setting up of the scenarios. Although it was proposed to treat risk as the dominant factor, this makes the guidelines more generally applicable and gives a better view of real-time possibilities.

3.5 Summary

In this chapter, we developed a qualitative p-hub problem which combines the quantitative part of the p-hub model, presented in section 3.1 and the qualitative measurements, shown in section 3.2. It is proposed to perform a sensitivity analysis to create Pareto efficient solutions. These scenarios should be defined to make a long term decision for selecting hubs. This new approach makes it possible to make a well-considered decision for the long term perspective regarding hub selection. A cost saving ~6% and a CO₂ saving of ~19% can be gained by applying the qualitative p-hub problem as will be shown in the case study in chapter 6.

4. Planning schedule

When hubs are selected, an exporting consignee needs to optimize their short term, operational transportation. This chapter will answer the following question:

- Given a set of hubs, how can an export consignee optimize their planning schedule?

A planning schedule consists of times a mode has to be present at different locations in order to get the cargo at the port at the planned time.

Deciding whether to use a pre-selected hub or to use direct shipments is the main decision in this process. This can be done by extending the vehicle routing problem. The Vehicle Routing Problem (VRP), introduced by Dantzig and Ramserl in 1959, states that m vehicles, initially located at a depot, need to deliver goods to n customers (Caric & Gold, 2008). Determining the optimal route used by a group of vehicles when serving a group of users represents a VRP problem. The objective is often to minimize the overall transportation cost. The solution of the classical VRP problem is a set of routes which all begin and end in the depot, and which satisfies the constraint that all the customers are served only once (Caric & Gold, 2008). The transportation cost can be improved by reducing the total travelled distance and by reducing the number of the required vehicles. In containerized transportation, reducing the number of required vehicles is not relevant, since one truck is needed per container. From the consignee perspective, the amount of other modes which are used is also not relevant.

Time scarcity can lead to problems for intermodal transportation (Sharypova, 2014). A time extension of the classical VRP model is set up to plan transportation within a time frame to minimize total transportation cost (Caric & Gold, 2008). Detention and demurrage cost will be included since they play an important role in hinterland transportation. In literature, detention and demurrage are often not included, which may lead to sub-optimal solutions. The model is referred to as an intermodal vehicle routing problem with detention and demurrage (IVRPDD)

The IVRPDD model will be developed and solution methods will be addressed. The model should be usable for planning transport towards a port, using containers. In section 4.1, the set-up of the model is discussed. Section 4.2 will present the model and 4.3 will discuss solution methods to solve the planning problem. Section 4.4 will discuss the influences of detention and demurrage by solving different settings using the solution methods discussed in section 4.3. to show the effect detention and demurrage have in different settings.

4.1 Set-up Model

A consignee needs to get their cargo on time at a port. For this, an empty container needs to be filled at an origin (warehouse) and transported to a port. The route of the empty and full container can be via a hub or directly from and to the port. Detention periods start at the release of an empty container and stops at the delivery at the port. Demurrage periods start at the delivery moment and stops when the sea vessel departs. Whenever the agreed upon periods are exceeded, cost occur (see Figure 3). A container can be released at a port, but whenever a hub stacks sufficient empty containers, it can be released at the hub.

The following will discuss the setup of the model per issue. Section 4.1.1. will discuss the routing of the cargo. Section 4.1.2. discusses the scheduled services, 4.1.3. the modeling of the waiting times, 4.1.4 will formulate detention and demurrage costs and 4.1.5 will discuss mode cost.

4.1.1 Routing

A container can be routed directly to a warehouse from a port, or via a hub in case of intermodal transportation. It is assumed that there is one port and every warehouse has this port as final destination. For this, mode b at hub j , mode f at hub k and time slot t of warehouse i can be used. $x_{n_i b_j f_k t_i}$ denotes 1 if order n of warehouse i travels via hub j using mode b for transporting an empty container to warehouse i and travels via hub k using mode f to transport a full container to the port, using time slot t of warehouse i . $j=0$ and $k=0$ denote direct shipments by truck. Logically, every demand needs to be fulfilled. To make sure every cargo reaches the port, constraints (4.1) are proposed.

$$\sum_{b_j, f_k, t_i} x_{n_i b_j f_k t_i} = 1 \quad \forall n \in N \quad (4.1)$$

This also makes sure that empty containers are shipped to the warehouses prior to delivery.

4.1.2 Scheduled services

Modes (aircraft, truck, rail, boats, ships, barges, etc.) travel via a time schedule. For example, a barge is scheduled to leave at 9:00, and the next barge leaves at 15:00. This results into the fact that modes are modeled as scheduled services. A scheduled service is defined as a service operating under a set timetable. Ayar and Yaman (2012) propose to use scheduled services for modeling intermodal transportation (Ayar & Yaman, 2012). Ayar and Yaman (2012) propose a cut off time for a scheduled service so that it only can be used whenever the container arrives before this cut off time (Ayar & Yaman, 2012). It is assumed that transit times are deterministic and known.

Several issues are modeled as scheduled services. The modes to hub j , modes from hub k and time slots at warehouse i are modeled as scheduled services.

For modeling the scheduled services a similar approach as Ayar and Yaman (2012) propose is used (Ayar & Yaman, 2012). However, a difference between the cut off time and the departure time of the mode at the scheduled service is proposed. This is to model the fact that filling a container or handling a container at a hub could take time or take place the next day. It is proposed to use cut off time P and departure time L . Logically, $L > P$. P_m is defined as the closing time of scheduled service m . L_m is defined as the departure time of scheduled service m . Using this notation, P_{bj} denotes the cut off time for mode b to hub j and L_{bj} is defined as the departure time for mode b to hub j . Similar notation are used for modes from hub k and time slots at warehouse i . Multiple scheduled services per hub are proposed to make the model applicable for real planning purposes. This makes it possible to also choose which mode to choose and thus making it a more operational decision making model.

Scheduled service can only be used when the container arrives at the hub or warehouse before the cut off time. For this, the buildup of the model starts at the end of the process and reasons back to the scheduled services. To make sure the cargo is on time at a port, the arriving time a_{n_i} should be smaller than the due date q_{n_i} , as proposed in constraints (4.2).

$$a_{n_i} \leq q_{n_i} \quad \forall n \in N \quad (4.2)$$

It is assumed that arriving on time is always possible. The arriving time of the cargo depends on whether a direct shipment is used or the transport from warehouse i is done via hub k . Whenever a direct shipment is used, the arriving time is the departure time at warehouse i (L_{t_i}) plus the transit time from warehouse i to the a port (τ_{i0}). Whenever the transport is done via hub k , the arriving time is equal to the departure time of the used mode b at hub k (L_{f_k}) plus the transit time of the used mode b of hub k to a port (τ_{f_k0}). This is shown in the formula (4.3).

$$a_{n_i} = x_{n_i b_j f_k t_i} (L_{f_k} + \tau_{f_k0}) + x_{n_i b_j b_0 t_i} (L_{t_i} + \tau_{i0}) \quad \forall n \in N \quad (4.3)$$

To ensure that whenever a direct shipment is used for the transport to a port ($k=0$) only the second term of the formula results into a time, constraints (4.4) are proposed.

$$L_{f_0} + \tau_{f_00} = 0 \quad \forall f \in F \quad (4.4)$$

The arriving time of a full container at hub k ($a_{n_{ik}}$) is equal to the departure time at warehouse i plus the transit time from the warehouse to hub k whenever mode b at hub k is used, as shown in formula (4.5).

$$a_{n_{ik}} = x_{n_i b_j f_k t_i} (L_{t_i} + \tau_{ik}) \quad \forall n \in N \quad (4.5)$$

Note that whenever the mode is not used, the arriving time is equal to 0.

The arrival time of an empty container at the warehouse ($a_{n_{ii}}$) depends on where the empty container was released. Empty container transport can be very different due to empty depot services. y_j denotes 1 if hub j is also functions as an empty depot. It is assumed that whenever the hub functions as an empty depot, it stacks sufficient containers. This is used to differentiate hubs and has a huge impact on the timing in the model. A container can be released at the hub or at the port. It can be released at a hub function as an empty depot. It is assumed that a hub stacks sufficient containers if it functions as an empty depot. If a hub doesn't have a stack of containers, the route can still be done via the hub, via mode b . Whenever an empty container is released at a port, the arrival time is equal to the departure time of mode b to hub j plus the transit time from the port to the hub, plus the transit time from hub j to warehouse i . Whenever the empty container is released at hub j , the arriving time is equal to the release time plus the transit time between hub j and warehouse i . $a_{n_{ii}}$ denotes the arriving time at warehouse i , as shown in formula (4.6).

$$a_{n_{ii}} = x_{n_i b_j f_k t_i} (r_{n_{ij}} + \tau_{ji}) y_j + x_{n_i b_j f_k t_i} (L_{b_j} + \tau_{b_j} + \tau_{ji}) (1 - y_j) \quad \forall n \in N \quad (4.6)$$

$a_{n_{ij}}$ denotes the arriving time of order n_i at hub j . The arrival time for the scheduled service at hub j is equal to release time whenever the empty container is released at a port and travels via hub j . This is expressed in formula (4.7). Note that whenever the mode is not used, the arriving time is equal to 0.

$$a_{n_{ij}} = x_{n_i b_j f_k t_i} (r_{n_{ij}} (1 - y_j)) \quad \forall n \in N \quad (4.7)$$

To ensure the containers only use scheduled services which they can use when time is considered, constraints (4.8)-(4.10) are proposed.

$$a_{n_{ij}} \leq P_{b_j} \quad \forall n \in N, \forall b \in B \quad (4.8)$$

$$a_{n_{ii}} \leq P_{t_i} \quad \forall n \in N, \forall t \in T \quad (4.9)$$

$$a_{n_{ik}} \leq P_{f_k} \quad \forall n \in N, \forall f \in F \quad (4.10)$$

A mode is assumed to have no capacity restrictions and a time slot can only be used once. This results into constraints (4.11).

$$\sum_n x_{n_i b_j f_k t_i} P_{t_i} \leq P_{t_i} \quad \forall t \in T, i \in I \quad (4.11)$$

4.1.3 Cost

Different cost are used set up the model. In 4.1.3.1. waiting cost will be discussed. Whenever containers arrive at a sub-destination too early, waiting cost occur. 4.1.3.2. will discuss demurrage

and detention cost which arise when the pre-determined days are exceeded. Inventory cost are discussed in 4.1.3.3. The cost function will be derived in 4.1.3.4., which will also include node cost.

4.1.3.1 Waiting cost

Whenever a container arrives at a sub-destination too early, waiting times arise. It is proposed to incur cost for these times, since it is costly to store a container at a hub or wait at a warehouse. w_m is defined as the waiting cost per unit of time for scheduled service m . The waiting time is equal to $P_m - a_{nm}$, which stands for the closing time of scheduled service m minus the arrival time of order n at scheduled service. Note that, due to constraints (4.8)-(4.10), this number is non-negative. Multiplying w_m with the corresponding waiting time leads to incurring waiting cost whenever order n arrives too early at the sub-destination. For the hubs, this only holds whenever the hub is used since when a hub is not used, the arriving time at that hub is still equal to 0. Therefore, (4.12) is proposed for modeling the waiting costs at the hubs.

$$\sum_{n_i, b_j > 0, f_k > 0, t_i} \left\{ w_k x_{n_i b_j f_k t_i} (P_{b_k} - a_{n_{ik}}) + w_j x_{n_i b_j f_k t_i} (P_{b_j} - a_{n_{ij}}) (1 - y_j) \right\} \quad (4.12)$$

Note that the factor $(1 - y_j)$ corrects for the fact that hub j could function as an empty depot. Whenever hub j functions at an empty depot, it is impossible for an empty container to incur waiting cost. This is due to the fact that an empty container arrives too early at hub j is not possible since it is released at hub j . In this case, the empty container doesn't travel via mode j . Using the same reasoning, waiting cost can also occur at the warehouses. Since every order needs to travel via a warehouse, this cost is as shown in (4.13).

$$w_i x_{n_i b_j f_k t_i} (P_{t_i} - a_{n_{ii}}) \quad \forall n \in N \quad (4.13)$$

The cost for waiting at hub j per time unit is denoted with w_j . w_i denotes the waiting cost at warehouse i and w_k denote the storage cost per unit of time at hub k .

4.1.3.2 Demurrage and Detention

Modeling demurrage is done by using the arriving date a_{n_i} . Whenever the cargo arrives x days before the departure date and y demurrage days are free, a demurrage penalty needs to be paid when $x > y$. α_{n_i} denotes the demurrage penalty cost per time unit for order n of warehouse i . η_{n_i} denotes the agreed upon demurrage free period. d_{n_i} denotes the departure of the vessel which order n at warehouse i uses.

Then, $d_{n_i} - a_{n_i}$ denotes the realized demurrage period. Whenever this period exceeds the agreed upon demurrage period η_{n_i} , penalty cost arise. Note that the departure date is not equal to the due date of a container. This is modeled as shown in (4.14)-(4.17).

$$\text{Demurrage cost} = \alpha_{n_i} ((d_{n_i} - a_{n_i}) - \eta_{n_i})\varepsilon \quad (4.14)$$

$$(a_i - \eta_i)\varepsilon \geq 0 \quad (4.15)$$

$$(a_i - \eta_i) \leq (a_i - \eta_i)\varepsilon \quad (4.16)$$

$$\varepsilon \in \{0,1\} \quad (4.17)$$

Two examples will show how this type of modeling works. Consider the situation where $\alpha_{n_i} = 200$, $d_{n_i} - a_{n_i} = 8$ and $\eta_{n_i} = 7$. The demurrage period should be 1 unit of time. $(8 - 7)\varepsilon$ will result into $\varepsilon = 1$, since $(8 - 7) \leq (8 - 7)*1$. Note that $\varepsilon = 0$ is not possible due to constraint (4.16). This would thus lead to $200*1$ demurrage penalty. Now consider the situation where $\alpha_i = 200$, $d_{n_i} - a_{n_i} = 6$ and $\eta_{n_i} = 7$. There shouldn't be penalty cost regarding demurrage. $(6 - 7)\varepsilon \geq 0$ will lead to $\varepsilon = 0$, making the penalty cost equal to 0. This is the desired effect. Note that $(6 - 7) \leq (6 - 7)*0$ still applies.

A similar technique is used for modeling detention. β_{n_i} denotes the detention penalty cost per time unit. Detention penalties arises when a container is in possession of the consignee for too long. The detention period starts when a containers is released at $r_{n_{ij}}$ and stops when a container is delivered at a port (a_{n_i}). As mentioned before, this can be done at a hub, or at the port. Whenever this period exceeds the agreed upon detention period γ_{n_i} , detention cost occur. (4.18)-(4.21) shows the modeling of detention cost.

$$\text{Detention cost} = \beta_{n_i} (a_{n_i} - r_{n_{ij}} - \gamma_{n_i})\varphi \quad (4.18)$$

$$(t_i - \gamma_i)\varphi \geq 0 \quad (4.19)$$

$$(t_i - \gamma_i) \leq (t_i - \gamma_i)\varphi \quad (4.20)$$

$$\varphi \in \{0,1\} \quad (4.21)$$

4.1.3.3 Inventory (in transit) cost

Inventory cost have effect on the timing of the planning process. A distinction between inventory cost and inventory in transit cost is made. From the moment the cargo arrives at the warehouse (v_{n_i}) until the moment the cargo is picked-up and used for filling the containers (the cut-off point of the used time slot), inventory cost is paid. Note that the arrival of the cargo at the warehouse is different than the arrival of the empty container.

The inventory cost per time unit is denoted with IC, which makes to inventory equal to formula (4.22).

$$\text{Inventory cost} = IC * (P_{t_i} x_{n_i b_j f_k t_i} - v_{n_i}) \quad (4.22)$$

To make sure the cargo arrives on time at the warehouse, constraints (4.23) are proposed.

$$v_{n_i} \leq P_{t_i} x_{n_i b_j f_k t_i} \quad \forall n \in N \quad (4.23)$$

The arrival of the cargo at the warehouse (v_{n_i}) is treated as a parameter. This will make the model less complex. Treating v_{n_i} as a parameter, the planning of the transport is decoupled with production. However, formula (4.22) indicates that the production should be as close to the cut-off time of the used time window to avoid inventory cost.

From the cut off time of the used time window (P_{t_i}), inventory in transit cost is paid. For this scope, this is paid until the departure at the port (d_{n_i}). The inventory in transit cost per time unit (ITC) needs to be multiplied with this time to derive to inventory in transit cost, as shown in formula (4.24).

$$\text{Inventory in transit cost} = \text{ITC} * (d_{n_i} - P_{t_i} x_{n_i b_j f_k t_i}) \quad (4.24)$$

This suggests that the transport should be done as close to the departure time as possible, to avoid inventory in transit cost.

4.1.3.4 Cost function

The cost function consist of the cost discussed in section 4.1.3.1.-4.1.3.4. It also includes node cost, denoted with c_{njk} . c_{njk} is defined as cost for order n which travels via hub j and k. This make the total cost function as shown in (4.25).

$$\begin{aligned} \text{Total cost} = & \sum_{n_i, b_j, f_k, t_i} \left\{ x_{n_i b_j f_k t_i} c_{njk} + \alpha_{n_i} ((d_{n_i} - a_{n_i}) - \eta_{n_i}) \varepsilon + \beta_{n_i} (a_{n_i} - r_{n_{ij}} - \gamma_{n_i}) \varphi \right. \\ & + w_i x_{n_i b_j f_k t_i} (P_{t_i} - a_{n_{ij}}) + \text{IC} * (P_{t_i} x_{n_i b_j f_k t_i} - v_{n_i}) + \text{ITC} * (d_{n_i} \\ & \left. - P_{t_i} x_{n_i b_j f_k t_i}) \right\} \\ & + \sum_{n_i, b_j > 0, f_k > 0, t_i} \left\{ w_k x_{n_i b_j f_k t_i} (P_{b_k} - a_{n_{ik}}) + w_j x_{n_i b_j f_k t_i} (P_{b_j} - a_{n_{ij}}) (1 - y_j) \right\} \end{aligned} \quad (4.25)$$

4.2 Model formulation

The setup of the model, discussed in 4.1, results into the model shown in (4.26)-(4.39). The variable list for this model can be found in Appendix B. The model is referred to as an intermodal vehicle routing problem with detention and demurrage (IVRPDD).

Minimize

$$\begin{aligned} & \sum_{n_i, b_j, f_k, t_i} \left\{ x_{n_i b_j f_k t_i} c_{n_j k} + \alpha_{n_i} \left((d_{n_i} - a_{n_i}) - \eta_{n_i} \right) \varepsilon + \beta_{n_i} (a_{n_i} - r_{n_{ij}} - \gamma_{n_i}) \varphi \right. \\ & \quad \left. + w_i x_{n_i b_j f_k t_i} (P_{t_i} - a_{n_{ii}}) + IC * \left(P_{t_i} x_{n_i b_j f_k t_i} - v_{n_i} \right) + ITC * (d_{n_i} \right. \\ & \quad \left. - P_{t_i} x_{n_i b_j f_k t_i}) \right\} \\ & \quad + \sum_{n_i, b_j > 0, f_k > 0, t_i} \left\{ w_k x_{n_i b_j f_k t_i} (P_{b_k} - a_{n_{ik}}) + w_j x_{n_i b_j f_k t_i} (P_{b_j} - a_{n_{ij}}) (1 - y_j) \right\} \end{aligned} \quad (4.26)$$

Subject to

$$\sum_{n, b, j, k, t} x_{n_i b_j f_k t_i} = 1 \quad (4.27)$$

$$\mathbf{a}_{n_i} = \mathbf{x}_{n_i b_j f_k t_i} (\mathbf{L}_{b_k} + \boldsymbol{\tau}_{b_k 0}) + \mathbf{x}_{n_i b_j f_0 t_i} (\mathbf{L}_{t_i} + \boldsymbol{\tau}_{i 0}) \quad (4.28)$$

$$a_{n_i} \leq q_{n_i} \quad (4.29)$$

$$L_{b_0} + \tau_{b_0 0} = 0 \quad (4.30)$$

$$x_{n_i b_j f_k t_i} (L_{t_i} + \tau_{i k}) \leq P_{f_k} \quad (4.31)$$

$$x_{n_i b_j f_k t_i} (r_{n_{ij}} (1 - y_j)) \leq P_{b_j} \quad (4.32)$$

$$x_{n_i b_j f_k t_i} (r_{n_{ij}} + \tau_{j i}) y_j + x_{n_i b_j f_k t_i} (L_{b_j} + \tau_{b_j} + \tau_{j i}) (1 - y_j) \leq P_{t_i} \quad (4.33)$$

$$(d_{n_i} - a_{n_i}) - \eta_{n_i} \leq ((d_{n_i} - a_{n_i}) - \eta_{n_i}) \varepsilon \quad (4.34)$$

$$(d_{n_i} - a_{n_i}) - \eta_{n_i} \geq 0 \quad (4.35)$$

$$a_{n_i} - r_{n_{ij}} - \gamma_{n_i} \leq (a_{n_i} - r_{n_{ij}} - \gamma_{n_i}) \varphi \quad (4.36)$$

$$(a_{n_i} - r_{n_{ij}} - \gamma_{n_i}) \varphi \geq 0 \quad (4.37)$$

$$v_{n_i} \leq P_{t_i} x_{n_i b_j f_k t_i} \quad (4.38)$$

$$x_{n_i b_j f_k t_i}, y_j, \varepsilon, \varphi \in \{0, 1\} \quad (4.39)$$

$$v_{n_i}, c_{n_j k}, \alpha_{n_i}, d_{n_i}, a_{n_i}, \eta_{n_i}, \beta_{n_i}, s_{n_i}, \gamma_{n_i}, q_{n_i}, L_{b_j}, L_{f_k}, \tau_{b_k 0}, L_{t_i}, \tau_{i 0}, \tau_{i k}, r_j, \tau_{j i}, L_{b_j}, \tau_{b_j}, \tau_{j i}, P_{t_i}, P_{b_j}, P_i \quad (4.40)$$

≥ 0

Assumptions for this model are:

- Deterministic transit times;
- Planning the set of orders on time is always possible;
- Whenever hub j stacks empty containers ($y_j = 1$), the number of empty containers stacked is enough to deal with demand;
- No capacity restriction on hub modes;
- The arrival of the cargo at the warehouse is fixed (parameter).

Deterministic transit times make it possible to know beforehand whether a scheduled service can be used. Relaxing this assumption makes the problem more complex since then it could be possible that a container arrives too late for a scheduled service and then an extra decision has to be made whether the container waits for the next scheduled service or that it is shipped directly to the port using trucks. Assuming that the set is always able to arriving on time makes the model able to create a solution in each situation. Otherwise, it could be possible that the model has no solution.

Assuming the amount of empty containers at an empty depot is sufficient to meet demand is needed to make it possible to model issues with the use of parameter y_j . Relaxing this assumption would make it a more complex model, since the amount of stacked containers at the time of requesting should be used as a parameter. This results into the fact that a hub can release some containers and needs to pick up some using mode j . The assumption can be justified by the fact that consignees make agreements on the service the hub operating company provides.

Setting no restriction on hub modes is done to show the consignee perspective. Mostly, consignees don't fill a mode all by themselves. Taking the constraint of the hub modes into account should result into a different perspective. The model would then need information of other consignees, which results into the loss of the consignee perspective. Inserting a capacity constraint for hub modes can be done similar to (4.11), but is seen as unnecessary as this model tries to represent the consignee perspective.

Treating the arrival of the cargo at the warehouse (v_{n_i}) as a parameter will make the model less complex. This assumption can be relaxed by making v_{n_i} a decision variable. However, in the notation of the model in (4.26)-(4.40), the model will then make v_{n_i} be equal to the cut-off time to avoid inventory cost. This would result into a lean situation, which is not always possible. Treating v_{n_i} as a parameter makes the planning of transport to be decoupled with production. However, formula (4.23) indicates that production should be as close to the cut-off time of the used time window to avoid inventory cost in reality.

Before discussing this influence of detention and demurrage, solution methods will be discussed. These methods will be used to investigate what impact detention and demurrage have. The model is more complex than the original vehicle routing problem (VRP). Since this VRP problem is NP-hard, this problem is considered to be NP-hard (Peiró, Corberán, & Martí, 2013). Therefore, solution methods are developed.

4.3 Solution methods

To solve the model presented in section 4.2, it is implemented in excel. The Excel solver is able to solve the model for 1 order, as can be seen in Verification 1 in Table 1. The model becomes too big for the excel solver when two orders are made (Verification 2), but the implementation can still be used to check whether when the constraints are met, the desired effect arises.

Variable	Verification 1	Verification 2
i	1	1
n	1	2
j	1	1
b(j=1)	1	1
k	2	2
b(k=1)	2	2
b(k=2)	2	2
t(1)	2	2
Result?	Yes	No

Table 1: Verification model

Whenever the constraints are met, only options which were meant to be possible are generated. It can be seen that only options are used which make use of scheduled services for which they arrive on time. Although this doesn't prove that the model works, it is assumed that the model is correct.

Since the problem becomes too big for the Excel Solver relatively fast, attempts to implement the model by using CPLEX are conducted. However, CPLEX couldn't implement constraints (4.12), since this formula didn't hold for the whole set of hubs. A similar problem arises for formula (4.3). Relaxing constraints (4.3) will result into the loss of the time perspective and relaxing (4.12) will result into the loss of incurring waiting cost.

Due to these problems, alternative methods are developed in section 4.3.1. Since there is a trade-off between time and cost, a time and cost perspective is taken. These perspectives are reviewed and make the methods applicable to multiple situations. Because cost could increase due to longer transit time of a net cheaper solution, it is not easily seen which routes should be taken. The constraints at the warehouses make it even more complex. Therefore, the time and cost of the solution are first decoupled as a starting point for the solution generation. Afterwards, the other perspective is included to make the solution feasible and better in terms of cost.

4.3.1 Alternative methods

Alternative methods will be proposed. Since the problem results in a trade-off between cost and time, these perspectives are taken. First, a cost first, time second method is proposed. Second a time-first, cost second approach is shown.

4.3.1.1 Cost first, time second (CFTS)

If only node cost were looked at, the p-hub problem could be applied when an order perspective was taken. Note that a direct shipment is also considered ($t=0$ as proposed in section 3.1). As mentioned in section 3.1.1, this problem is NP-hard. It is proposed to first solve the cost problem, since it is assumed that this would be a good starting point for looking at time issues. Starting with a “bad” solution would probably make the end solution harder to reach. The genetic algorithm, discussed in section 3.1.1, was proposed since the amount of hubs was not fixed. Now, the hubs are pre-selected and therefore fixed. Since the amount of hubs is fixed, the only decision which should be made is to use a pre-determined hub or not. This results in only one bit per origin, making the bit array contains of N (origins) bits. Genetic algorithm with the parameter values in section 3.1.1. are proposed to create the cheapest solution regarding node cost.

The genetic algorithm could also be applied to the total model presented in section 4.2. A bit could denote if order n travels via time slot t or not. However, since there are a lot of orders and modes and time slot possibilities, this would lead to a large bit array. Also, deciding on the release time is problematic using bits. Genetic algorithms are not suited for models on an operational level, since a lot of options are possible which would result in a large bit array.

After a solution regarding the node cost is generated, other cost parameters should be calculated by including the time perspective in this solution. Detention, demurrage and waiting cost can most of the time easily be avoided by altering the release time of the empty containers. An earliest due date is proposed to rank the orders. The release time should be in line with the time windows, such that the time windows are filled evenly. Detention could be avoided by transporting empty containers and/or full-containers directly. Demurrage cost can be avoided by changing the release time or increasing waiting times at sub-locations. It is proposed to first alter release times to minimize detention, demurrage and waiting cost. Afterwards, waiting times can be altered to minimize demurrage cost. Whenever the detention and demurrage and waiting cost are greater than the difference than whenever the containers are shipped directly, the decision for direct shipment should be made.

4.3.1.2 Time first, cost second (TFCS)

When the time perspective is considered first, it is assumed that intermodal transportation is cheaper. This would lead to the goal of creating a solution with intermodal transportation without detention and demurrage cost. Since hub use is given, the starting point is to plan only intermodal transportation, with as few detention and demurrage charges. This is basically creating a simpler cost function, only minimizing detention and demurrage cost and not using direct shipments. Minimizing detention and demurrage charges can be done by altering release time and waiting times. This is similar as in the cost first, time second algorithm.

4.3.1.3 Proposed alternative method

The time first, cost second (TFCS) assumes that intermodal transport is cheaper than direct shipments and tries to plan as much cargo via the hubs as possible. In this case, solving the p-hub problem is no longer necessary, which saves time. From real offers, it can be shown that this assumption is reasonable. Therefore, it is proposed to use the time first, cost second approach. It should be noted that for solving the problem, cost structures are important. For example, whenever detention and demurrage cost are a lot higher than other cost, these should receive more attention.

4.4 Influence detention and demurrage

Now we know how to solve the IVRPDD problem approximately, we will discuss the influence of detention and demurrage. This influence is investigated by using the one-order Excel model and by solving some small examples by using the proposed alternative method. Creating insights in the influence of detention and demurrage (D&D) helps specifying the proposed alternative method for practical purposes and elaborates on why D&D should be included in intermodal VRP problems for containerized transport.

If the amount of D&D days almost never result into planning problems, detention and demurrage cost have a similar effect as inventory cost. Production is scheduled later to avoid inventory (investment) cost and the cargo is shipped as late as possible. Detention and demurrage (D&D) also push the orders forward in time, but only until the order are “penalty-free”. Inventory cost push the orders even further. When the amount of D&D days is low and lead to planning problems often, direct shipments are used more to avoid D&D charges. This effect is not included in inventory cost, which makes including D&D in the VRP model an important extension.

The height of the D&D charges is relevant since it has an impact on the decision whether to use intermodal transportation or not. Whenever these cost are not avoidable when using a hub, the difference between the D&D charges and the additional node cost for direct shipment influences the decision whether to use intermodal or direct transportation.

If the inventory cost are higher than inventory in transit cost, the orders are scheduled as soon as possible, since inventory in transit is preferred to inventory cost. In this situation, the cargo is shipped as soon as possible. Note that this situation could result from the fact that the arrival time of the cargo at the origin is treated as a parameter and inventory cost (other than investment cost) have to be paid. In this situation, inventory cost and D&D have opposite directions, which will result into transporting the cargo as soon as possible within the D&D periods.

To summarize, the influences of detention and demurrage (D&D) are:

- The amount of D&D days influences the decision whether to use intermodal transport or direct shipments;
- The height of the D&D charges influences the decision whether to use intermodal transport or direct shipments;
- If inventory cost > inventory in transit cost, D&D influence the timing of transporting the cargo.

4.5 Summary

In this chapter, we developed an extended intermodal vehicle routing problem by including detention and demurrage (IVRPDD). The solution method “time first, cost second” (TFCS) is developed to solve this problem since excel couldn’t solve the large problem and attempts to implement the problem into CPLEX failed. The one-order Excel model and results gained from solving simple problems with the proposed solution method TFCS were used to gain insights for the planning schedule. The influence of detention and demurrage was discussed and shown to be relevant for containerized intermodal transportation. The developed solution method TFCS reduce detention and demurrage cost, which are up to 10% of the total supply chain cost.

5. Synchronization

Most of the research regarding minimizing empty container distance is conducted on collaboration between hubs and/or ports (Horst & Langen, 2008). But consignees could also work together directly in order to decrease empty container distance. In the Netherlands, Multimodal Smart Match (MSM) is one of few initiatives to make consignees collaborate (REWIND, 2014). This initiative tries to bundle flows by sharing information. The goal of this initiative is to find opposite flows (import/export) or to create sufficient volume for a new intermodal line.

In the MSM initiative, flows are bundled at hubs, but consignees could also directly bundle flows. We will call this direct bundling “synchronization”. Synchronization builds upon the idea of bundling flows at hubs. It refers to the bundling of import and export flows by transporting empty containers from an importer towards an exporter. This will result into a round-trip, which will lead to a decrease of empty container distance.

Synchronization is a novel idea which will be first discussed in this thesis in this way. Since synchronization consist of direct collaboration between consignees and thus takes the consignee perspective, it is relevant for this thesis. It is not directly implemented in the planning process since this new concept needs to be explained and developed first. Benefits arise from synchronizing flows and a cooperative game theory approach is used to look how these benefits can be allocated among different partners. This chapter will answer the following question:

- What benefits arise from synchronization and how can a consignee use it?

Potential synchronization partners, benefits and allocation of these benefits should be defined. Cooperative game theory is proposed for this purpose since it provides allocation rules for dividing benefits for collaborating companies. In general, companies are only willing to collaborate when there is a gain.

Section 5.1. will describe the concept of synchronization. Section 5.2 will discuss convincing potential partners to collaborate. This includes the allocation of benefits, which will be discussed using cooperating game theory. Section 5.3 will discuss the challenges which may arise while implementing synchronization. Section 5.4 will summarize the results discussed in this chapter.

5.1 Description

An “ideal” situation for synchronizing import and export flows is generated when multiple companies transport exactly the same amount of containers from the exact same location, but with opposite (import/export) flows collaborate. This would lead to no empty container transportation. This is only realistic for a single company which both exports and imports from the same location. It is assumed that this is not the case. The goal is to find a company or companies from which a coalition as close as possible to the ideal situation results. First, a relative simple idea (1 exporter, 1 importer, 1 hub) is presented to explain the idea and to show potential benefits. Afterwards, a multiple actor approach is used to create a more realistic situation.

5.1.1 - 1 Exporter, 1 Importer, 1 hub

Synchronization of import/export flows leads to a decrease in empty containers kilometers by creating a round trip. It should be noted that when using synchronization, also handling benefits arise. However, this is out of scope in this thesis.

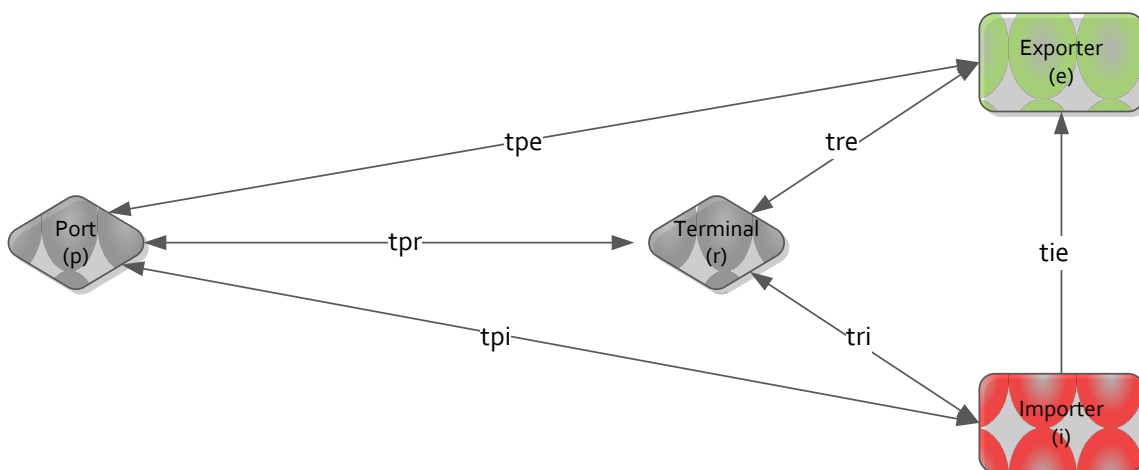


Figure 9: Synchronization import/export flows

As can be seen in Figure 9, consignees can use a hub or choose to transport directly to a port. Synchronization of import and export streams would lead to a roundtrip. Note that synchronization has no effect to the full container distance. Therefore, only empty containers distance will be looked at.

To calculate the empty container distance, some variables are defined. Whenever the hub provides an empty container depot service, y denotes 1. x_e denotes 1 if the exporter uses the hub and x_i denotes 1 if the importer uses the hub. It is assumed that whenever a hub is used, no direct shipments are done. λ_e and λ_i are the amount of containers the exporter and importer needs to transport respectively. t_{ij} denotes the distance between location i and j . e denotes the location of the exporter, i of the importer, p denotes the port and r denotes the terminal (hub).

The empty container distance (ECD) for respectively the exporter (e) and the importer (i) when no synchronization (ns) is done, equals:

$$ECD_{e-ns} = \lambda_e (x_e(t_{re} + t_{pr}) - t_{pr}y_{x_e} + t_{pe}(1 - x_e)) \quad (5.1)$$

$$ECD_{i-ns} = \lambda_i (x_i(t_{ri} + t_{pr}) - t_{pr}y_{x_i} + t_{pi}(1 - x_i)) \quad (5.2)$$

ECD_{e-ns} denotes the empty container distance for an exporter when no synchronization is considered. ECD_{i-ns} denotes the empty container distance for an importer when no synchronization is considered. Logically, the total distance in this situation (ECD_{ns}) becomes:

$$ECD_{ns} = ECD_{e-ns} + ECD_{i-ns} \quad (5.3)$$

Note that there are also empty kilometers needed for picking-up the containers. These are assumed to be the same as the distance shown in (5.1) and (5.2), which assumes symmetric distances. These distances are not shown, since they are equal and explaining the concept of synchronization is the goal of this section.

Whenever synchronization of the import/export flows is scheduled, the export consignee picks up containers at the import consignee location after unloading or the import consignee delivers their empty containers to the exporting consignee. Intensive collaboration is necessary to plan this type of synchronization. This would lead to an empty container distance of t_{ie} for the possible synchronization containers. Note that the pick-up of the containers distance is also equal to t_{ie} when assuming symmetric distances. Similar as in (5.1) and (5.2), only “one” direction of the distance is shown. For the surplus of containers, distances equal to the no synchronization situation are derived, as shown in formula (5.4).

$$ECD_s = \min(\lambda_i; \lambda_e) * t_{ie} + (\lambda_i - \lambda_e)^+ * ECD_{i-ns} + (\lambda_e - \lambda_i)^+ * ECD_{e-ns} \quad (5.4)$$

For a situation to be interesting, the distance of no synchronization should be greater than the distance when the flows are synchronized, as shown in formula (5.5).

$$ECD_{ns} > ECD_s \quad (5.5)$$

In the following, a more complex situation is discussed (N importers, M Exporters and P hubs) to give a more realistic view.

5.1.2 - N Importers, M Exporters, P hubs

Considering multiple importers, exporters and hubs, the problem becomes more complex. Every exporter and importer can now choose which hub to use and which consignee to collaborate with. When no synchronization takes place, the distance of the exporter and the importer are independent and similar to the 1 actor situation.

x_{er} denotes 1 if exporter e uses terminal r , x_{ir} denotes 1 if importer i uses terminal r . Also, having empty depot services at a terminal, denoted by y_r is specified per terminal r . The empty container distance becomes the summation of the actors, as shown in (5.6)-(5.8).

$$ECD_{e-ns} = \sum_{e \in E, p \in P} \left\{ \lambda_e \left(x_{er} (t_{pr} + t_{re}) - t_{pr} y_r x_{er} + t_{re} (1 - x_{er}) \right) \right\} \quad (5.6)$$

$$ECD_{i-ns} = \sum_{i \in I, p \in P} \left\{ \lambda_i \left(x_{ir} (t_{pr} + t_{ri}) - t_{pr} y_r x_{ir} + t_{ri} (1 - x_{ir}) \right) \right\} \quad (5.7)$$

$$ECD_{ns} = ECD_{e-ns} + ECD_{i-ns} \quad (5.8)$$

Since no synchronization takes place, these values are similar to the 1 exporter, importer and hub situation. Differences with the situation discussed in 5.1.1. arise when synchronization is scheduled. The main reason for this is that an exporter now can decide from a potential set of importers to synchronize their flow with. λ_{ie} denotes the amount of containers of importer i are synchronized and used by exporter e . Logically, an exporter can only use the amount of containers importer i imports.

$$\lambda_{ie} \leq \lambda_i \quad (5.9)$$

The empty containers distance with synchronization is equal to:

$$ECD_s = \sum_{e \in E, i \in I} \{ \lambda_{ie} t_{ie} + (\lambda_e - \lambda_{ie}) ECD_{e-ns} + (\lambda_i - \lambda_{ie}) ECD_{i-ns} \} \quad (5.10)$$

To make sure that $\lambda_e - \lambda_{ie} \geq 0$, constraints (5.11) are proposed. This makes sure that an exporter only synchronizes containers that it will use.

$$\lambda_{ie} \leq \lambda_e \quad (5.11)$$

The problem becomes.

Minimize

$$ECD_s = \sum_{e \in E, i \in I} \{ \lambda_{ie} t_{ie} + (\lambda_e - \lambda_{ie}) ECD_{e-ns} + (\lambda_i - \lambda_{ie}) ECD_{i-ns} \} \quad (5.12)$$

Subject to

$$\lambda_{ie} \leq \lambda_i \quad \forall i \in I, \forall e \in E \quad (5.13)$$

$$\lambda_{ie} \leq \lambda_e \quad \forall i \in I, \forall e \in E \quad (5.14)$$

From this, numerous conclusions can be drawn. It can be seen that synchronization leads to more benefits than empty depots, which are mostly mentioned in literature. The effect of synchronization is larger than using empty depots if (5.15) holds.

$$t_{ie} \leq t_{pi} + t_{pe} \quad (5.15)$$

Using triangle inequality in triangle i-e-p, this holds for every solution (Wolfram, 2014). Synchronization has a greater impact if:

- Hubs are used which don't provide empty depot services;
- Import/Export flows are of the similar amount;
- Distances between importer and exporter are small.

Using synchronization, handling occurs less. With using empty depots, the importer delivers the container at the depot and the exporter picks-up the container. With synchronization, the delivery handling at the terminal no longer occurs. This means that synchronization will reduce distances travelled and handling cost.

Synchronization combined with empty depot use for the surplus containers is proposed to minimize empty container kilometers.

5.2 Convincing potential partners

Companies are often not willingly to share flow information. The idea is to address potential partners with a cost savings situation in which all companies benefit. Unfortunately, a lot of flow information (such as volumes) is not available. It is assumed that locations and whether containers are used for import/export is known. Distances are proposed to be leading for setting up a list of partners. Distance information is easier to obtain, from for example Google Maps (Google, 2014). When intermodal transportation is used, potential partners could also arise from the pool of companies which use the same hub(s). Whenever a list of potential partners is set up, partners still need to be convinced to synchronize flows. It is proposed to do this by presenting and allocating the benefits and setting up a collaboration plan.

Presenting the benefits will be considered in section 5.2.1 Methods for allocating the benefits will be shown in section 5.2.2 and a collaboration plan is set up in 5.2.3.

5.2.1 Benefits

Benefits arise from more efficient transport of empty containers, as shown in section 5.1. These benefits will lead to transport distance decrease. It is assumed that this also leads to cost decreases. Translating these benefits directly to cost savings can be difficult. Showing distance savings is proposed to convince partners to collaborate. Also indicating that handling occurs less is proposed. Whenever flow information on volumes is available, a "total savings potential" can be calculated by using the empty distance container formulas (5.3) and (5.10). Since companies don't share flow information easily, it is proposed to use the percentage of empty container distance savings per container.

This indicates an upper bound of the savings percentage, since this percentage assumes that every container can be synchronized. Benefits can be presented by setting up a characteristic function $v(\{S\})$, which denotes benefit v when coalition S is set up. An example of a characteristic function for a three player game is shown in Table 2.

$\{S\}$	$\{1\}$	$\{2\}$	$\{3\}$	$\{1,2\}$	$\{1,3\}$	$\{2,3\}$	$\{1,2,3\}$
$v(\{S\})$	0	0	0	3	4	5	6

Table 2: Example characteristic function

This example shows that whenever a player doesn't cooperate, it achieves no benefits. Whenever player 1 and 2 cooperate, denoted by coalition $\{1,2\}$, a benefit of 3 arises. Whenever player 1 and 3 cooperate, their benefit is equal to 4 and so on. It can be seen that, in this example, cooperation pays off. It can be seen that whenever the benefits are equally divided, player 2 and 3 will cooperate and exclude player one since each player will get a benefit of 2 when $\{S\}=\{1,2,3\}$ and player 2 and 3 will have a benefit of 2,5 when $\{S\}=\{2,3\}$. In general, an allocation rule for the benefits is applied to make sure that every player will benefit from collaboration in order to make sure a collaboration is chosen and players have no incentive to leave the coalition or set up a different one.

5.2.2 Allocation

The main fundamental question in cooperative game theory is how to allocate the total benefits among all players in the coalition in a fair way (Gilles, 2010). For this, benefits which arise due to the cooperation of a player are important. Players who contributes more to a coalition should be given more payoff. For example, it could be the case that two partners benefit a lot from each other since there are located close to each other and that a third player also cooperates, but is located further away. The first two players should receive more payoff from this collaboration, since they create most benefits. Also, the company which invests more in the collaboration should receive more benefits. Investments can be in terms of cost, but could also be seen in terms of power and knowledge. Looking at synchronization, companies which take care of the transport between the importer and exporter should receive more benefits. It might be interesting for a consignee to trigger a cooperation. Triggering results into a leading position, which could lead to more long-term benefits.

Given a characteristics function, a payoff can be predicted or recommended to be awarded to each player given a coalition. Such predictions or recommendations can be proposed by using different allocation concepts (Serrano, 2007). In cooperative game theory, the core represents a set of solutions from which no sub-coalition can differ from to gain more benefits. These solutions will result into a "stable" solution.

The set C of stable solutions, is called the core and is shown in formula (5.16) (Ferguson, 1994).

$$C = \{x = (x_1, \dots, x_n) : \sum_{i \in N} x_i = v(N) \text{ and } \sum_{i \in S} x_i \geq v(S), \text{ for all } S \subset N\} \quad (5.16)$$

A stable solution basically means that no player has an incentive to change.

The main allocation concept proposed in cooperative game theory literature is the Shapley value. Shapley defined a value for games to be a function that assigns a pay off $\phi_i(v)$ for each player i in game v within coalition S (Roth, 2005). The Shapley value is “a solution that prescribes a single payoff for each player, which is the average of all marginal contributions of that player to each coalition he or she is a member of” (Serrano, 2007). The Shapley value is usually viewed as a good normative answer to the allocation question posed in cooperative game theory. It is proven, that whenever the core is non-empty, the Shapley value lies within the core and thus provides a stable solution. It is assumed that the core of this game is non-empty, meaning that there is at least one allocation which is stable. Then, the Shapley value represents a solution from which no sub-coalition will deviate, making it a “stable” solution.

It is proposed to use the Shapley value for dividing the benefits, since the Shapley value has an additive property:

- Additivity: if two coalition games described by gain functions v and w are combined, then the distributed gains should correspond to the gains derived from v and the gains derived from w .

Additivity relates to the issue of a player needs to receive more benefits when they contribute more. The Shapley value has, besides additivity, the following desirable properties (Serrano, 2007):

- Efficiency: The total gain is distributed;
- Symmetry: If i and j are two actors who are equivalent in the sense that for every subset S which contains neither i nor j , $\varphi_i(v) = \varphi_j(v)$. This means that whenever players invest the same, they should receive the same benefit;
- Zero Players: The Shapley value of a zero player i in a game v is zero. A player i is a zero player if a zero player doesn't add value to any coalition ($v(S \cup \{i\}) = v(S)$ for all coalitions S). This means that whenever a player doesn't contribute anything, this players should not receive any benefit.

Given a player set N , the Shapley value is the only payoff vector that satisfies all four properties from above (Roth, 2005).

The Shapley value can be calculated as shown in formula (5.17).

$$\varphi(N, v) = \frac{1}{N!} \sum_{S \subseteq N \setminus \{i\}} |S|! (|N| - |S| - 1)! [v(S \cup \{i\}) - v(S)] \quad (5.17)$$

The Shapley value captures the average marginal contribution of a player, averaging over all the different orders according to which the coalition could be built up from the empty coalition. The following example will show how this works. Consider the following game, which is referred to as the glove game. The glove game is a coalitional game where the players have left and right hand gloves and the goal is to form pairs. Consider the case where $N = \{1,2,3\}$, where players 1 and 2 have right hand gloves and player 3 has a left hand glove. Note that player 3 has more power, since he can either cooperate with player 1 or 2. The value function shown in Table 3 for this coalitional game in similar notation as in Table 2.

$\{S\}$	$\{1\}$	$\{2\}$	$\{3\}$	$\{1,2\}$	$\{1,3\}$	$\{2,3\}$	$\{1,2,3\}$
$v(\{S\})$	0	0	0	0	1	1	1

Table 3: Glove game example

Basically, the marginal contributions $(v(S \cup \{i\}) - v(S))$ in all possible orders of entering the coalition needs to be calculated. The following table displays the marginal contributions of player 1.

Order	Marginal contribution
1,2,3	$v(\{1\}) - v(\emptyset) = 0 - 0 = 0$
1,3,2	$v(\{1\}) - v(\emptyset) = 0 - 0 = 0$
2,1,3	$v(\{1,2\}) - v(\{2\}) = 0 - 0 = 0$
2,3,1	$v(\{1,2,3\}) - v(\{2,3\}) = 1 - 1 = 0$
3,1,2	$v(\{1,3\}) - v(\{3\}) = 1 - 0 = 1$
3,2,1	$v(\{1,2,3\}) - v(\{2,3\}) = 1 - 1 = 0$

Table 4: Marginal contributions

This results into the value for player 1: $\varphi_1(v) = 1 * \left(\frac{1}{6}\right) = \frac{1}{6}$. In a very similar way or by using symmetry, $\varphi_2(v) = \frac{1}{6}$. Due to the efficiency property we know that the sum of all the Shapley values is equal to 1, which means that all the benefits are shared and that the share for player 3 becomes: $\varphi_3(v) = \frac{2}{3}$. It makes sense that player 3 receives more, since player 3 has more power in this example since it can choose either play 1 or 2 to collaborate with. Note that none player has an incentive to leave the coalition, since in this case, that player will receive no pay off.

Using the Shapley value, benefits can be allocated to different parties within the coalition. As proposed, there should be more benefits for the companies which contribute more. It is proposed to use the percentage of empty container distance savings per container for the benefits and the percentage of total investment cost for the investment part.

5.2.3 Collaboration plan

Setting up a collaboration plan is assumed to make the probability for being able to set up a coalition higher. Complexity and secrecy are identified as relevant issues for convincing partners to synchronize flows. Whenever a company knows a benefit is possible, it wants to be assured that additional processes won't be too complex and that information will be dealt with confidentially.

Reducing complexity can be done by taking care of the empty container transportation. This even reduces complexity for the partner, since it doesn't have to deliver containers back to a port or an empty depot.

Secrecy issues can be dealt with by setting up a secrecy document which states that information shouldn't become available for other parties.

5.3 Challenges

Regarding the practical applicability of synchronization, it is hard to convince consignees to share flow information (REWIND, 2014). Not using a hub for the transfer of containers results into direct contact and planning between an importing- and exporting consignee. In section 5.1 it was assumed that locations and whether containers/reefers are used for import/export is known. This assumption is not violated by the lack of volume information. After partners are convinced, specific flow information is needed, but this is assumed not to be a problem since collaboration is already discussed at that point in time. Signing a secrecy document is proposed to overcome this challenge.

Detention and demurrage structures need to change in order to make synchronization possible. The current structure implies that a container needs to be returned after a fixed amount of detention days. It is proposed to use a consignee-combined detention and demurrage structure. Demurrage and detention is proposed to be structured as can be seen in Figure 10. Structuring detention and demurrage as shown in Figure 10, accountability for detention needs to be defined. Import and export consignees can agree upon a 50-50 division of the detention days or find other structures.

For changing detention and demurrage structures, carriers need to join the discussion. Carriers may not be willing to change current structures regarding detention and demurrage. Combining detention for multiple companies result into a longer period for the container to be out of the possession of the carrier, which creates risk.

However, synchronization leads to a more efficient use of the containers. Whenever the exporter and importer don't synchronize their flows, it is likely that the total time the containers are out of possession of the carriers is higher than when the exporter and importer do synchronize their flows. This makes it possible to use the containers for more consignees. This argument should be used in order to convince the carriers in changing detention demurrage structures.

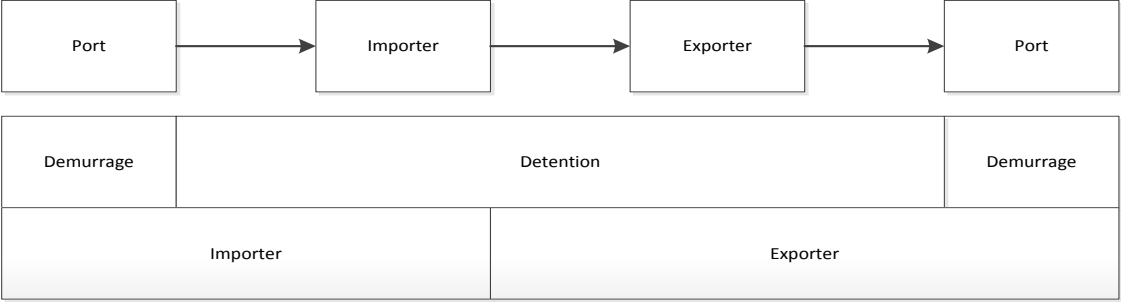


Figure 10: D&D Synchronization

The main challenges for synchronization are identified as:

- Convincing consignees to share flow information;
- Convincing carriers to change detention and demurrage structure.

It is proposed to do the following in order to overcome the challenges:

- Show benefits and sign secrecy documents;
- Show that the carrier could use the containers for more consignees by arguing that the total detention days are less when synchronization takes place.

5.4 Summary

In this chapter we developed the novel idea of synchronization and showed which benefits can arise from it. A description of a 1-actor and a N-actor situation showed that the benefits from synchronization are greater than using empty depots which is suggested by current literature. Allocating the benefits is done with use of the Shapley value. The Shapley value is proven to be within the core whenever this is non-empty, making it a stable allocation method. Secrecy and complexity should be taken into account when a coloration is set up. Challenges in convincing potential partners lie in the sharing of information and changing the detention and demurrage structure.

6. Case study – Vion Food Group

A case study will be conducted at VION Food Group to show how the developed guidelines can be used by a consignee. This is done quite extensively to show what problems might occur when specifying the guidelines for a practical situation.

VION Food Group is one of the larger food companies in the Netherlands and is represented all over the world. Yearly, 4500 40 ft. reefer containers containing frozen pork are exported to all over the world. The pork meat is stored at several cold stores across the Netherlands. From these cold stores, the meat is picked-up and transported to the port of Rotterdam. Since reefers are very expensive, VION Food Group leases them from carriers. In negotiations with such carriers, detention and demurrage lengths are set. Detention refers to the amount of time the containers can be held on to by the trucking company. Demurrage refers to the amount of time is available to deliver a container to the port of Rotterdam. The combination of detention and demurrage results into a penalty-free delivery period when the pick-up date is set. Detention and demurrage can cause high additional costs when this period is not met. Time management of the transportation is therefore extremely relevant and is considered a problem.

Optimizing VION Food Groups hinterland supply chain will be done, as proposed, in threefold. Hub selection will be discussed in section 6.1. In section 6.2, the planning schedule is optimized by using the alternative methods discussed in section 4.3. Third, in section 6.3, synchronization is discussed for VION Food Group similar to the general part of chapter 5.

6.1 Hub selection

The proposed guidelines for hub selection are relatively general and need further attention when looking at a specific situation. Therefore, hub selection is discussed extensively in this case study. Specific issues are addressed for optimizing the decision making process regarding hub selection.

The qualitative part of the qualitative p-hub problem is investigated by using the factors proposed in section 3.2.1. VION Food Group needs to set up criteria which can be bundled to risk, cost, emissions and complexity. Furthermore, a consensus model, as shown in section 3.2.2. based on these topics is set up. Afterwards, the qualitative p-hub median problem is set up by combining the consensus based model with the original p-hub median problem, similar to section 3.2.3. The practical view on the topics will be discussed in the following to elaborate on the relevant factors for VION Food Group.

6.1.1 Qualitative p-hub problem

This section will elaborate on which issues came up during the case study. Straight forward issues will not be discussed.

The combination of risk, cost, emissions and complexity is referred to as a “total solution”. Only partners which can provide such a solution should be selected. For measuring the criteria, a questionnaire is set up which can be found in Appendix . Since there are only a few hubs which will fill in the questionnaire, the questions are not scaled on for example a Likert scale. Scaling is not done since bias would arise from the subjectivity of the hubs. Logically, they will fill in the questionnaire such that they will perform well on the criteria. Therefore, open questions are set up and scoring will be done based on these answers. In this way, the bias will come from the subjectivity of the consignee. Since the goal is to create the best solution for the consignee, the consignee will try to give more realistic, and thus objective, scores.

Potential hubs partners were asked to sign a secrecy document in order to prevent rumors within the supply chain. Current logistic operators could become counterproductive when they notice change is coming which might exclude them. The goal of this network design is selecting potential partners, but current partners could prove better. Due to this secrecy, some information will not be shown in this document.

6.1.1.1 Relevant factors

The relevant factors shown in Figure 6 (risk, emissions, cost and complexity) need to be addressed.

Risk plays a key-role in the transport of frozen food. VION only wants to select reliable, flexible, experienced hubs/logistic providers which can provide a “total solution”. These measures are included in the questionnaire. It is chosen to also include services a hub can provide into the risk issue. Services as PTI, AEO and track & trace are taken into account when scoring the hubs on risk.

Emissions can be estimated by using data from Stream (Stream, 2011). Estimations of CO₂-emissions per tonkm are proposed for different sets of modes and are therefore relatively easily to use. Distances will be looked at to derive estimations of the emissions per mode. Handling emissions are in some case specified per hub at the website of InlandLinks (InlandLinks, 2014). Whenever handling information is not available, the average of 4,9 kg CO₂ per reefer is used. Together with estimations based on distance information, a score is given for the amount of emissions.

Inventory cost are excluded from the selection process. This is due to the fact that many orders are already available at the beginning of the week. Production is decoupled due to the push-supply chain VION Food Group has.

VION Food Group has limited control on the amount of pork which needs to be processed, since farmers can bring their pork to the production plant whenever they want. Since the products are already stored, shipping them sooner doesn't result in an increase in investment in the products. The investment cost on transportation cost are negligible, since even 10% investment cost per year results in a cost of €0,14 per container per day, assuming a transportation cost of €500,- (€500,- is considered high).

The veterinary control also has an impact on the cost. A veterinarian has to check the cargo when it departs due to food regulations. This is a costly operation. Therefore, VION Food Group wants to fill multiple containers and let them be checked all at once. This has an impact on the "free" time a logistic operator gives for filling the containers. This is also included in the questionnaire. Discussions on whether this check could be done at the hub were conducted, but due to regulations this was not possible.

VION Food Group is looking for a simple solution. Combining barge and rail transport would lead to different approaches and make the supply chain more complex. Also, rail incurs more risk due to congested rail roads by passenger transport. Although rail transport will likely score better on emissions, it will score worse on complexity. Only using rail transport is seen as impossible. There are not a lot of rail service providers which are located properly for the transport from the locations of VION to Rotterdam (Google, 2014). Rail transport is also considered only profitable for long distances. Bureau Voorlichting Binnenvaart (2014) states that the break-even-distance for rail transport lies around 300 km (Bureau Voorlichting Binnenvaart, 2014). Resor and Blade (2004) states that rail transport becomes profitable when considering distances greater than 200 km, and the University of Westminster (2010) even suggests a distance of 500 km (Resor & Blade, 2004), (University of Westminster, 2010). Only using inland waterway transportation is proposed to reduce complexity.

The resulting relevant selection factors are shown in Figure 11.

As mentioned before, a questionnaire is sent to each hub which is located in the middle and south of the Netherlands to score the potential partners on the four topics. This questionnaire can be found in Appendix and will try to get an answer to the question:

- Which hubs can provide a "total solution"?

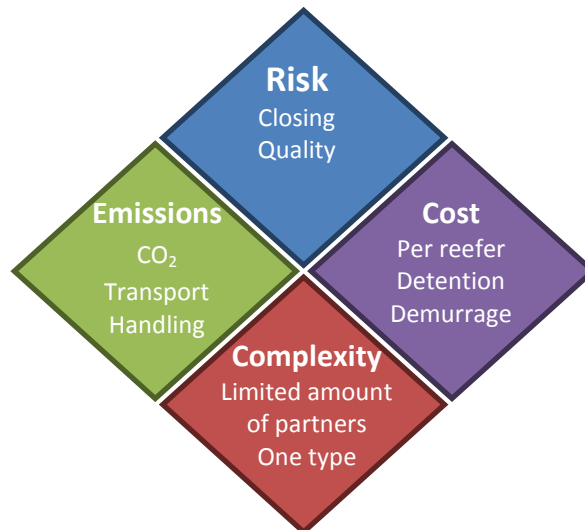


Figure 11: Relevant selection factors - VION Food Group

A “total solution” is defined as a solution with low risk and operational simplicity with reasonable cost and emissions. Due to planning simplicity, the amount of different hubs and partners should be limited. Also, one type of intermodal transport (waterways) is proposed.

6.1.1.2 Scoring

The following will elaborate on the specific issues during scoring of the options. It is proposed to develop scores per cold store per hub, since the decisions are independent across cold stores.

Regarding risk in the supply chain, issues as reliability, flexibility and experience of the logistic service provider are identified as important. These are measured using a questionnaire (Appendix). With the use of the answers to the questions, an assessment on risk is made. Each topic is scored on a [0,1] scale so that it can be used for the consensus based decision making. Weights are used to calculate a “total” score per hub on risk.

CO₂-emissions differ per hub and are also related to the distance of the cold store which uses this hub and the handling efficiency at a hub. For this, an distance approach is used and insights in operations at the hub are addressed by the use of the questionnaire (Appendix). Distances for road transport are gathered by using Google Maps (Google, 2014). Distances for barge transport are gathered using the calculation tool of EcoTransit (EcoTransit, 2014). With the use of distance information, estimations for CO₂ emissions can be derived. Stream (2011) provides CO₂ figures for road, barge and rail transportation per tonkm (Stream, 2011). For VION, the loading is assumed to be 27 ton per container (almost full container), and the truck is assumed to weigh 15 ton. An empty reefer container weighs 4,6 ton (Ter Haak Group, 2014). CO₂ values per cold stores are handled with care, since the linear CO₂ emission factors could cause problems on short distances.

Using these values and the answers on the sustainability questions from the questionnaire, a score per cold store per hub between 0 and 1 is given.

Although the cost of using a hub use is highly correlated with distances, some hubs could be more efficient than others so that they can offer lower prices. To review cost, a total price for transporting a container via the hub is taken into account per hub. Some hubs provide a price for synchromodal transport. Synchromodal transport indicates that the hub provides truck transport when necessary and barge transport when possible. Both cost are looked at, and an indication of the probability of needing truck transport will be used to assign weights to these costs. The combination of amount of shipments per week and the amount of time is needed for a barge to arrive at the port of Rotterdam is used to estimate this probability. Whenever the probability that a reefer has to be transported by truck is higher, the weight for this type of cost also increases.

Complexity will be minimized by giving a score per cold store per hub and by only selecting limited amount of partners and of one type of intermodal transportation (barge). The score will be based on the amount of services the hub can provide.

Using the scores in the range of [0,1) of the four issues (risk, emissions, cost and complexity), a consensus based selection is conducted. As mentioned before, providing a “total solution” with low risk is the goal for VION. Cost are also relatively important, and emissions and operations are seen as less important, but could make the difference between some solutions.

6.1.2. Initial solution

The qualitative p-hub problem, as shown in section 3.1, was implemented using the CPLEX tool in AIMMS (AIMMS, 2014). The following parameter values were proposed for the situation at VION:

Parameter	Value	i	λ_i
γ	0,6	Risk	0,4
p	4	Cost	0,3
x	4	Emissions	0,2
α	0,6	Complexity	0,1

Table 5: Proposed parameter values

The values presented in Table 5 represent the current situation at VION. It represents high importance of risk minimization, but also considers cost, emissions and complexity. The “total solution” implies that the utility of a partners is more important than the benefits which arise from distances, resulting in $\gamma=0,6$. Also, the amount of hubs which are used should be limited. $p=4$ is proposed to see which solution arises when only a few hubs are selected. The locations of the cold stores of VION also indicate a division in “south”, “middle” and “north” locations.

Since a “total solution” implies that weak scores should be more important than strong ones, the distance power is 4 ($x = 4$). From emission values from CE Delft, α is assumed to be 0,6. The average emission of a barge is equal to 38 g CO₂ per tonkm. For trucking, the factor is 64 g CO₂ per tonkm. A barge is thus $38/64 \approx 0,6$ as emitting as a truck. Since this problem is relatively small, it can be implemented and solved relatively easily. CPLEX was used to solve the problem (AIMMS, 2014) and resulted into the solution which uses hubs from Veghel, Cuijk and Tiel (Figure 12).



Figure 12: Overall Solution

6.1.3. Sensitivity analysis

In the previous analysis a lot of assumptions are made for reaching a total score for the solutions. To show the effects of these assumptions, a sensitivity analysis is conducted on the values and weights of the scores to come up with different scenario's. These different weights are to create the following scenario's.

- Risk
- Cost
- Emission
- Complexity

These scenarios are shown in Figure 13.



Figure 13: Risk-Cost-Emissions-Complexity scenarios

Also, a sensitivity analysis on the distance power is conducted. The following issues will be investigated, using the “overall” solution values for the other parameters and are shown in Figure 14:

- Weak dominance
- Strong dominance

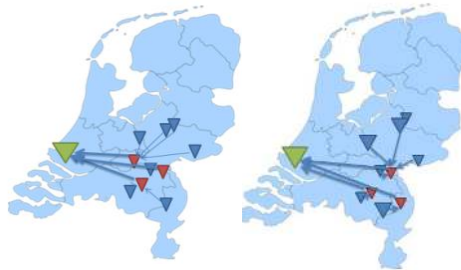


Figure 14: Weak - Strong scenarios

As mentioned before, this sensitivity analysis can be done using CPLEX since it is a relatively small problem. The genetic algorithm is not needed to solve this problem. The analysis gives insight in the robustness of the overall solution. It can be seen that the overall solution is quite robust, since it performs well on risk and emissions and the weak dominance scenario. However, when strong dominance is selected, the result changes quite fast.

6.1.4. End Result

It is proposed to use the overall solution. This solution also performs good when considering the risk and emission perspective and creating a weak dominance scenario. Inland Terminal Veghel is proposed Asten and Boxtel, Inland terminal Cuijk for the Weurt and CTU Rivierenland is proposed for Harreveld, Apeldoorn, Scherpenzeel and Olst (Figure 15).



Figure 15: End Result – Selected hubs

Planning benefits and flexibility arise from the fact that the hub in Cuijk and Veghel have the same owner and have a centralized planning. This reduces complexity and results in a “total solution”. This solution has a cost saving of ~6% and a CO₂ emissions reduction of ~19%.

6.2 Planning schedule

Planning orders in an optimal way could reduce expenses regarding waiting, detention and demurrage cost. This section will use the alternative method suggested in section 4.3.1.3. to show that the applicability is relatively simple. For this, the situation for planning orders at VION is discussed in section 6.2.1. and the mechanism is applied in section 6.2.2.

6.2.1 Situation VION Food Group

VION Food Group receives orders weekly, which they have to plan for the week ahead. The planning horizon of one week makes it possible to independently make decisions for each week. Orders include reefers which have to be filled at a certain cold store and transported to the port of Rotterdam before a certain point of time. An example of (a part of) the orders is shown in Appendix . These orders have to be planned in order to arrive at the cold stores to fill the reefers. This information needs to be communicated with the cold stores, in order to be able to process the orders. The cold stores can be treated independent due to non-dependent flows since the hubs don't provide economies of scale benefits. Therefore, a planning for one cold store is considered. Cold stores are external parties, which also store products for other companies. Due to this, there are limited time windows VION can use to fill reefers. This restriction results into spreading of orders across the week. For VION Food Group, the planning consists mainly of determining which time windows to use, given the filling restrictions. A new decision will be whether intermodal transport can be used or direct shipment is needed.

Currently, planning is done as close as possible to the closing at the port to avoid demurrage and detention fees. Whenever possible, the filling of the reefers occurs at the same day as the closing. Whenever the time windows are full, loadings are done a day before. It is chosen to try to deviate as little as possible from current operations to make the implementation of the new system easier.

6.2.2 Solution method

Assuming that intermodal transport is cheaper is appropriate as received offers indicate, which makes the proposed method of "time first, cost second" usable. A solution with at least waiting detention and demurrage fees is proposed while using as much intermodal transportation as possible. Planning to minimize detention and demurrage charges is proposed via a similar rule as the Earliest Due Date rule. A so-called Detention Date (DTD) rule is proposed as a priority rule. This rule will be referred to as the "Earliest Detention Date" rule (EDTD). The Detention Date for order i which uses carrier j is calculated as shown in formula (6.1).

$$DTD_{ij} = \text{Departure date}_i - \text{Free Demurrage days}_j - \text{Free Detention days}_j \quad (6.1)$$

It is proposed to use the Detention Date to give priority to an order. As shown in Table 6, order 1 should be done before order 2. This should be done per warehouse, which make the planning less complex.

Order	Departure Date	Detention days	Demurrage days	DTD
1	25-06-2014	6	3	16-06-2014
2	25-06-2014	5	2	18-06-2014

Table 6: Earliest Detention Day Example

When planning on the DTD is not possible, it should be scheduled to next day and so on to avoid detention cost. It should be noted that when the DTD lies before the day the planning is made, the first possible day should be taken into account. Then, detention is not an issue if the first picked-up orders are also delivered first when assuming a daily barge service. It could be possible that, due to filling restrictions at the cold stores, the day of closing at the port of Rotterdam is needed to fill sufficient containers. In this case, this should be done and the cargo should be shipped directly to the port by using truck. This is done to not miss the closing.

To avoid demurrage penalties, shipments should be “pushed” forward in time, such that each order arrives within the demurrage free period. Only orders which otherwise would incur demurrage cost should be pushed forward by planning them on a later date. Pushing further should not be done, since inventory cost are assumed to be higher than inventory in transit cost due to storage cost at the cold stores. Whenever avoiding demurrage cost is not possible, storage at the hub or trucking the order at the last day can be done. Whenever the cost for storing at the terminal are higher than storage cost, orders should be trucked. If this is not the case, trucking should not be done and the storage fees should be paid (Figure 16). This assumes that storing cost and additional truck cost are less than the demurrage fees. From received offers this is seen as a reasonable assumption. It is assumed that the middle situation in Figure 16 holds. It is proposed to store the reefers at the hub to avoid demurrage cost and only use trucking whenever the last day is needed to fill enough reefers. This method will be referred to as the “Forward Detention Date” method.

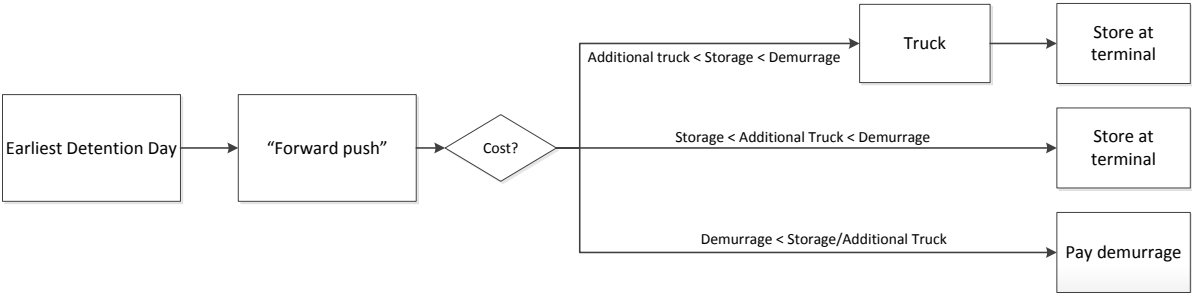


Figure 16: Forward Detention Date method

6.3 Synchronization

For finding synchronization partners, VION has to find importers of cooled products since reefers are needed. In practice, finding partners is difficult. Searching for partners can be done by using knowledge gained in the market, but there is no platform which shows where importing/exporting consignees are located.

In the Netherlands, the initiative Multimodal Smart Match (MSM) is set up to provide such a platform. MSM is trying to build a database with high-level flow information of consignees. The purpose of this database is to bundle different flows, with different outcomes. Bundling flows could lead to potential intermodal possibilities due to sufficient volume bundling. It could also lead to finding and bundling opposite flows, minimizing empty container distances. This last goal is similar to the synchronization issue, but still has a hub-perspective since this is perceived as less complex. Synchronization is a more direct collaborating than bundling flows.

Unfortunately, data unavailability led to the fact that this section could not be further elaborated. It should be noted that detention and demurrage structures need to change for synchronizations to work. Discussions with carriers need to be conducted for this. It is proposed not too only convince potential partners, but to start with convincing carriers of the benefits of synchronization. Less empty container distance leads to more efficient use of containers if containers are (un)loaded without additional storage.

For VION, it is proposed to collaborate in initiatives like MSM. Such initiatives can help VION in minimizing their empty container kilometers. Also, such initiatives will keep VION up to date regarding possibilities in hinterland supply chain optimization.

6.4 Summary

In this chapter, a case study was conducted to show the applicability of the guidelines proposed in chapter 3-5. The qualitative p-hub problem is shown to be a straightforward way to select partners for the hinterland supply chain for VION Food Group, but time-consuming. The process should not be underestimated since a long-term solution is made. A cost saving of 6% and a CO₂ reduction of 19% was gained by using the qualitative p-hub problem. Also, a perceived low risk and complexity solution resulted. An intermodal VRP problem with extensions regarding detention and demurrage (IVRPDD) was used to optimize the planning schedule. The proposed solving method for solving the IVRPDD problem is further specified to come up with an simple process of implementing the planning process for VION Food Group. Regarding synchronization, it was shown that information sharing and changing the detention and demurrage structure is needed to make synchronization work. Although synchronization is in theory a simple idea, it is difficult to implement.

7. Conclusions and recommendations

This master thesis looked at the hinterland supply chain optimization from a different perspective than most literature. Literature often takes the port perspective regarding this issue, but the consignee point of view is needed to create demand for the network. Stimulating demand will have a beneficiary impact on the hinterland supply chain which incrementally develops. More demand stimulates more supply, which will stimulate more demand.

In this thesis, we answered the following questions:

- How can a consignee select hubs based on quantitative and qualitative measures?
- Given a set of hubs, how can a consignee optimize their planning schedule?
- What benefits arise from synchronization and how can a consignee use it?

Consignee hinterland optimization is proposed in threefold due to different time perspective decisions. First, the intermodal transport network should be designed by selecting hubs. This is done by solving a qualitative p-hub median problem. Second, the planning schedule is optimized by using an extended intermodal vehicle routing problem by including detention and demurrage. Third, synchronization of import/export flows is proposed to reduce the empty containers distance. This is done to answer the main question:

- How can an export consignee optimize their hinterland container supply chain?

7.1. Conclusions

It has been shown that qualitative measures are relevant in hinterland supply chain optimization. Risk management is considered to be more important than cost due to the high values of the cargo. We extended a p-hub problem with utility function, based on a consensus model using identified relevant factors. A mathematical problem which implements qualitative measurements resulted, which made it more suitable for sensitivity analysis. Sensitivity analysis is proposed to mitigate the influence of subject parameter values. This so-called qualitative p-hub median problem is developed to select hubs for the hinterland supply chain.

An intermodal vehicle routing problem, extended with and detention and demurrage (IVRPDD) was developed to plan cargo flows. Literature neglects the effect of detention and demurrage on the planning decision, but these costs are often leading in the planning process. We developed an alternative method, a time-first, cost second (TFCS) method, to solve the IVRPDD problem and to study the influence of detention and demurrage. The influence of detention and demurrage is shown to be relevant for planning intermodal containers flows.

We developed a new concept, referred to as synchronization. Synchronizing import and export flows is proposed to reduce the empty container distance. It is shown that this new concept improves the supply chain by ensuring round trips. Cooperative game theory was used to allocate benefits among collaborating partners. Furthermore, a collaboration plan was set up to convince partners to share information and synchronizing flows with other consignees and to convince carriers to change detention and demurrage structures.

A case study was conducted at VION Food Group to show the applicability of the developed guidelines. The case study showed that some guidelines are easily implemented and that others needed some specifications to make them applicable to a consignee-specific situation. The qualitative p-hub problem provided a straightforward way to select partners for the hinterland supply chain. Nevertheless, this process is time-consuming and should not be underestimated. The qualitative p-hub problem was used for sensitivity analysis and showed the relevance of the different parameters. For VION Food Group, this analysis resulted into an advice to select terminals in Veghel, Cuijk and Tiel, and to a cost saving of ~6% and a CO₂ emission savings of ~19%. The alternative method needed to be further specified to come up with an easy way of implementing the planning process. An “Forward Earliest Detention Date” was proposed to minimize detention and demurrage cost. Synchronization is in theory a simple concept, but showed to be difficult to implement in reality. VION Food Group could use this idea to start up more initiatives regarding synchronization. Nowadays, the focus lies on container/reefer depots. These depots do decrease the empty kilometers, but synchronization could lead to a better solution.

7.2. Recommendations

The proposed guidelines in this thesis will help consignees in their decision process on whether to use intermodal transportation and how to use it. Recommendations for consignees are shown in section 7.2.1 and recommendations for future research are shown in 7.2.2.

7.2.1 Consignees

For consignees, it is proposed to use the developed guidelines presented in this thesis. It is shown that the qualitative p-hub problem could lead to significant cost and CO₂ saving, respectively 6% and 19%, as shown in the case study of VION Food Group.

Furthermore, it is proposed to use the planning method discussed in section 6.2.2. For exporting consignees, the “Forward Earliest Detention Date” method will minimize detention and demurrage cost. Intermodal transportation is considered interesting for consignees with at least 5 days of detention and 3 days of demurrage.

Furthermore, it is recommended to follow or start initiatives regarding collaborations among consignees. Synchronization is shown only to be possible whenever multiple consignees are willingly to collaborate. The concept of synchronization is shown to minimize the empty containers distance even more than empty depots.

7.2.2. Future research

This master developed several guidelines to optimize the hinterland supply chain from a consignee perspective. Although the case study showed that the models are applicable, future research is needed to validate the results. The four relevant factors could be lacking applicability to other industries.

Moreover, the impact of viewing the problem from one perspective on the whole supply chain should be investigated. It was already stated that for the development of the total network, more consignees should use the network. This would lead to an incremental development in where more demand results into more supply, and that this would lead to more demand. Whenever more consignees use intermodal transportation, more economies of scale arise, which could make intermodal transportation interesting for other consignees. However, conflicting goals could arise while using the proposed models. Further research is needed to investigate the long term effects of using these models towards the network as a whole.

Also, more research on the impact of detention and demurrage cost is needed. Literature almost never considers these cost, but these play an important role in intermodal container transportation. Since intermodal transportation takes more time, detention cost can arise. This research should also consider other cost structures regarding leasing of containers. Fazi (2014) suggested to use combined detention and demurrage periods and showed that for ports and importing consignees this could prove beneficial (Fazi, 2014). Similar research should be conducted for export transportation and the impact on the decision making of consignees should be studied. The planning schedule is driven by the current detention and demurrage rules. Studying what impact different leasing structures have on the decision on whether to use intermodal transportation can result into an additional incentive to use intermodal transportation.

More research is needed on the synchronization concept. It is shown that empty kilometer distances can be decreased, even compared with the empty depot concept. But synchronization also leads to less handling, which may cause synchronization to be beneficial in more situations. Future research is needed to investigate the magnitude of the benefits of synchronization. This could be done by setting up case studies. Also, applicability in reality should be investigated in order to reveal potential unforeseen challenges.

Furthermore, implications of synchronization for consignees, hubs and carriers need to be further investigated. Altering detention and demurrage structures are necessary for synchronization and needs to be discussed with the carriers. The impact on their processes needs to be investigated in order to convince carriers to agree with this issue.

Bibliography

- Abdinnour-Helm, S. (2000). Using simulated annealing to solve the p-hub median problem. Wichita, Kansas, USA : Wichita State University .
- AIMMS. (2014). Customized download AIMMS. Retrieved April 9, 2014, from AIMMS:
<http://www.aimms.com/downloads/aimms/download-aimms>
- Ayar, B., & Yaman, H. (2012). An intermodal multicommodity routing problem with scheduled services. *Computer Optimization Application*, 131-153.
- Ben-Ameur, W. (2004). Computing the initial temperature of simulated annealing. *Computational Optimization and Applications* , 369-385.
- Brandenburger, A. (2007). *Cooperative game theory*.
- Broek, F. v. (2010). *Green Supply Chain Management, Marketing Tool or Revolution?* Breda: NEA.
- Bureau Voorlichting Binnenvaart. (2014). Intermodaal vervoer. Retrieved April 4, 2014, from Bureau Voorlichting Binnenvaart:
<http://www.bureauvoorlichtingbinnenvaart.nl/vervoeren/logistieke-keten/intermodaal-vervoer>
- BusinessDictionary. (2014). BusinessDictionary. Retrieved June 6, 2014, from Intermodal:
<http://www.businessdictionary.com/definition/intermodal.html>
- Campbell, J. F., & O'Kelly, M. E. (2012). Twenty-Five Years of Hub Location Research. *Transport Science*, 153-169.
- Caric, T., & Gold, H. (2008). *Vehicle routing problem*. Vienna: In-Teh.
- Cordeau, J., Gendreau, M., Laporte, G., Potvin, J., & Semet, F. (2002). A Guide to Vehicle Routing Heuristics. *The Journal of the Operational Research Society*, 512-522.
- DeJong, K., & Spears, W. (1990). An Analysis of the Interacting Roles of Population Size and Crossover in Genetic Algorithms. *Proc. First Workshop Parallel Problem Solving from Nature*, 38-47.
- Diaz-Gomez, P. A., & Hougen, D. F. (2006). *Initial Population for Genetic Algorithms:A Metric Approach*. Oklahoma: University of Oklahoma.
- EcoTransit. (2014). EcoTransit Calculation. Retrieved Februari 16, 2014, from EcoTransit:
<http://www.ecotransit.org/calculation.en.html>
- Ernst, A. T., & Krishnamoorthy, M. (1996). Efficient algorithms for the uncapacitated single allocation p-hub median problem. *Location Science*, 139-154.
- Fazi, S. (2014). *Combined detention demurrage*. Eindhoven: University of Technology Eindhoven.
- Ferguson, T. S. (1994). *GAME THEORY*. Los Angeles: UCLA - Department of Mathematics.
- Gilles, R. (2010). Chapter 2: The Core of a Cooperative Game. In R. Gilles, *The Cooperative Game Theory of Networks and Hierarchies* (pp. 29-70). Berlin: Springer-Verlag Berlin Heidelberg.

- Google. (2014). Google maps. Retrieved April 7, 2014, from Google: www.maps.google.nl
- Greenwell, R., Angus, J., & Finck, M. (1995). Optimal Mutation Probability for Genetic Algorithms . *Mathematical and Computer Modelling*, 1-11.
- Horst, M. v., & Langen, P. d. (2008). Coordination in Hinterland Transport Chains: A Major Challenge for the Seaport Community. *Maritime Economics & Logistics* , 108-129.
- InlandLinks. (2014). Nieuws. Retrieved April 23, 2014, from InlandLinks: <http://www.inlandlinks.eu/nl/nieuws/highlight:205#news-205>
- Jacobson, L. (2013, April 11). Simulated Annealing for beginners. Retrieved May 2, 2014, from The Project Spot: <http://www.theprojectspot.com/tutorial-post/simulated-annealing-algorithm-for-beginners/6>
- Kelleher, G., El-Rhalibi, A., & Arshad, F. (2003). Scheduling for Intermodal Transport. *Logistics Information Management*, 363-372.
- Klincewicz, J. G. (1992). Avoiding local optima in the p-hub location problem using tabu search and grasp. *Annals of Operations Research*, 1-4.
- Konings, R., Kreutzberg, E., & Maras, V. (2013). Major considerations in developing a hub-and-spoke network to improve the cost performance of container barge transport in the hinterland:the case of the port of Rotterdam. *Journal of Transport Geography* 29, 63-73.
- Kratka, J., Stanimirovic, Z., Tomic, D., & Filipovic, V. (2007). Two genetic algorithms for solving the uncapacitated single allocation p-hub median problem. *European Journal of Operational Research* , 15-28.
- Libelli, S. M., & Alba, P. (2000). Adaptive mutation in genetic algorithms . *Soft computing*, 76-80.
- Lin, C.-C., Lin, J.-Y., & Chen, Y.-C. (2012). The capacitated p-hub median problem with integral constraints: An application to a Chinese air cargo network . *Applied Mathematical Modelling*, 2777-2787.
- Lin, W.-Y., Lee, W.-Y., & Hong, T.-P. (2003). Adapting Crossover and Mutation Rates in Genetic Algorithms . *Journal of information science and engineering*.
- Magalhaes-Mendes, J. (2013). A Comparative Study of Crossover Operators for Genetic Algorithms to Solve the Job Shop Scheduling Problem . *WSEAS TRANSACTIONS on COMPUTERS* , 164-173.
- Martin, J. (2004). Success and the Supply Chain: How Chemical Companies Can Master Complexity. *Chemical Market Reporter*, 17-19.
- Mittal, N., Boile, M., Baveja, A., & Theofanis, S. (2013). Determining optimal inland-empty-container depot locations under stochastic demand. *Research in Transportation Economics*, 50-60.
- Peiró, J., Corberán, A., & Martí, R. (2013). Uncapacitated r-Allocation p-Hub Median Problem. Valencia (Spain): University of Valencia.

- ResearchGate. (2014). Question. Retrieved June 2, 2014, from ResearchGate:
http://www.researchgate.net/post/Why_is_the_mutation_rate_in_genetic_algorithms_very_small
- Resor, R. R., & Blaze, J. R. (2004). SHORT HAUL RAIL INTERMODAL: CAN IT COMPETE WITH TRUCK? Cherry Hill: Zeta-Tech Associates.
- REWIN. (2014). Multimodal Smart Match. Retrieved May 12, 2014, from REWIN:
<http://www.rewin.nl/samenwerken-innoveren-en-groeien-in-west-brabant/logistiek/multimodal-smart-match--598.html>
- Roth, A. E. (2005). Introduction to the Shapley Value. In A. E. Roth, The Shapley Value: Essays in Honor of Lloyd S. Shapley (pp. 1-10). Cambridge: Cambridge University Press.
- Sangsawang, O., & Chanta, S. (2012). Artificial Bee Colony algorithm for solving the uncapacitated single p-hub median problem. IIE Annual Conference. Proceedings (pp. 1-8). Orlando: IIE.
- Scholand, A. (2014). Genetic Algorithm (GA) Parameter Settings. Retrieved June 2, 2014, from <http://eislab.gatech.edu/people/scholand/gapara.htm>
- Serrano, R. (2007). COOPERATIVE GAMES: CORE AND SHAPLEY VALUE. Providence: Department of Economics, Brown University and IMDEA-Social Sciences.
- Sharypova, K. (2014). Optimization of Hinterland Intermodal Container Transportation. Eindhoven: Eindhoven University of Technology.
- Stanimirovic, Z. (2010). A GENETIC ALGORITHM APPROACH FOR THE CAPACITATED SINGLE ALLOCATION P-HUB MEDIAN PROBLEM. Computing and Informatics, 117-132.
- Stream. (2011). STREAM internation freight 2011: Comparison of various transport modes on a EU scale with the STREAM database. Delft: CE Delft.
- Ter Haak Group. (2014). 40 ft container. Retrieved April 23, 2014, from Ter Haak Group Amsterdam:
<http://www.terhaakgroup.com/wps/wcm/connect/thg/ccanl/Producten/Koel+en+Vries+containers/40ft+Reefer+container>
- The Guardian. (2011, November 10). Consumers put firms under pressure to lead the way in sustainable living. Retrieved February 18, 2014, from The Guardian: Latest news, sport and comment from the Guardian : <http://www.theguardian.com/sustainable-business/consumer-behaviour-companies-sustainable-living#start-of-comments>
- University of Westminster. (2010). Freight Modal Choice Study: Addressable Markets . Westminster: University of Westminster: Department for Transport .
- Vannieuwenhuyse, B., Gelders, L., & Pintelon, L. (2003). An online decision support system for transportation mode choice. Logistics Information Management, 125-133.
- Veenstra, A., & Zuidwijk, R. (2011). The future of seaport hinterland networks.

Veenstra, A., Zuidwijk, R., & Asperen, E. v. (2012). The extended gate concept for container terminals: Expanding the notion of dry ports. *Maritime Economics & Logistics*, 14-32.

Veenstra, A., Zuidwijk, R., & Asperen, E. v. (2012). The extended gate concept for container terminals: Expanding the notion of dry ports. *Maritime Economics & Logistics* 14, 14-32.

VION Food Group. (2014). About VION. Retrieved February 13, 2014, from VION Food Group: <http://www.vionfoodgroup.com/en/about-vion/profile/>

Wolfram. (2014). Triangle Inequality. Retrieved May 8, 2014, from Wolfram Mathworld: <http://mathworld.wolfram.com/TriangleInequality.html>

Appendix A

Genetic algorithms (GAs) represent problem-solving meta-heuristic methods which has similarities to the mechanisms of evolution and natural genetics (Kratika, Stanimirovic, Tosic, & Filipovic, 2007). A typical genetic algorithm requires:

- A genetic representation of the solution domain;
- A fitness function to evaluate the solution domain.

A number of solutions will form the genetic representation of the solution domain. For this, the solutions are translated into a genetic code, called a “chromosome”. This chromosome is a bit array, which show all decisions in bits. For hub selection, this is the decision whether to use a hub or not. Note that this includes the possibility of selecting “maximum” p-hubs. Determining how large this representation should be is a well-studied topic. This problem results in a trade-off between creating a “good” solution and computation time (Diaz-Gomez & Hougen, 2006). Inserting a relative small amount of perceived “good” solutions is proposed.

The fitness function determines the relative “goodness” of each solution in the genetic representation. It is the relative value of the objective function of the solution compared to the average value of all the solutions in the representation. This value determines which solutions are more likely to stay in the population. The solutions with a fitness value of >1 will stay in the representation and have a possibility of $F_s - 1$ to be represented twice. Logically, solutions with a value of >2 , will be represented at least twice. Solutions with a fitness value <1 will have a probability of F_s to stay in the representation.

The operations crossover and/or mutation are applied to the solutions. Crossover results into a swap of a part of the bit array, making a new solution. Mutation changes a bit randomly, creating a more random solution. These operations create a new “generation” of situations.

This process is conducted multiple times. When the algorithms stops is predetermined. Amount of generations, computation time, fitness and other variables can be used as a stop-indicator.

Concluding, only fit solutions will “survive” and become fitter over “generations” since only successful cross-overs and mutations will “survive” in the new generation. This is the main reason why these algorithms are referred to as genetic.

This process is summarized in Figure 5. It can be seen that genetic algorithm are relative simple in principle, but the algorithms success depends on many parameters which are harder to define.

Appendix B

Decision variables

$x_{n_i b_j f_k t_i}$	1 if order n of warehouse i uses mode b at hub j, mode f at hub k and time slot t at warehouse i. (j=0 and k=0 denote direct shipments by truck)
$r_{n_i j}$	Release time for order n at warehouse i at hub j

Variables

a_{n_i}	Arriving time of order n of warehouse i at the port
$a_{n_i k}$	Arriving time of order n of warehouse i at hub k
$a_{n_i i}$	Arriving time of order n of warehouse i at warehouse i
$a_{n_i j}$	Arriving time of order n of warehouse i at hub j

Parameters

α_{n_i}	Demurrage penalty per unit of time for order n of warehouse i
d_{n_i}	Departure time of the vessel for order n of warehouse i
η_{n_i}	Penalty free demurrage period for order n of warehouse i
β_{n_i}	Detention penalty per unit of time for order n of warehouse i
γ_{n_i}	Penalty free detention period for order n of warehouse i
w_i	Waiting cost at warehouse i
w_k	Waiting cost at hub k
w_j	Waiting cost at hub j
y_j	Denotes 1 if hub j stacks enough containers to function as an empty depot
L_{b_k}	Leaving time of mode b at hub k
P_{b_k}	Closing time of mode b at hub k
L_{t_i}	Leaving time of time slot t at warehouse i
P_{t_i}	Closing time of time slot t at warehouse i
L_{b_j}	Leaving time of mode b at hub j
P_{b_j}	Closing time of mode b at hub j
$\tau_{b_k 0}$	Transit time of mode b at hub k to the port
$\tau_{j i}$	Transit time from hub j to warehouse i
$\tau_{i k}$	Transit time from warehouse i to hub k
$\tau_{i 0}$	Transit time from warehouse i to the port
$\tau_{b k}$	Transit time from the port to hub k
$c_{n_j k}$	Cost for order n which travels via hub j and k
v_{n_i}	Arrival time of the cargo belonging to order n of warehouse i

Appendix C

1. Bedrijfsprofiel

- a. Hoeveel personeel heeft de hub in dienst?
- b. Hoeveel containers worden er vervoerd via de hub op jaarbasis (export + import)?
- c. Hoeveel reeferers worden er vervoerd via de hub (export + import)?

2. Betrouwbaarheid

- a. Is de hub bereid om garanties af te geven m.b.t. afspraken vanuit VION in de vorm van een SLA?
- b. Is er een voorbeeld van een SLA beschikbaar die de hub op dit moment gebruikt?
- c. Hoe garandeert de hub dat de reeferers altijd met de binnenvaart barge mee kunnen?
- d. Hoe garandeert de hub dat de reeferers veilig staan op de hub?
- e. Hoe garandeert de hub dat de producten tijdens handling niet beschadigd raken?
- f. Hoe garandeert de hub dat de reeferers altijd op temperatuur (-22 C) blijven op de hub?
- g. Wat is de oplossing van de hub als de reefer niet met de binnenvaart barge mee kan?

3. Voortransport

- a. Kan de hub het voortransport voor zijn rekening nemen?
- b. Is het voortransport in eigen dienst of uitbesteedt?
- c. Hoeveel vrije uren rekent de hub voor het vullen van de reefer?

4. Doorlooptijd

- a. Hoe lang zit er tussen pick-up bij een locatie en de aankomst t.a.v. de closing in Rotterdam?
- b. Welke hubs in Rotterdam worden er door de hub aangedaan?
- c. Hoe zien de vaarschema's eruit?

5. Duurzaamheid

- a. Is de hub in staat om een lange termijn oplossing te verzorgen?
- b. Wat zijn de toekomstplannen van de hub?
- c. Welke duurzaamheidscertificaten (bv. ISO 14000) heeft de hub?
- d. Wat is de CO2-footprint van de hub?
- e. Met wat voor motor (bv. Eur 5/Eur 6) rijden de trucks voor het voortransport?
- f. Van welke typen barges maakt de hub gebruik?

6. Planning

- a. Welke systemen worden er gebruikt voor de planning voor de containers en de vrachtauto's?
- b. Wanneer dient een planning uiterlijk gecommuniceerd te worden?
- c. Welke data moet er worden aangeleverd en op welk tijdstip?

7. Flexibiliteit

- a. Wat is de cut-off tijd van een wijziging op een order?
- b. Wat zijn de openingstijden van de hub (kantoor en operationeel)?
- c. Hoeveel ruimte en tot wanneer is het mogelijk om wijzigingen door te voeren in de planning?
- d. Van welke rederijen zijn er reefers bij de hub aanwezig?
- e. Hoeveel dagen detention/demurrage gelden er wanneer er via de hub gewerkt wordt?
- f. Is het na een wijziging mogelijk (en tot wanneer) om een reefer te laten staan op de hub?

8. Ervaring

- a. Hoeveel ervaring heeft de hub met reefer transport en met wat voor producten?
- b. Met welke partners/soort gelijke klanten werkt de hub?
- c. Met welke rederijen werkt de hub?
- d. Wie zijn de top 3 reefer exporteurs en hoeveel reefers exporteren die?
- e. Wie zijn de top 3 containers exporteurs en hoeveel containers exporteren die?

9. Overige services

- a. Welke services zijn bij de hub aanwezig (PTI, Cleaning, Douane en AEO)?
- b. Kunnen de zendingen via een online service gevolgd worden (track & trace)?
- c. Zijn er nog andere zaken die de hub van belang vindt?

Appendix D

Week	SALE NO.	LOAD DATE	LOAD TIME	LOAD PLACE	CUST. CLEAR	DESTINATION	ETS	CLOSING
41	10874	7-10-13	9:00	weurt	UTI	Los Angeles	10-10-13	7-10-13
41	10967	7-10-13	10:00	weurt	UTI	Oakland	10-10-13	7-10-13
41	10453	8-10-13	9:15	s'zeel & A	UTI	Tokyo	15-10-13	11-10-13
41	10453	8-10-13	11:00	Apeldoorn	UTI	Tokyo	15-10-13	11-10-13
41	10453	8-10-13		Apeldoorn	UTI	Tokyo	15-10-13	11-10-13
41	10453	8-10-13		Apeldoorn	UTI	Tokyo	15-10-13	11-10-13
41	11000	8-10-13	10:00	s'zeel & A	UTI	Tokyo	15-10-13	11-10-13
41	11000	8-10-13		s'zeel & A	UTI	Tokyo	15-10-13	11-10-13
41	11000	8-10-13		s'zeel & A	UTI	Tokyo	15-10-13	11-10-13
41	11000	8-10-13	11:30	Apeldoorn	UTI	Tokyo	15-10-13	11-10-13
41	11000	8-10-13		Apeldoorn	UTI	Tokyo	15-10-13	11-10-13

Table 7: Example Shipping day