Network characteristics and the performance of voluntary order-sharing networks in the container transport industry

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ABSTRACT

The road transport industry is characterized by fierce competition, low margins and many suppliers. This thesis deals with an order-sharing network that allows hauliers to interchange orders to improve operational efficiency and create a competitive advantage. The main goal of this thesis is to examine how network characteristics affect the performance of the network and it's participants. A probabilistic framework is developed and examined by means of simulations to assess the effect of network characteristics on the performance of the network. Mixed-integer linear programming has been used to empirically study the cost saving ability of an existing network: the Boxreload project. Multiple regression analyses have been conducted to assess how individual network characteristics affect the cost saving ability and the performance of the network in general. The results show that positive scale economies can be achieved in the network. Both the average amount of 'reloads' per order and the cost savings made by a reload are positively related to the size of the network. Due to directional restrictions (every import must be matched with an export), not every new entrant will enhance, and might even worsen the performance of the network. Voluntary order-sharing networks are, on average, more beneficial for small hauliers compared to large hauliers, because they are less capable to make internal reloads. An optimal size of the network has not been derived. However, the concave relationship between network size and network performance, and the rationale behind transaction costs imply that at some point, bigger is not always better.

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Chapter 1. Introduction

Transport by road has been the main way of moving freight in Europe for many decades. With a current share of 72% (tkm) , inland transport by road stays well ahead of transport by rail (17%), inland waterways (6%) and pipelines (5%) (European Commission, 2014). The market for road transport is characterized by predominantly small enterprises which face fierce internal competition, as well as rivalry with other modalities like barge ships and trains. For this reason, road transport companies (hauliers) are constantly pursuing cost reductions and innovations to maintain the competitive edge. This thesis aims at exploring the dynamics of a distinct order-sharing network for container hauliers that has the potential to become such an innovation. By means of theory, a case study and simulations, the dynamics of a voluntary order-sharing network will be studied. This thesis examines how network characteristics affect the performance of the system and discusses the "optimal" network configuration. The goal is to use theory, numerical experimentation and empirics to identify generic relationships that are applicable for all voluntary order-sharing networks. This way, recommendations can be made regarding the set-up, regulation and development of voluntary order-sharing networks in general.

1.1 The road transport market

The total market share of the five largest road transport companies accumulated to only 8.6% in 2006, which affirms the strength of the internal competition and absence of concentration in the road transport industry (DHL freight, 2006). The low concentration can be explained by both the nature of the demand and the characteristics of the transport business. The demand for transport is a so called derived demand, meaning that consumers do not value it in its own right, but value it because it allows consumers to satisfy other demands. This makes it hard for transport firms to diversify themselves on aspects other than price, speed and reliability. The main characteristics of the transport market are low entry barriers, pro-cyclicality, strong market dynamics, availability of substitutes and constant returns to scale (Zhang, 1997). These characteristics, combined with the nature of the demand, result in a market that has a lot of suppliers (hauliers), a low average amount of employees and low margins. In 2012, for example, there were 526.000 road freight enterprises in Europe with an average amount of 5 employees per company, confirming the overpoise of small enterprises in the road transport industry (Eurostat, 2012).

The internal- and external pressure described in the first paragraph put a constant stress on hauliers to keep their prices low, while maintaining a high level of speed and reliability. To stay competitive, hauliers have increased efficiency in multiple ways. Rising fuel prices, for example, resulted in improvements in the aerodynamics of trucks and ease of legislation allowed hauliers to reduce labour costs by hiring eastern-European employees. A distinctive problem in the transport industry is the amount of empty kilometres that hauliers have to incur. Currently, around 21% of the total distance travelled by trucking companies is conducted without a load (Eurostat, 2012). In container transport, this is probably even higher, due to additional constraints coming from the ownership of a container. This implies that a significant amount of the operational costs are incurred during the performance of a non-value adding activity (hence, no money is being earned). Hauliers are therefore always trying to minimize the amount of empty kilometres, but are often impaired to do so due to their limited size. An order-sharing network might reduce this number significantly. By exchanging orders between hauliers, operational efficiency might be enhanced, because multiple orders can be combined in a single trip. A truck that moved a container from Rotterdam to Amsterdam, for example, might be able to pick-up a container from another haulier in Alkmaar on its way back to Rotterdam, in return for financial compensation. This way, the amount of empty kilometres is reduced, because the trip back to Rotterdam is conducted with a load, but also because there is no longer a need make an empty drive to Alkmaar to pick up the container.

New types of collaboration are emerging as way to stay competitive. They allow hauliers to exploit scale economies that can't be exhausted internally. By collaborating, hauliers can extend their resource portfolio, create a more efficient transport planning and strengthen their market position (Krajewska, 2006).

Operational collaboration, the type of collaboration that is studied in this thesis, is often done in two ways: order-sharing and capacity sharing.

- Order-sharing is done by combining the orders from multiple hauliers to create an optimal, aggregated routing scheme. The optimal configuration is then reallocated to the hauliers, which now have more efficient (and hence profitable) routes to drive. This way of horizontal collaboration is basically the exploitation of scale economies that reduces the travel distance for every participating haulier.
- Capacity sharing, on the other hand, means that hauliers don't exchange their orders, but are able to use each other's vehicles, which decreases the required capital for the transport enterprises.

This thesis examines the dynamics of an operational order-sharing system that is based on voluntary exchanges between its participants. The current literature mainly covers route optimization for single hauliers and joint-route planning for multiple hauliers with less-than-truckload (LTL) orders. This thesis specifically addresses the way network variables affect the performance of a network with multiple hauliers who deal with full-truckloads (FTL), based on voluntariness. It covers the research gap where the determinants of the performance are being studied, rather than just the performance itself. Furthermore, it addresses the research on joint-route planning theoretically, whereas most studies have used simulations only.

1.2 Research approach

This thesis examines how order-sharing networks have an impact on the operational efficiency of its participants and how the characteristics of the network affect the functioning of the network. The research question that is going to be addressed is:

‘*How do network characteristics affect the functioning of an order-sharing network and the operational efficiency of its participants?’.*

The sub-questions that are going to be addressed are:

- How does the network size affect the amount of reloadable orders?
- How does the network affect the cost-saving ability of a reload?
- Are there scale economies in voluntary order-sharing networks?
- How does the import/export ratio affect the performance of the network?
- Is every additional participant beneficial for the network?
- Do small hauliers have larger benefits from an order-sharing network, compared to large hauliers?
- Is there an ideal size of the network?

The study consists of six stages. First, the case study used to examine order-sharing networks, Boxreload, is described to identify the relevant aspects of order-sharing networks. Second, a literature study is conducted to place this thesis in the existing literature, answer the research question based on the existing literature and define the added value of this thesis. Third, a theoretical framework is constructed to derive hypotheses regarding the network characteristics and the performance of order-sharing networks. The fourth part describes the data and methodologies that have been used to test the hypotheses and the fifth part elaborates on the results of these tests. The sixth and final part summarizes these stages and concludes this thesis by describing the implications that these results have for voluntary order-sharing networks in general.

Chapter 2. The Boxreload project

This chapter describes the structure and functioning of the case study that is used to study voluntary order-sharing networks: the Boxreload project. Examining the characteristics of this specific order-sharing network is important, because it allows us to recognize the aspects that are likely to affect the performance of a network and are therefore relevant for this thesis. It also enables us to classify the concerning aspects in the existing literature, which should result in useful insights and further clarify in what ways this type of network differs from other types of networks. These aspects are also important concerning the choice of methodology, since these are dependent on the characteristics of the network. First, the idea behind the network, users and selection criteria will be described. Then the growth process and prospects will be examined.

2.1 The goal, participants & selection criteria

During the analysis of the case study, there were eleven hauliers participating in the Boxreload project, including the four initiators. The Boxreload project is an initiative of four hauliers in the Port of Rotterdam area called ‘truckload match’ and has been expanding since Hutchison Port Holdings started a co-operation with the initiators and the network was renamed as Boxreload. The goal of the network is to improve operational efficiency for all the participants by letting them exchange orders. The orders that are being exchanged result in financial compensation for the ‘seller’ of the order who gets paid by the client. The goal is to create so called ‘reloads’. A reload is conducted when a haulier ships a container from the port to an inland location (an import), drops the container, picks up a load that needs to be brought back to the port (an export) and drops this load at the port. By conducting a reload, the haulier reduces the amount of empty kilometers by means of triangulation and therefore reduces costs. Using a network like Boxreload enables hauliers to combine empty trips from themselves with empty trips from other participants to create a more efficient routing scheme. A more detailed description is found in section 2.3. The participants themselves have multiple characteristics in which they differ from each other. The most notable differences are the size of their fleet, service areas, import/export ratio, the shipping lines they serve and the size of their order portfolios. These will be examined below.

Fleet size

The average size of the fleet of the participants is around 75 vessels with a standard deviation of 37. As can be seen in table 1, the distribution seems to be uniformly distributed between 20 and 150, implying that Boxreload can be of interest to a heterogeneous set of companies. The average fleet size seems relatively high, since the average amount of trucks per transport company is around 9 (TLN, 2014). The participants of Boxreload, however, are specialized in container transport, which differs significantly from the road transport industry in general. This makes the comparison somewhat unfair, since container transport companies are often larger due to higher investment requirements. Although there are no clear numbers on the average amount of vessels per container-transport company, both Hutchison and the companies describe the participants as SME's, which is also an entry requirement. The relevance of this statement is that the Boxreload network deliberately avoids large corporations, because small clients are afraid those might take away their customers. The other two entry requirements are the need of owning the operating fleet and the obligation to pay a fixed fee to Hutchison.

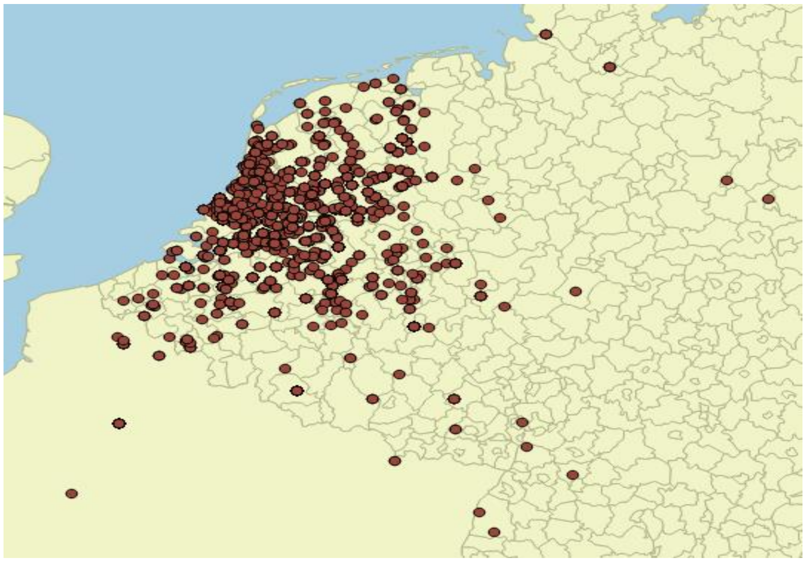
Table 1. Fleet size of the current participants

Haulier	Fleet size
1	0
2	21
3	35
4	40
5	80
6	85
7	100
8	110
9	120
10	150

Location pick-up/drop-off points

The clients of the participants are often clustered in cities, spread across the Benelux area and the western part of Germany. Looking at figure 1, which displays all shared orders from 27-4-'15 until 1-5-'15, it can be seen that the orders are spread across the entire map, but are mainly covering the western region, probably due to the demographic clustering of people. The figure should be examined with care, because it only shows the locations served, and not the intensity (i.e. the amount of orders to/from that location).

Figure 1. Collection point of the imports/exports



Although the map is based on just a 5-day sample, it is assumed that it is representative for other periods as well. This is confirmed by interviews with four planners where every interviewee stated that 60-70% of their orders are regularly conducted. The individual pick-up/drop-off portfolio of the hauliers are shown in Appendix 1. This is mainly of interest for the functioning of the network which will be discussed in the literature study.

Orders shared & orders/Vessel

The amount of orders shared and orders/vessel ratio (o/v) are relevant statistics for the functioning of the network. Assuming that hauliers with a larger fleet have a larger order portfolio compared to the smaller hauliers, the orders/per vessel ratio should be relatively constant across the sample size of the hauliers or even slightly declining with size, due to higher internal reload options that bigger hauliers might have. It is therefore a basic proxy to see how 'willing' a participant is to share orders with other hauliers. The haulier might offer just a part of their portfolio for varying reasons. For example, they are reluctant to share information regarding their clients or have the obligation towards certain customers that want to be served by the company they specifically hired to conduct the order. The o/v ratio is mainly interesting for the regulators of the network. A low o/v ratio might imply that some hauliers have become reluctant to use the network, which could hurt the functioning of the network. The underlying reason for differing o/v ratios are derived from the interviews with the hauliers and stated in chapter 5.

Order portfolio

Besides the size of the shared portfolio, the composition is likely to be important for the usefulness to the network. Four factors play a role regarding the composition: the order being an import/export, the location of the pick-up/drop-off point, the shipping line owning the container and the time frame. The import/export ratio gives a general proxy of matching abilities, since every import has to be matched with an export. When the import/export ratio of the network is skewed to one side, it is likely that the network would benefit more from a haulier with an order portfolio skewed to the counterpart, rather than being skewed in the same direction.

An overview of the descriptive statistics are given in table 2. These statistics show the number of vessels per company, their location, the amount of orders, the import/export ratio and orders shared per vessel and capture the essential characteristics of the participants.

Table 2. Descriptive statistics of the hauliers

Haulier	Number of vessels	Location	Orders shared	%Imports	%Exports	Orders shared / Vessel
Haulier 1	0	Rotterdam	-	-	-	-
Haulier 2	21	Rotterdam	87	74%	26%	4.1
Haulier 3	35	Rotterdam	172	30%	70%	4.9
Haulier 4	40	Ridderkerk	344	66%	34%	8.6
Haulier 5	80	Geldermalsen	-	-	-	-
Haulier 6	85	Rotterdam	255	41%	59%	3
Haulier 7	100	Rotterdam	822	60%	40%	8.2
Haulier 8	110	Zierikzee	507	34%	66%	4.6
Haulier 9	120	Rotterdam	668	54%	46%	5.6
Haulier 10	150	Spijkenisse	869	55%	45%	5.8
Haulier 11	n/a	De Rijp	147	-	-	-
Total	741	-	3871	52%	48%	5.2

2.2. Growth process and prospects

As stated earlier, the Boxreload network is based on a co-operative partnership between four hauliers. The network has been expanding to the current amount of eleven hauliers, which will increase to 25 by the end of 2015. The goal of Hutchison is to create a network of 40 particpants, which should be feasible by the end of 2016. Although Hutchison has a clear incentive to expand the network (they get a monthly fee from every participant), it is unclear what the impact of the amount of the participants is on the functioning of the network. This is a very important aspect regarding the attractiveness of new participants. This shall be examined more extenstively.

2.3. Using Boxreload

Boxreload is a optimization program developed by Paris Optimal Planning, a subsidiary of Hutchison Port Holding UK. The user can start the program and enter the orders they are willing to match. The program then tries to match the import/export order of the haulier with export/import order from another haulier. Per order, it shows the three potential matches with the highest monetary saving potential. These are also the matches with the highest CO2 potential (according to the system), due to the perfect collinearity between CO2 and costs in the optimizing algorithm. When the orders are entered into the system, there are five possible scenarios:

- Scenario 1: haulier 1 selects one of the suggested matches, haulier 2 receives the suggestion and accepts. Haulier 1 is now conducting the order of haulier 2 as well and gets a financial compensation from haulier 2.
- Scenario 2: haulier 1 selects one of the suggested matches, haulier 2 receives the suggestion and declines. There are no shifts in orders.
- Scenario 3: haulier 1 enters his orders, receives a suggestion from haulier 2 and accepts the suggestion. Haulier 2 is now conducting the order for haulier 1 and haulier 1 financially compensates haulier 2.
- Scenario 4: haulier 1 enters his orders, receives a suggestion from haulier 2 and declines the suggestion. There are no shifts in orders.
- Scenario 5: haulier 1 enters there orders, there are no suggestions by either one of the participants. There are no shifts in orders.

Voluntariness, discreteness and profit division

Some important aspects concerning the way orders are being exchanged are voluntariness, discreteness, and profit division. The voluntary aspect concerns the method of matching the orders. The hauliers can enter their orders in the system, check the attractiveness of the suggested matches (either made by themselves, or by other participants), but are never obliged to conduct a reload or outsource their own orders. This way, hauliers have an incentive to enter orders into the network, since they can never be worse off and often get the opportunity to improve their operations. The main barrier, however, is the information about their portfolio that they share with the other participants. Boxreload reduces the amount of shared information by only showing the best potential matches (instead of the entire order set). Furthermore, hauliers are free to leave certain orders out of the portfolio which they upload to the network, whenever they are afraid that clients can be captured by other participants. They are also allowed to apply filters to the group of participants, restricting the system to make suggestions with selected participants only. The role of information sharing and social control will be discussed in the literature study.

The division of the synergies created by the network is conducted in a simple and transparent way. The four initiators of Boxreload have regular meetings in which they state their tariffs per kilometre driven per TEU. The average of these tariffs is taken and is used as the financial compensation factor in the network. For example, when haulier 1 decides to match and conduct an order (A to B) from haulier 2, haulier 1 gets a financial compensation given by the amount of kilometres between A and B times the compensation factor derived by the initiators. Haulier 2 is still getting paid by his client, but needs to pay haulier 1 his financial compensation. In general, such a match is only agreed upon when there is a clear win-win situation.

Role of the shipping lines

A significant constraint in the matching process is the ownership of a container used to conduct the order. A reload can only be conducted when the container is owned by the same shipping line both for the import and the export. Otherwise, the haulier who conducts the orders needs to change containers at an empty depot which is often expansive and time consuming and significantly decreasing the synergy of a reload. Although this is an interesting and relevant aspect, the relationship between hauliers and shipping lines won't be dealt with in this thesis.

The alternative

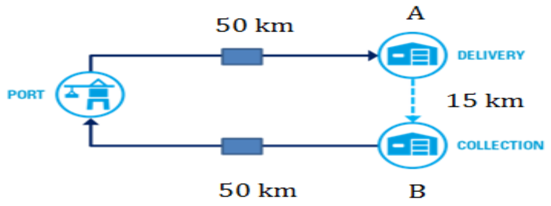
Of course, sharing orders is not a new phenomenon in the road transport industry. The predecessor of Boxreload was a mailing list called Multimail. Multimail, a mailing list consisting of approximately 80 hauliers, in which the subscribed hauliers could either offer or ask for orders and send their request to the other subscribers. The main benefit of Boxreload is that it automatically recognizes the best matches and gives a proper estimation of CO2- and cost reductions. Furthermore, it allows hauliers to look at opportunities to improve their portfolio, even when it is already profitable to conduct the orders themselves. In general, Boxreload is easier to use, increases reload opportunities and reduces the time to construct reloads.

So far, the structure, development and use of the network have been discussed. Now, the basic model behind Boxreload will be examined and the source of the synergies will be briefly discussed.

Triangulation

The basic idea behind Boxreload is straightforward: firms exchange orders to improve their operating scheme, reduce empty kilometres, costs, emissions and increase profits. They do so by triangulating their orders in a way that the total distance that needs to be covered by two hauliers, decreases when it is conducted by a single haulier. The basic idea is shown in figure 2.

Figure 2. Basic Triangulation



The figure above represents a simplified situation in which haulier 1 needs to move an import from the port to A and haulier 2 needs to move an export from B to the port. When these orders are conducted separately, haulier 1 picks up the import from the port, drops it off at A, and goes back empty to the port[1]. Haulier B drives empty from the port to B, picks up the export and drops it off at the port. In this example, both parties have driven empty 50% of the time (50 kilometres). Suppose haulier 1 and 2 collaborated and assigned both orders to one party. Haulier 1 could move the import from the port to A, drive empty from A to B and pick-up the export at B and bring it to the port. This way, only 13% (15km) is being driven empty, significantly reducing the conjoined operating costs of the orders. The remaining question is how these benefits are divided between haulier 1 and 2. As mentioned in section 3.2.1., both hauliers get paid by their respective clients. The haulier conducting the reload of the other haulier gets financial compensation from the other haulier at a predetermined rate. The synergy is created because haulier 1 increases its utility rate, due to the reduced amount of empty kilometres it has to drive and haulier 2 gets paid by the customer, makes no operating costs and only has to pay haulier 1 a financial compensation that is lower than the amount he gets paid by the customer, since the payment of the client also includes some margin for the compensation of the

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[1] The place of the trucking depot isn't relevant, because the total amount of empty kilometres stays constant. When the trucking depot is located at A, the haulier needs to drive empty to the port and return with the import, still having the same amount of empty kilometres. Since all-but-one hauliers are located in Rotterdam, it is assumed that this is their start-off point.

operating costs made by driving empty. This way, a win-win situation is created in which both hauliers increase their profits by reducing the combined amount of empty kilometres.

The example given in the previous paragraph explained the basic idea behind the Boxreload project. In reality, however, there are more aspects that need to be taken into account. Hauliers, for example, are often able to make internal reloads, are reluctant in sharing information about their clientele and form internal clusters which can significantly reduce the use of the network. The goal of the subsequent literature study is to review existing literature on the aspects of the order-sharing network discussed in this chapter. By examining the aspects that have- and have not been studied, the thesis will be placed in the existing literature and its contribution towards the literature shall be clarified. Furthermore, the appropriate methodology to study the network and the associated characteristics will be derived.

2.4 In short

In this chapter, the structure and functioning of the network has been described. By describing the network and the way it operates, the main characteristics of the network are derived, which are used to place this network in the existing literature. The Boxreload project itself is an order-sharing network with a current amount of eleven participating hauliers. These hauliers are specialized in the transport of sea containers and have either import- or export orders. The participants are heterogeneous in terms of vessel size, import/export ratio, amount of orders and orders/vessel. The amount of participants is expected to double by the end of 2015 and be capped at 40 by the end of 2016. Entering requirements are the classification of SME (according to Hutchison), ownership of own fleet and a fixed, annual fee for using the system. In Boxreload, participants can enter their orders and will receive match suggestions created by an algorithm that instantly shows potential savings in terms of costs, emissions and kilometres. The synergies are derived from the triangulation of import and exports. The system itself operates on a voluntary base, meaning that participants have no obligations and are free to enter any order they want. The hauliers can accept/decline offers from other participants or make offers themselves. The orders are shown in a discrete way, meaning that hauliers can only see the suggested matches. When a match is made, the haulier conducting the reload receives financial compensation from the other participant at a predetermined rate. This way of order-sharing aims at replacing the outdated multimail system, encouraging hauliers to co-operate more often and reducing the costs, empty kilometres, emissions and road congestion.

Based on this chapter, the performance can be measured in three ways: the amount of reloads that are being conducted by the network, the total amount of kilometers/CO_2 saved because of the network and the monetary gains for the participants because of the use of this network. The variables that are likely to affect these performance indicators are: the total amount of participants, the amount of orders per participants (market share distribution), the import/export ratio of the order portfolios, the locations of the orders and the amount of orders per shipping line. The next chapter examines the current literature on (voluntary) order-sharing networks. Together with this chapter, it will provide us with the variables that are going to be examined in this thesis.

Chapter 3. Literature study

In this chapter, the existing literature on horizontal collaboration in the road-transport industry, vehicle routing problems with backhauling and order-sharing mechanisms will be reviewed. The main goal is to place this thesis in the existing literature and examine to what extent the research question can be answered based on the existing literature. Note that this also defines the added value of this thesis. The starting point will be the most generic description of the voluntary order-sharing network: horizontal collaboration. From the general description, more specific literature regarding voluntary order-sharing networks will be reviewed.

3.1. Horizontal collaboration

A wide variety of definitions are used to describe the relationship in which two or more firms work together to achieve commonly determined goals. Collaboration, alliance and co-operation are among many terms to describe this relationship. In the existing literature, there is no consistent way of using these terms, neither is there a clear scale or universal measure to rank the types of horizontal cooperation. In this thesis, terms used to describe horizontal collaboration are interchangeable.

Horizontal collaboration entails the co-operation of firms which operate at the same level of the supply chain and share their private information and/or resources to create mutual benefits (Sridharan, 2002). These benefits are often referred to as relational rents; synergies created by the participating companies that result in win-win situations. These synergies can be hard (e.g. measurable cost reductions) or soft (e.g. learning) and are either created by economies of scale or economies of scope. Order-sharing networks like Boxreload exploit synergies created by scale economies, because the efficiency is created by volume, rather than variety.

In the road-transport industry, the synergies mentioned above can be categorized as operational-, coordination,- and network synergies. Operational synergies are exploited when the co-operating companies are only co-operating on an operational level. For example, by exchanging orders to increase efficiency or share capacity in case of over-utilization. Coordination synergies are exploited when companies are aligning their strategies to create structural benefits. For example, they create a centralized planning system instead of occasional order exchanges. Network synergies are exploited when firms start long-term co-operations in which not only strategies are aligned, but tangible joint investments are being made. For example, two hauliers who start a joint maintenance center for their trucks (Vos, et al., 2002).

This thesis deals with the dynamics of an order-sharing network based on operational synergies. Firms solely co-operate by exchanging orders to improve their utilization rate and create operational benefits. They don't interfere with each other's strategic goals and are not participating in any joint activities other than Boxreload.

Operational synergies in the road-transport industry are exploited in various ways. In general, operational collaboration in the road transport industry is conducted by means of order-sharing or capacity-sharing. Order-sharing refers to a co-operation in which hauliers exchange orders to improve efficiency, reduce costs and therefore increase profitability. Capacity sharing refers to a co-operation in which vehicle capacity, rather than orders are being exchanged (Verdonck, 2013). So both operational collaboration types aim at improving efficiency; order-sharing by reallocating demand, capacity sharing by reallocating supply. Since the aim of this thesis is to study the dynamics of order-sharing networks, these shall be examined more extensively.

3.2. Order-sharing

The essence of order-sharing networks is the exploitation of scale economies by combining orders of multiple hauliers to improve operational efficiency. In other words, firms are aiming at operating as if they are one merged firm. The existing literature describes five order sharing techniques that aim at reallocating orders to improve efficiency: (1) joint route planning, (2) auction based mechanisms, (3) bilateral lane exchanges, (4) order swapping and (5) shipment dispatching policies. An extensive review of these techniques can be found in Verdonck et al. (2013).

The Boxreload network is best described as a combination of the joint route planning- and an auction-based order-sharing technique. It combines features of both sharing techniques to improve the hauliers' routing schemes by centrally optimizing the routes via an optimization program and exchanging orders via an auction-based mechanism. The relevant aspects of both techniques that are applied in Boxreload will be reviewed. Since a large part of this thesis deals with the configuration of reloads, it is also important to examine how the optimization (or establishment) of the reloads has been developed in the existing literature. In other words: how is the optimal joint route planning configured? The most common reference to a reload is the so called Vehicle Routing Problem with Backhauling (VRPB). Since this is the starting point of the co-operation, this will be reviewed first.

3.2.1. Vehicle Routing Problem with Backhauling

A vehicle routing problem with backhauling (VRPB) exists when a haulier needs to deliver and(!) collect its orders from multiple locations. For example, a company that delivers new fire extinguishers and picks up old ones to be recycled. This is basically the same problem as port-bound container transport, since imports need to be delivered inland and exports need to be shipped back to the port.

One of the first studies that examined backhauling with FTL's has been conducted by Burns et al. (1984) who studied a simple backhauling system for trucks with only two terminals, full-truckload orders, no travel times/time restrictions and no capacity restrictions. Two specific models have been used: a continuous backhaul model that assumes that customers are located randomly over a region at a constant density and a discrete model that used the actual travel distances between each terminal and each customer. The continuous analysis showed that total backhaul savings were the highest when there was an equal market share distribution (comparable to an equal division between imports and exports in this thesis), that the reduction of imbalances of orders led to diminishing marginal savings, and that the location of the terminal played a significant factor in the minimization of empty miles. The discrete model answered the question which backhauls (reloads) to conduct specifically.

Multiple studies have since been conducted to develop heuristics that optimize the route planning with respect to costs and empty mileage. These heuristics have been developed, because firms still have to make tradeoffs between solution quality and computational requirements (finding the single best solution can require exceptional computing time). Deif et al. (1984) used an extended version of the basic linear programming method developed by Clarke and Wright (the sequential savings algorithm) to optimize backhauling routes for less-than-truckload orders (Clarke, 1964) (Deif, 1984). Goetschalckx developed a heuristic that also dealt with LTL's, but used space filling curve heuristics (i.e. clustering the customers) to derive an initial solution, after which the second solution can be derived in much less time. This heuristic performed better than the heuristics used by Clarke et al. (Goetschalckx, 1993).

The first study that presented an exact approach for the solution of the VRPB with LTL's has been presented by Toth and Vigo (1997). The authors reformulated VRPB as an asymmetric problem and used an integer linear programming model to derive a Langrangian lower bound. The same problem, however (the tradeoff between computation time and solution quality), still existed (Toth. Vigo, 1997). For this reason, Toth and Vigo also developed a new heuristic algorithm two years later. In their paper, they presented a so-called tabu search algorithm. The main idea behind a tabu search, is that an initial solution is being valued to see 'how well' the solution is and check the solutions that are close to the initial solution (i.e. only differ in one or two details). Choose the best solution that is close to the initial solution (even if it's worse) and place the other solution in a tabu list (from which the solutions aren't being considered anymore). If the new solution is better, use that solution to start over again (Toth, 1999).

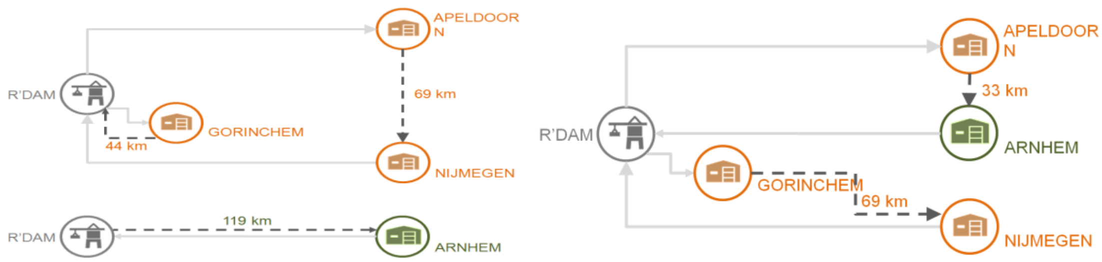
The best VRPB heuristic so far that is related to FTL-orders has been developed by Imai et al. (2007). Imai et al. developed a subgradient heuristic based on a Langrangian relaxation. It has been tested on a wide variety of problem examples and was able to efficiently solve large instances of the problems in a better way than its predecessors (Imai, 2007).

So far, we have classified voluntary order-sharing networks in the existing literature and reviewed how VRPB problems have been solved exactly and by means of heuristics. The next paragraphs will deal with the existing literature on the order-sharing techniques themselves and how they affect the optimal planning of their participants. First joint route planning will be discussed, than auction-based mechanisms.

3.2.2. Joint route planning

A joint route planning technique is applied when orders from multiple hauliers are collected and a single, optimal, routing scheme is created. These orders are then optimally reassigned over the hauliers, based on an optimization technique. The specific type of technique depends on the optimization problem which is defined by the characteristics of the routing problem (e.g. FTL/LTL, centralized/decentralized). An example of joint route planning is given in Figure 3, where two hauliers use a joint route planning to reduce empty kilometres. Haulier 1 has to conduct three orders: bringing an import from Rotterdam to Apeldoorn, bringing an export from Nijmegen to Rotterdam and bringing an import from Rotterdam to Gorinchem. Haulier 2 has one order: bringing an export from Arnhem to Rotterdam. When these orders are reallocated between the hauliers, haulier one is now conducting haulier 2's export from Arnhem to Rotterdam and haulier 2 is conducting haulier 1's import from Rotterdam to Gorinchem. By using joint route planning, the amount of empty kilometres is reduced by 57%. Note that this an extreme example with the sole purpose of demonstrating the technique.

Figure 3. Reload example


Situation 1

Situation 2

Joint route planning has been used in multiple studies, where different types of joint route planning techniques have been tested.

Cruijssen & Salomon (2004) conducted a case study in the Dutch flower industry, to assess the saving potential of joint route planning for less-than-truckload orders that needed to be delivered from a centralized warehouse. To compare the performance of the before- and after situation, the authors used four performance indicators: (1) total fixed & variable costs, (2) number of kilometres travelled, (3) number of trucks used and (4) load factor of the trucks. The former three can be used as performance variables for the dynamic cost savings model used in this thesis, the latter one isn't, since Boxreload relates to full-truckloads. The general savings were found to be between 5-15%, a significant cost reduction in the transport industry. Of relevance for this thesis, however, were the variables that had an impact on these savings that were identified by the authors. These were the number of transportation orders, the clusteredness of the demand points, the number of participating companies and the market share distribution. Average order size was also considered, but isn't relevant for this thesis because of the use of full truck loads. The number of transportation orders, clusteredness and amount of participants were positively related to the performance of the network (in terms of costs), the market share distribution was negatively related to the network performance (i.e. a less equal division of market share is negatively related to the savings made by the network).The findings of this study have been confirmed by a more recent study of Cruijssen et al. (2007) where they studied joint route planning under various market conditions for a random routing problem with 1,000 orders and 3 hauliers. The authors showed that the use of joint route planning can result in a cost reduction of 30.7 per cent. However, they also noted that this is highly dependent on the industry and configuration of the network. This can be illustrated by two other case studies. The first case study considered three Dutch companies (Douwe Egberts, Unipro and Masterfoods) whom decided to start a joint distribution of their frozen products. Because temperature controlled trucks are very expensive compared to 'normal' trucks, and the customers of the companies were located very close to each other, savings were around 30.8 per cent (Cruijssen F. B., 2007). In a different case study on consumer goods (cosmetics), conducted by Bahrami (2002), costs reduction accomplished by joint route planning of two firms were only 15.3 per cent (Bahrami, 2002), which makes it clear that the characteristics of the network play a significant role in its saving ability.

For this reason, three years later, Cruijssen et al. studied how different market situations would lead to different saving outcomes for an LTL order network . By varying the amount of participants, the amount of orders per participants, the standard deviation of the order size (he studied LTL's), time window width, size of the distribution area's and the market shares of the particpants, the authors managed to assess the relationship between each variable and the cost savings ability of the network. Relevant for this thesis are only the amount of participants, the amount of orders per participant, the size of the distribution area's and the market shares since FTL's are being discussed.

The results of their analysis showed that the number of orders per company tend to increase the average per cent savings up to a certain point, after which it starts declining. This can be explained by scale economies that increase cost saving opportunities, but only up to a certain point because firms will also become more capable of making more efficient reloads by themselves (internal scale economies). The results also showed that the amount of participants is positively related to the saving ability of the network (i.e. synergy value). The authors also mention that this doesn't necessarily means that a large group is always better since transaction costs are also involved in the set-up and maintenance of the network. The size of the distribution area has also been varied by changed the distance of each drop-off location from the depot. The results showed that the synergy value of the network decreasingly increased when distances increased. In other words: joint route planning seems more profitable in sectors in which actors are more distant to each other compared to a clustered sector. The last market variable, market shares of participants, has been examined by changing the Gini coefficient (a competition proxy from social welfare theory). Simulations showed that the saving ability of the network decreased when market share inequality increased.

3.2.3. Auction-based mechanisms

Joint route planning is proven to be a suitable technique to decrease transport costs for an order-sharing network. The main difference with the network studied in this thesis is the method used to exchange orders between companies. In joint route planning, optimization software often distributes the orders to the haulier that is able to conduct the order at the lowest cost. The biggest issue is that the optimal division doesn't automatically result in a pareto-improvement for all hauliers. Some hauliers bring in orders that are profitable for themselves, but are reallocated to other participants. When the hauliers gets less profitable orders (or no orders at all) in return, it is likely that they will leave the network quickly if not compensated sufficiently. Furthermore, joint route planning is based on the idea that participants integrate an entire transport division with the transport division of others. Voluntary order-sharing networks are based on the idea that only some individual orders are being exchanged. Joint route planning mechanisms optimize the entire portfolio. Auction based mechanism optimize the best match for every order individually.

In auction-based order sharing, each participant can voluntarily place his orders in the system. Other hauliers can then bid on the orders and are financially compensated for conducting the trips. From a game-theoretic approach, the use of a Vickrey-auction should lead to a configuration in which profits are being maximized, given that each haulier benefits from the network (Berger & Bierwirth, 2010). This means that every haulier can place an offer anonymously and the winner gets the order for the second-highest price. So whereas the joint route planning results in a configuration that minimizes costs, auction-based optimizing maximizes profits, given that each haulier should benefit from co-operating.

The fact that the auction-based characteristic of voluntariness plays a significant role in the functioning of the network implies that some additional factors, beside the ones mentioned in joint route planning, play a role in the dynamics of a voluntary order-sharing network. These are based on the transaction costs mentioned in section 3.2.2. (Cruijssen et al. 2007) and will are reviewed below.

Reputation and experience

According to Wang & Kopfer (2011), the most common risk in horizontal collaboration is the presence of opportunistic behaviour. When a company conducts a reload, it is conducting a trip for his own client, as well as a client of another participant. Opportunistic behaviour arises when the incentives of the co-operating hauliers are diverging (Wang & Kopfer, 2011). The haulier that gets paid by the client has an incentive to deliver the load on-time and in a proper manner to keep the client satisfied. The haulier that is conducting the reload for another haulier is mostly concerned that the container gets there as cheap as possible. This might lead to a situation in which the conducting haulier does a poor job on the delivery, for example by arriving late or giving bad service. The client is likely to blame the original haulier to whom the order has been appointed. It is therefore important that there are clear arrangements between the participants and some sort of a contract to avoid opportunistic behaviour (Cruijssen & Braysy, 2007).

Another form of opportunistic behaviour that is especially relevant in horizontal collaboration is the opportunity of participants to capture clientele from other hauliers. By sharing orders, firms are automatically sharing information about the clients they serve and the amount of orders they conduct. Other hauliers might benefit from this information by actively approaching other hauliers' clients. When a haulier has an insufficient amount of trust that its partner averts opportunistic behaviour, this might lead to a reload scheme in which a haulier accepts to incur extra costs due to distrust.

Trust

Although trust plays a considerable role regarding opportunistic behaviour, it is expected to be of extra importance to new entrants. Contrary to existing participants, new entrants often can't rely on a good reputation, since they simply haven't any historic records with other participants. This results in the question why current participants would want to work with new entrants in the first place. Initial trust, according to McKnight et al. (1998) is based on the disposition of the current participants to trust (how willing they are to rely on others) and initial beliefs, based on the characteristics that can be derived from other parties. Furthermore, experience of co-operating with new entrants has an influence on the willingness to start new co-operations (Williamson 1993). Solutions to trust issues have also been proposed. According to Braun (2002), trust becomes redundant when systematic mechanisms like formal contracts are able to regulate opportunistic behaviour. Excessive use, however, can backfire when regulation becomes too costly or time consuming (Fulop, 2000). In Boxreload, there are no controlling mechanisms (e.g. penalties). Poor performance will harm the relationship, but isn't regulated by a centralized system. The adoption of new firms in the Boxreload is therefore expected to depend on two factors: the disposition of trust and characteristics of the entrant. Entrants are therefore likely to start using the network by co-operating with the users most open to collaboration, expectantly the initiators of the network. Some entrants are also expected to have more difficulties in the start, due to their characteristics. Big companies, for example, might have more difficulties in the beginning, since these are often suspected of stealing clients from smaller participants. The role of trust, focussed on new entrants, will be evaluated in interviews with the hauliers.

(Un)fairness

A major difference between JRP and AB-mechanisms, is that hauliers using AB-mechanisms decide for themselves how orders are being reallocated. Although the division of gains is clear (due to the standard compensation tariff), there might still be issues regarding the fairness perception. In general, firms prefer to conduct orders themselves rather than outsourcing them to other parties due to the profit margin that is incurred by the conductor. Since nearly all firms are located in/near Rotterdam, it is fair to assume that some orders can be conducted by the same haulier while keeping savings constant. Because conducting the order is assumed to be more profitable than outsourcing it, firms prefer to conduct the reload, rather than share their order. Fairness, in this case, refers to an equal division of reloads between the hauliers. The extent to which this has an impact on order sharing is an interesting question and especially relevant in voluntary order sharing systems like Boxreload.

3.3. Overview

In this chapter, the existing literature on voluntary order-sharing networks and its relevant characteristics have been reviewed. This type of collaboration can be classified as operational co-operation in which participants exchange orders to achieve synergies. Voluntary order-sharing networks combine three topics in the existing literature: vehicle based problems with backhaul (VBPB), joint route planning and auction based mechanisms. VBPB deals with the way order portfolios can be conducted in the most efficient way. In the case of voluntary order-sharing networks, this means that VBPB is used to find the most efficient (i.e. cost minimizing) match for every particular order. The joint route planning literature discusses how cost savings can be achieved by optimizing the combined portfolios of multiple hauliers and how the cost saving ability differs for varying market conditions. Auction based mechanisms is a topic that covers the way in which hauliers decide to actually exchange orders and which factors affect this decision. The added value of this thesis is therefore the examination of individual network characteristics and the development of a probabilistic framework to add explanatory power to the existing concepts. Furthermore, occasional exchanges have been studied, rather than full integration of systems.

Chapter 4. Theoretical Framework

In the previous two chapters, the relevant characteristics regarding the functioning and performance of voluntary order-sharing networks have been derived and reviewed. In this chapter, hypotheses regarding the research question will be constructed. The methods and data used to test these hypotheses are described in the next chapter.

In chapter 2, the main characteristics of a voluntary order-sharing network, the Boxreload project, have been described. Four measurements of performance have been derived: (1) total amount of reloads made, (2) the amount of kilometres that has been reduced, (3) monetary savings and (4) total CO_2 reduction. The main characteristics of the network itself were the amount of participants, the total amount of orders put into the system, the amount of orders per participant (market share distribution), the import/export ratio of the order portfolio, the fleet size and pick-up/drop-off points of the orders. From a practical point of view, the most convenient way to study how network characteristics affect the functioning of the network is to examine how the amount of reloads will change for varying market conditions, because it is assumed to be representative for the monetary savings, reduction of empty kilometres (and CO_2) and is less complex to compute from a probabilistic point of view. To answer the research question and study how these variables affect the performance of the network, a theoretical depiction of the network is described below.

In a voluntary order-sharing network with FTL-orders, each participant can enter their orders (being an import or an export) into the system. For each orders they enter, they see the most profitable reloads for them to suggest to other hauliers. They can also receive suggestions from other hauliers and can accept or decline these. First, let us assume that the probability that an import n and export m can be matched (i.e. meet time- and shipping line criteria) is equal for all order combinations and is equal to p. The network can now be depicted as figure 4. Under this assumption, hypotheses regarding the research question will be derived.

Figure 4.. network overview with probabilities on being reloadable

	I_1	I_2	I_3	. . .	I_n
E_1	p	p	p		p
E_2	p	p	p		p
E_3	p	p	p		p
.					
.					
.					
E_m	p	p	p		p

4.1 Network size and reload opportunities

First, the relation between the network size and the amount of reloads will be studied. This will give the first implications about the relationship between the amount of participants, the amount of orders per participant and their impact on the performance of the network. Furthermore, the first implications about the usefulness of the network related to the size of the participant will be derived.

Determining the relationship between network size and the amount of reloads made in a network is a very complex problem. This is due to the fact that every reload possibility is related and dependent on all the other reload possibilities and every order can only be matched once. For example, when there is a match between Export 1 and Import 3, this means that all the export orders cannot be matched with import 3 and all the import orders can't be matched with export 1. This makes the problem very complex from a probabilistic point of view, because of the fact that if a reload can be conducted, it doesn't necessarily mean that it will be conducted.

The following example will further clarify the problem: suppose we have three import orders, two export orders and there are six reload opportunities: a, b, c, d, e and f (figure 5). Besides the probability that a reload could be conducted, the chance of it actually being conducted also depends on the outcomes of the other reload opportunities. Combination a, for example, has a probability *p* of being reloadable. The chance that a is actually going to be a reload also depends on the chances of c, b and e being conductible. So far, it is not that difficult. The complexity comes from the fact that c, b and e (which a is dependent on) also depend on all the other reload opportunities. If a, b and c are the only conductible reload opportunities, the maximum amount of reloads is 2, but if a is conducted, both b and c drop out and the amount of reload is only 1. It is therefore very complex to derive an expected amount of reloads given a certain probability for a combination of orders of being reloadable.

Figure 5.. Network probability example.

	I_1	I_2	I_3
E_1	a	b	e
E_2	c	d	f

To simplify the problem, it is assumed that the maximum amount of reloads that can be made, given the outcomes of each combination being reloadable or not, is a proxy for the amount of reloads that are actually conducted. This is based on the idea that more reload opportunities in general, increase the attractiveness of the reload options, increase the amount of orders that can be matched and will therefore lead to more reloads being conducted. The maximum amount of reloads that can be calculated is as follows:

If a column or row has at least one reload opportunity that takes the value 1 (i.e. in that specific row/column, an import can be matched with an export), the entire column/row takes the value 1. The maximum amount of reloads that can be conducted is the sum of rows and columns that take the value 1, minus the absolute difference between these 2. Using the expected maximum amount of reloads still suffers from the interdependency problem described above, but the relation between network size and expected maximum amount of reloads can now be constructed by deriving an upper- and lower bound between which the expected amount of reloads must lie.

The upper bound is chosen as a very straightforward value: it is equal to half the total amount of orders minus the absolute difference between imports and exports. In other words, it is equal to either the total amount of import or exports, depending on which category has the fewest orders. The lower bound is chosen by means of an heuristic. This heuristic is based on a greedy algorithm which takes the first combination of import and export in the matrix that can be conducted as the reload that will be conducted (starting from left to right, from top to bottom). This is a lower bound of the expected maximum amount of matches, because this heuristic takes the first reload opportunity according to a “first come first serve principle” and therefore systematically underestimates the expected amount that can be conducted. This can be illustrated by the same example as given in figure 6. Suppose a, b and c are all conductible. The maximum amount of reloads is 2 (b and c). The greedy heuristic, however takes *a* as a reload and therefore excludes *b* and *c*. This, in turn, means that the maximum amount of reloads isn’t reached. This example illustrates how the heuristic systematically underestimates the expected maximum amount of reloads.

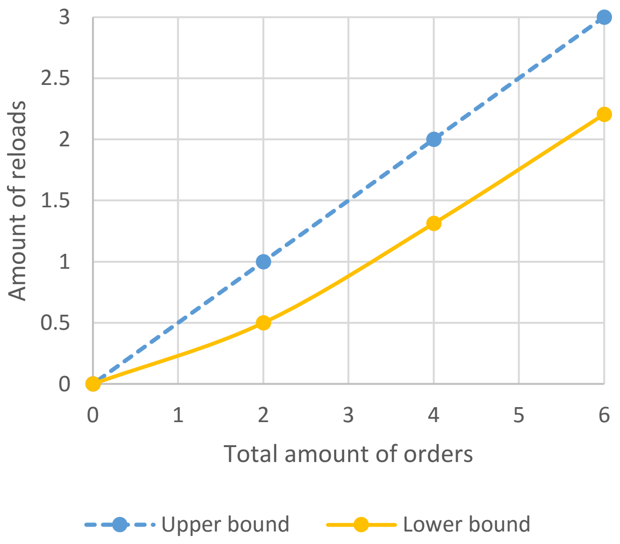
Now that the upper- and lower bound of the expected maximum amount of reloads have been defined, it's relationship with the network size can be examined. To do so, the expected values for all combinations of 3 imports and three exports have been determined for p=0.5. These are equal to the chance for every combination of being involved in a reload. These have been derived by manual calculations on probability trees.

Figure 6.. Expected values for p=0.5

	I_1	I_2	I_3
E_1	$^{1}/_{2}$	$^{1}/_{4}$	$^{1}/_{8}$
E_2	$^{1}/_{4}$	$^{5}/_{16}$	$^{13}/_{64}$
E_3	$^{1}/_{8}$	$^{13}/_{64}$	$^{121}/_{512}$

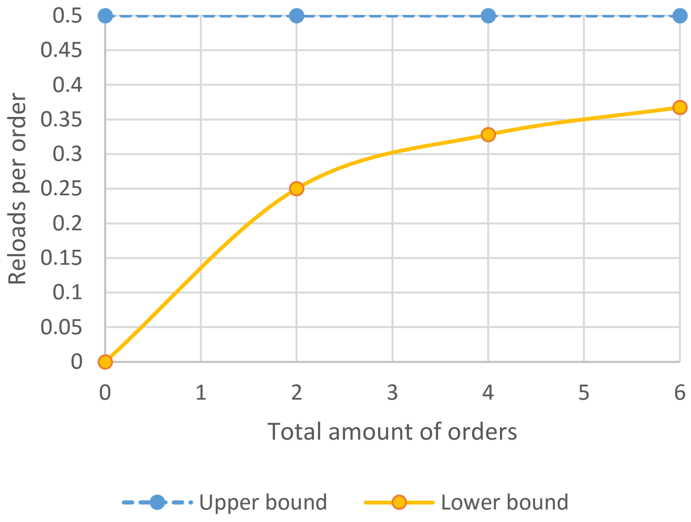
To derive the relationship between the expected maximum amount of reloads and the network size, the upper- and lower bounds of the expected values of three different network-size portfolios can be plotted. These are shown in figure 7.

Figure 7. Upper- and lower bound for expected maximum amount of reloads with p=0.05



An even better way to represent the relationship between network size and the expected maximum amount of reloads is to plot network size against the average amount of reloads per order. This is done in figure 8.

Figure 8. Upper- and lower bound for expected maximum amount of reloads per order with p=0.5



Since the expected maximum amount of orders must lie in between the upper- and lower bound, a concave relationship between network size and the amount of reloads per order is expected to exist. Both figures imply that there are positive scale economies: networks tend to perform better when they are bigger. From these observations, the following hypotheses can be derived:

Hypothesis 1: there is a positive relationship between the amount of orders in a network and the average amount of reloads.

Hypothesis 2: the number of participants is positively related to the performance of the network.

Hypothesis 3: voluntary order-sharing networks are more beneficial for smaller hauliers compared to larger hauliers.

Note that each of these hypothesis basically answers the same question: are scale economies present in voluntary order-sharing networks? They are addressed individually, however to emphasize the different implications that the outcome may have on the governance of the network. To answer the question about scale economies specifically, the relationship between network size and the saving potential of the reloads themselves must also be examined. In other words: is there a relationship between the size of the network and the average savings that are made by a reload? This is examined in the next paragraph. The role of the amount of shipping lines isn't considered individually, since reloads can only be made at hauls with the same shipping line owning the container. An increased amount of orders/increased amount of participants can therefore be considered as an increased amount of orders per participant for that specific shipping line. This is included in the probability function, since it is one of the requirements for conducted a reload.

4.2 Network size and saving potential of a reload

In the previous paragraph, the relationship between the amount of orders and reload opportunities has been examined. In this paragraph, the relationship between network size and the saving potential of a reload will be discussed. This paragraph, combined with the previous one will give insight in the presence of scale economies in the container transport industry. When the amount of orders increases, the distance between a randomly selected order and its closest counterpart (i.e. import and export) is likely to become smaller. This is based on the assumption that orders tend to be spread across a certain area. A higher density leads to a higher proximity between orders and therefore results in reload opportunities for which a smaller total amount of kilometres needs to be driven. For this reason, it can be expected that increasing the order portfolio does not only result in more reloads, it is also expected that it will lead to more efficient reloads. The hypothesis regarding this topic can therefore be written as:

Hypothesis 4: network size is positively related to the average cost saving ability of a reload.

Combining these hypotheses, the main question regarding network size can be answered:

Hypothesis 5: voluntary order-sharing networks show positive scale economies.

4.3 import/export ratio

One of the basic criteria for order-sharing in the container transport industry is that an import always needs to be matched with an export. When there is an imbalance between these type of orders, it affects the matching ability of the network. This also implies that not every new entrant is necessarily improving the functioning of the network, since it can worsen the balance between imports and exports. To examine the effect of any imbalances, the same representation of the network, based on matching probabilities is being used. Instead of using an import/export ratio, the ratio of imports to total amount of orders is being used to create a linear scale.

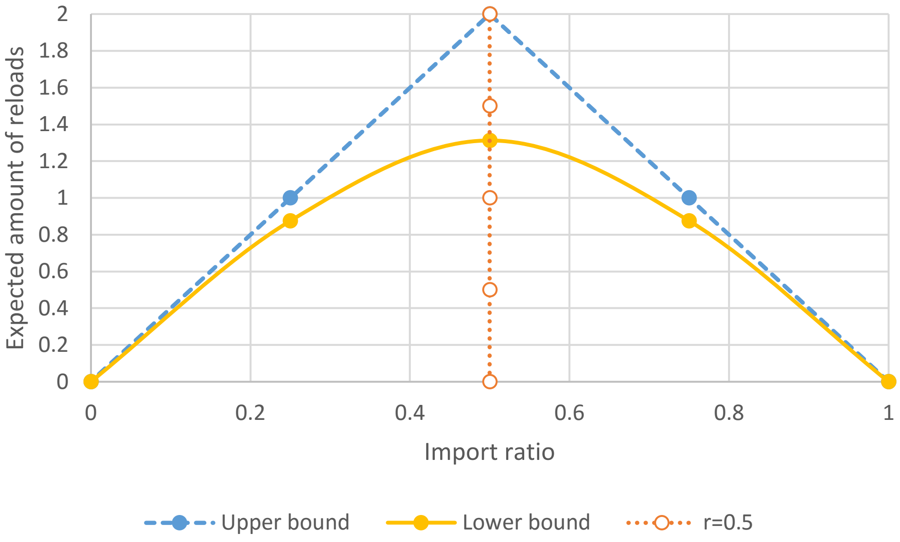
In paragraph 4.1, the relationship between network size and the maximum amount of reloads has been examined by deriving an upper- and lower bound. These upper- and lower bounds can also be used to derive the relationship between the import ratio and expected maximum amount of reloads.

Using the same order-network with p=0.5 and varying the import ratio from 0 to 1 for a constant amount of 4 orders, the expected maximum amount of reloads can be derived. This is shown in figure 9. The figure clearly shows the symmetry at an import ratio of 0.5, because the amount of imports, at this point, is equal to the amount of exports. Since the probability of being suitable for a reload is equal for every order, this graph is symmetric at ratio 0.5. From this figure, the negative relationship between any deviation from import ratio 0.5 and the expected amount of reloads can be derived. The nature of this relationship (i.e. linear/nonlinear) remains, however unclear. This will be examined by means of simulations. The hypotheses regarding this characteristic are formulated as:

Hypothesis 6: there is a negative relationship between deviations from import (export) ratio 0.5 and the expected maximum amount of reloads.

Hypothesis 7: a new entrant can worsen the functioning of the network.

Figure 9. expected maximum amount of reloads with 4 orders, p=0.5 and an import ratio varying from 0 to 1.



4.4 Ideal network

In the previous paragraphs, the effects of multiple variables on the performance of the network have been discussed. Combining these variables automatically leads to the following question: is there an ideal or optimal network configuration? This question is partly based on the findings of Cruijssen et al. that agency costs play a role when hauliers start a co-operation (Cruijssen & Braysy, 2007). This could mean that, for example, bigger isn't always better. The hypothesis regarding this statement is therefore:

Hypothesis 8: there is an optimal network configuration in terms of size under which the system performs best in terms of monetary savings.

Chapter 5. Data and methodology

This chapter describes and underpins the choice of methodology and the data used in this thesis. First the data will be discussed, then a description will be given about the methods that are used to test the hypotheses and answer the research question.

4.1 Data

The data used in this thesis is collected by Paris Optimal Planning, a subsidiary of Hutchison Port Holdings, and is a collection of all the orders that have been entered into the system by the participants. The data is collected from the 6th up to the 17th of July, 2015. Every order contained the following information: being an import/export, haulier, container type, shipping line owning the container, coordinates and name of the pick-up/drop-off points, the address of the pick-up/drop-off points. Pick-up/drop-off date and time with an lower and upper bound. A fictive example is given in Table 3. An average day contained 900 orders from 29 shipping lines, conducted by the 11 participants mentioned earlier.

Table 3. Fictive order example

I/O	CON	EQUIPMEN	SHIPPING_L	CITY_NAME	ADDRE	X_COORD	Y_COORD	DATE_FRON	TIME	DATE_TO	TIME	PORT_NAME
I	VM	40HC	UAC	BREDA	4816	48013	515987	6-7-2015	00:00	6-7-2015	14:00	MAASVLAKTE

Due to computational constraints, only one day has been simulated in the case study. This makes the outcomes vulnerable for seasonal and daily bias, but should not affect the results too much. Both seasonal and daily fluctuations mostly affect the amount of orders and perhaps the i/e ratio and location of the orders. The regression analysis takes these factors into account, which is why it is not likely to have a huge effect on the outcomes in this study. To simplify the model, it is assumed that all orders are conducted with a 40ft. container. The orders not going to the Port of Rotterdam have also been filtered out of the sample to simplify the model. This should is also not affect the outcomes of this study, but adding extra ports might have an impact on the use of the system. The role of the amount of ports is, however, beyond the scope of this thesis.

4.2 Methodology

4.2.1. Simulations and mixed-integer linear programming

The main results regarding the dynamics of an order-sharing network are derived from simulations. Simulation is a useful technique, because it is able to show the influence of certain variables on the rest of the model, without the need to repeatedly build these new models. In other words, when variables are altered, a simulation is able to give a (relatively) quick overview of the impact this has on a network. Another reason why simulation is suitable for this thesis, is that the case study, Boxreload, is still in its starting phase, meaning that there is not a lot of data available. Actual reloads, for example, are not available, because hauliers often fail to enter the actual reloads they conducted into the system. A simulation is able to make a rational estimation about what hauliers "should have done", under the assumption that they try to minimize costs. Although it is unlikely that the suggested reloads are always conducted, it results in useful insights about the impact of the variables on the rational optimum. This also leads to the downside of simulations; the fact that they rely on assumptions that simplify reality. It is important that a simulation is able to capture the essential functioning of a network without diverging from reality too much. Because simulations often consist of complex programming, it is important that the outcomes are substantiated by theoretical models to verify if the outcomes make sense. This has been done in the previous chapter.

In this thesis, simulations have been used to test hypothesis regarding network size, the import ratio of the network and the expected amount of reloads in a network. Two types of simulations have been conducted to test the hypotheses regarding these variables. The first type of simulation tests the theoretical model developed in chapter 4 (figure 4). In these models, each combination of an import and export has an equal probability p of being reloadable. By varying the network size and import ratio, the relationship between these variables, the expected maximum amount of reloads can be examined. Remember that the expected maximum amount of reloads is equal to the sum of rows and columns that have at least one reloadable import/export combination, minus the absolute difference between these two. The expected maximum amount of reloads is assumed to be a proxy of the expected amount of reloads that are actually going to be conducted. In chapter 4, the theoretical upper- and lower bound of this relationship have been examined. The goal of this simulation is to verify these upper- and lower bounds and the theoretical relationships that were derived in the theoretical framework. So besides the hypothetical network with six orders and p=0.5, multiple networks can be simulated to see how the network characteristics affect the amount of reloads.

During the simulations, network size and import ratio will be varied. Network size will vary between 0 and 200. All network sizes consisting of a multiple of 10 orders will be examined (e.g. 10,20,30…200). The import ratio will be tested by varying the import ratio on an order network of 100 orders from 0 to 1 with sub steps of 0.1. All simulations will be conducted for three probability values: p=0.01, p=0.1 and p=0.5, except the import ratio. This will be tested with p=0.01, p=0.02 and p=0.1, because these values emphasize the relationship more clearly. Each network configuration will be simulated 1.000 times.

The second type of simulation will empirically validate the model by using data from the Boxreload network. Eleven order portfolios are being considered and the orders of all hauliers will be combined per shipping line (to satisfy the shipping line constriction). First, the maximum amount of reloadable orders will be derived by applying the restrictions considered below. Then, the order portfolios will be optimized with respect to costs to examine how the savings created by an individual reload are likely to be affected by network characteristics. This is done by means of mixed-integer linear programming.

The model used to optimize the portfolios is described below:

$$Min \sum_{i=1}^{n_d} \sum_{j=1}^{m_d} c_{ij} a_{ij} + \sum_{i=1}^{n_d} b_i c_i + \sum_{j=1}^{m_d} b_j c_j$$

Where:

n_d = number of imports from shipping line d

m_d = number of exports from shipping line d

c_{ij} = cost of shipping import i and export j in one trip

a_{ij} = dummy variable concerning reload constrictions

b_i = dummy variable that ensures all imports are delivered

b_j = dummy variable that ensures all exports are delivered

c_i = cost of delivering import i and driving back empty to the port

c_j = cost of driving empty to export j and bringing delivering the export in the port

The model describe above is subject to the following constraints:

(1) $a_{ij} = 1$ if:

$d_i = d_j$ (the import and export are conducted by the same shipping line)

$t_b + t_{pi} + t_{ij} + t_j < t_e$ (the haulier is able to conduct import i and arrive on time at j)

(2) $b_i = 1$ if $a_{0j \ldots ij} = 0$, otherwise 0 (if import i isn't involved in a reload, the truck will return empty)

(3) $b_j = 1$ if $a_{i0 \ldots ij} = 0$, otherwise 0 (if export j isn't involved in a reload, the truck will leave empty)

t_{pi}, t_{ij} and t_j are the respective travel times from the port to import i, import i to export j, t_b is the starting time at the port and t_e is the time export j needs to be delivered at the port.

To calculate the travel times between the different locations, the distance between the locations had to be divided by the average speed of a truck, while handling time needed to be added. To estimate the distance between the locations, the coordinates of these 'points' were used in the Pythagorean theorem (appendix 2). Because this resulted in straight lines between the points, a constant used to multiply this distance with has been used to create a more realistic representation of reality. The constant was derived by getting the 'real' driving distances[2] of 50 randomly selected routes and dividing the summation of these 'real' driving distances by the distances of the 50 straight lines derived from the Pythagorean theorem. The resulting constant resulted in a more accurate way of estimating the real driving distances between locations, although it still underestimates the driving distance of locations that are relatively close to each other, as compared to locations that are further away from each other. Because the Port of Rotterdam does not have one clear pick-up/drop-off point, the centre of Maasvlakte 1 has been used. The handling time is assumed to be half an hour, but because time restrictions are fairly strict, a one hour handling time has been chosen as a minimum requirement to conduct a reload. The average speed of a truck is assumed to be 80 km/h, which is 20 km/h lower than the maximum speed, due to the time spent on non-highway roads. Now that the distances have been estimated, the cost to conduct the orders can be estimated as well. C_{ij} is calculated

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[2] These routes were collected by using the Google Maps application.

as follows: c_{ij} = (distance port to import (L_{pi})+ distance import to export(L_{ij}) + distance export to port (L_{jp}))* 0.95[3]

$c_i=2*L_{pi}*0.95$

$c_j=2*L_{jp}*0.95$

With the estimated cost of each trip and restrictions to make a reload, the model can be optimized with respect to costs. This is done with the OpenSolver application of Microsoft Excel.

4.2.2. Simple- and multiple linear regression analyses

After the results from the simulations have been derived, single- and multiple linear regression analyses are conducted to assess the impact of the variables on the functioning of the network. The reason why these regression analyses are needed, beside the simulation, is that the simulation isn't fully able to distinguish the singular effect of certain variables. This is mainly due to the fact that actual data from Boxreload (the actual orders of eleven participants) are being used. The simulation is being used to optimize operations, given certain constraints. The regressions are used to assess the impact of the independent variables on the dependent variable. In other words: the simulation provides the data which is analysed by means of a linear regressions. A least-square method is used to estimate the relation between the dependent and independent variables. The simple linear regression is conducted with the statistical program Eviews 9.

The first regression that will be conducted will regress the maximum amount of reloads per order on the total amount of imports (exports), depending on which of these is smaller compared to the other. The smaller one is always taken and can be referred to as the maximum amount of reloads that could be conducted in theory (since every import can only be matched with an export). However, to avoid confusion (the word maximum has been used quite extensively in this thesis), this variable will be referred to as directional minimum. The directional minimum has been chosen as the independent variable, since it is able to represent size, while correcting for any imbalances between imports and exports. The regression (partially) tests hypotheses 1,2,3 and 6 (equation 1).

$$Equation\ 1: \qquad max.reloads\ per\ order = \beta 0 + \beta 1 * directional\ minimum + \varepsilon$$

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[3] This rate is derived from interviews with hauliers who, on average, stated that the operating cost of a truck is 0.95 euro /km. The standard deviation of this rate was only 5 cents, which verifies the use of this formula.

The second regression will regress the average saving made by a reload on maximum amount of reloads per order to test hypotheses 4 and 5 (equation 2). However, the average savings also highly depend on the average distance that needs to be travelled to conducted every order. To correct for that, the average distance of the combined portfolios for each shipping line is added to the regression. This way, we get a more isolated view on the relationship between the average saving made by a reload and the maximum amount of reloads. The outcome of this regression The regression can now be written as equation 2:

$$
\begin{aligned}
Equation\ 2:\quad & average\ cost\ saving\ per\ reload \\
& = \beta 0 + \beta 1 * max.reloads\ per\ order + \beta 2 * avg.distance\ portfolio + \varepsilon
\end{aligned}
$$

Combining the outcomes of equation 1 and 2, the effect of network size, the import/export ratio and network performance can be derived. This also tells us whether scale economies play a role in voluntary order-sharing networks and indicates if there could be an ideal size of the network. From these observations, hypotheses 6, 7 and 8 can also be verified/falsified.

Chapter 5. Results

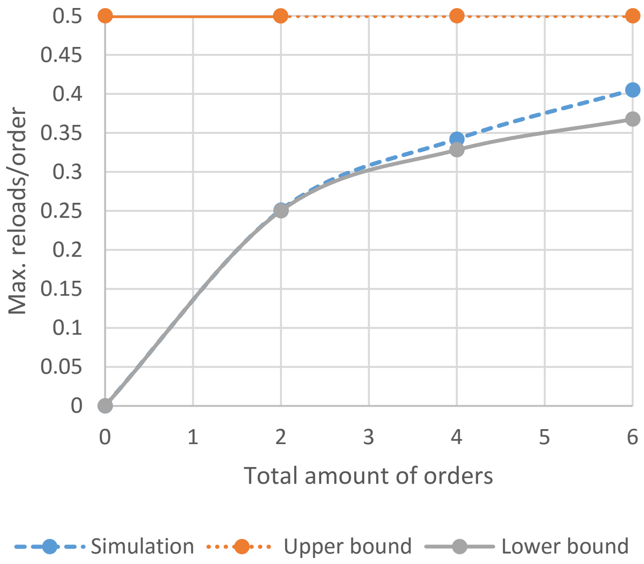
The previous chapters introduced the topic, the research question, placed this thesis in the existing literature and developed a theoretical framework to derive the hypotheses. The data and methodology used to test these hypotheses have also been discussed. This chapter shows the results of the tests that have been conducted. First, the results of the simulations of the theoretical model will be presented. Then the outcomes of the regressions will be discussed.

5.1 Simulations theoretical model

5.1.1. Network size simulations

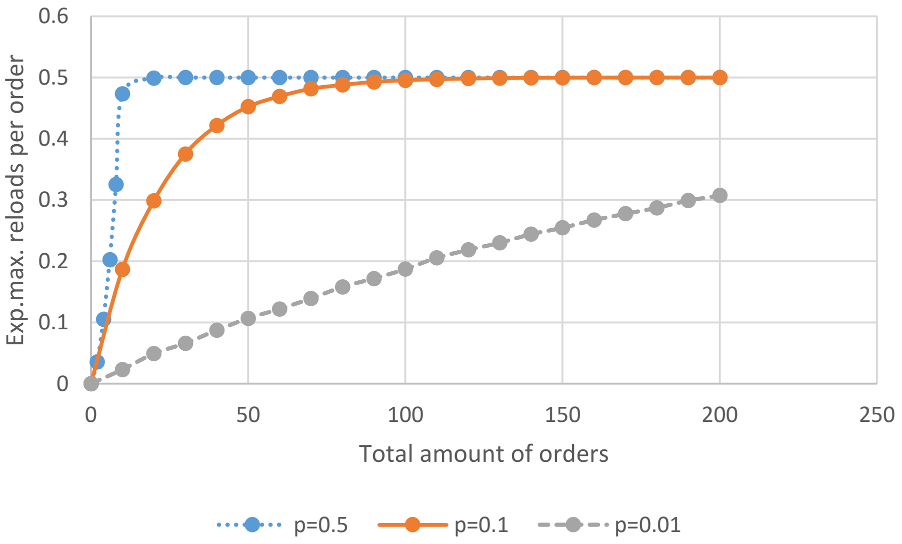
The first simulation that has been conducted was a small one to validate the upper- and lower bound statements that have been done in chapter 4. Figure 10. shows that the expected maximum amount of orders lies indeed between the upper- and lower bound derived in the previous chapter.

Figure 10. Upper bound, lower bound and expected maximum amount of reloads per order for 6 orders and p=0.5.



The figure above only validates the construction of the hypotheses. It is much more interesting to see how network characteristics affected the functioning of the network (in terms of reloads) for much larger numbers. First, the network size has been varied from 0 to 200 orders for p=0.01, p=0.1 and p=0.5 with the import-ratio constant at 0.5. The results of the simulations are shown in figure 11.

Figure 11. Expected maximum amount of reloads per order for different network sizes and matching probabilities.

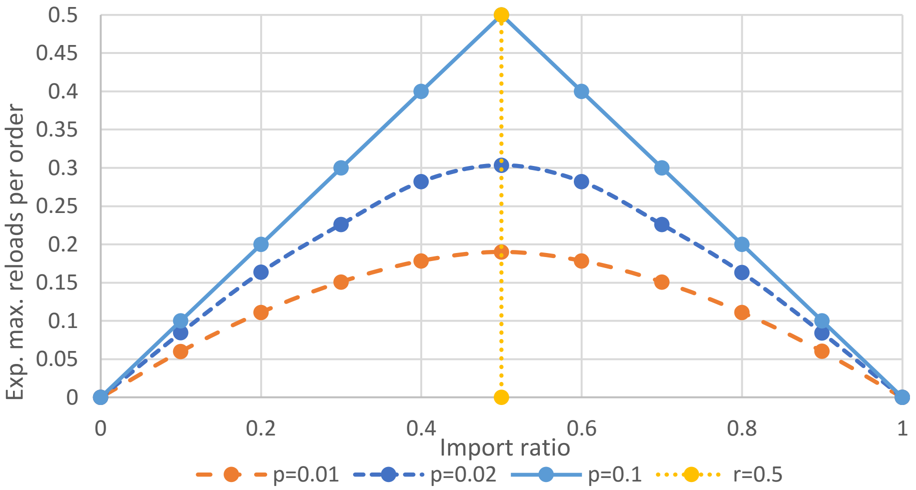


The results of these simulations clearly show the presence of scale economies in terms of reloads. The expected maximum amount of reloads per order decreasingly increases (concave function) with the total amount of orders. The steepness of the slope highly depends on the matching probability. These results imply that network size plays a major role in the functioning of the network. More importantly, when transaction costs are taken into account, these results show that there can be indeed an optimal network size, since the benefits derived from the network can already be near its optimum when only a small amount of participants have entered. When this amount is increased, the performance of the network in terms of reloads per order doesn't increase by much, while transaction costs do. Note that this also highly depends on the matching probability. Transaction costs aren't examined in depth in this thesis, but by making the basic assumption that they increase with network size, it can be reasoned that bigger is not always better. From these results, hypotheses 1 and 2 hold. The results also show that hypothesis 3 will not be rejected. They show that small hauliers are more likely to struggle with making internal reloads compared to large hauliers. This means that small hauliers are likely to share a larger part of their portfolio with the network which, in turn, means that they are likely to have relatively more benefits from a voluntary order-sharing network.

5.1.2. Import ratio

The second network characteristic that has been examined is the import ratio of the network. The results of the simulations are shown in figure 12. Figure 12 clearly shows the negative, non-linear relationship between deviations from import ratio 0.5 and the expected maximum amount of reloads per order. Hypothesis 6 is therefore not rejected. It makes intuitive sense that the system performs best when the amount of imports and exports are balanced (r=0.5). More importantly, the figure amplifies the need to correct extreme imbalances. Small imbalances are severely less restricting compared to large imbalances. This holds especially when the matching probability is high (and therefore for large networks as well). Since reloads can only be conducted when both the import and export are conducted by the same shipping line, the goal should be a balance between imports and exports per shipping line, rather than a balance in general. Furthermore, it shows that not every entrant is necessarily beneficial for the network as a whole. For example, when a new entrant brings in imports from a certain shipping line in which the network already has an surplus, the chance of matching one of their imports declines for all the other participants and the amount of reloads per order also declines. Hypothesis 7, that not every entrant is necessarily beneficial for the network, is therefore verified from this theoretical point of view. According to these results, keeping the import/export ratio balanced can be considered as one of the main tasks that the governance of the network should be able to conduct, since it has a large impact on the performance of the network.

Figure 12. Expected maximum amount of reloads per order for multiple matching probabilities.



5.2 Empirical analysis

The simulations of the theoretical models showed how order-sharing networks are likely to be affected by network characteristics, given equal, independent matching chances. This section shows the results of the empirical analysis.

The first analysis is a regression where the maximum amount of reloads per order (derived from the simulations of the combined portfolios per shipping line) have been regressed on the size of the portfolio as explained in the methodology chapter. The results are shown in Table 4. The results show that the maximum amount of reloads per order is positively related to the directional minimum (which represents size) and that this relationship is significant at the 1% level. The coefficient estimates that the maximum amount of reloads will rise by approximately 0.007 for every additional unit of the directional minimum (i.e. an import or export order).

Table 4. max.reloads per order regressed on directional minimum.

Dependent variable: max. reloads per order
Method: Least Squares
Observations:10

Variable	Coefficient	t-Statistic	Prob.
C	0.079624	2.712281	0.1126
Directional minimum	0.007225	3.265463	0.0031
R-squared	0.290843	F-statistic	10.66325
Adjusted R-squared	0.263568	Prob.	0.003062

The t-statistic implies that the null-hypotheses that there isn't a relationship between maximum amount of reloads per order, and the directional minimum is rejected. The Breusch-Pagan test (Appendix 3) shows that the null-hypothesis that the error variances are all equal is not rejected. Because the chi-square value is small, heteroscedasticity is not a problem (or at least not a multiplicative function of the predicted values). The Jarque-Bera test rejects the null-hypothesis that skewness and excess kurtosis are zero. This means that the t- and F-statistics do not follow exactly t- and F- distributions. The OLS is, however, still BLUE and hypothesis 1 and 6 hold. Furthermore, since the directional minimum is directly affected by the ratio between imports and exports, this result also shows the importance of this ratio and implies that, in accordance with hypothesis 7, not every entrant is necessarily beneficial to the network. So bigger is often, but not always better.

To further examine the presence of scale economies, the relationship between the maximum amount of conductible reloads, the average distance of the orders from origin to destination, and average savings per reload have been regressed. The results are shown in Table 5.

Table 5. avg. savings per reload regressed of maximum amount of reloads and avg. distance.

Dependent variable: avg. savings per reload
Method: Least Squares
Observations: 28

Variable	Coefficient	t-Statistic	Prob.
C	99.00521	-0.917636	0.3676
Max. reloads	20.31945	2.853862	0.0086
Avg. distance	-0.039809	-0.143748	0.8869
R-squared	0.256852	F-statistic	4.320339
Adjusted R-squared	0.197400	Prob.	0.024459

These results show that the average savings per reload, corrected for the average distance of a portfolio, is indeed positively related to the maximum amount of reloads that can be conducted. This relationship is significant at the 1% level. The Breusch-Pagan test (Appendix 3) shows that the null-hypothesis, that the error variances are all equal, is not rejected. Because the chi-square value is small, heteroscedasticity is not a problem (or at least not a multiplicative function of the predicted values). The Jarque-Bera test rejects the null-hypothesis that skewness and excess kurtosis are zero. This means that the t- and F-statistics do not follow exactly t- and F- distributions. The OLS therefore remains BLUE.

The results show that more options (maximum amount of reloads per order) lead to more efficient reloads. The relationship between the average savings per reload and the average distance of the origins and destinations of the orders in the portfolio is not significantly related. This could be due to the fact that when the average distance between origin and destination increases, the distance that needs to be covered between export and import is also likely to increase. The effect on the average savings per reload might therefore remain ambiguous. More reload opportunities do lead to significantly more efficient reloads ceteris paribus. Hypothesis 4, that the network size is positively related to the average cost saving ability of a reload therefore holds. Furthermore, this result, combined with the results from the first regression, show that there are indeed positive scale economies and that the network performs better when it is bigger, ceteris paribus. This also means that increasing the amount of participants will enhance the performance of the network c.p. and that voluntary order-sharing networks are more beneficial for small hauliers compared to large hauliers. It doesn't necessarily mean that a large network will be preferred over small networks. The theoretical network, combined with the simulations, showed that network performance is decreasingly increased with its size. The literature briefly discussed the role that transaction costs play in the functioning of the network. These transaction costs can limit the optimal size of the network if they either are higher than the benefits at the beginning, or rise faster compared to the benefits of the network by network expansion. This is an interesting topic for further research.

Chapter 6. Conclusion

The road transport industry is characterized by a large amount of suppliers, near homogenous goods and a derived demand for transport. With only few aspects in which hauliers can diversify themselves, innovation is one of the few methods from which they can create a competitive advantage. This thesis examined an innovation in which hauliers used a voluntary order-sharing system for container transport to reduce the amount of kilometres without conducting an order (empty kilometres) and increase operational efficiency. The main research question was "how do network characteristics affect the functioning of a voluntary order-sharing network and the operational efficiency of its participants?". The empirical study has been based on an existing voluntary order-sharing network: the Boxreload network, which is recently being in use in the Benelux area.

Multiple complimentary methods have been used to answer the research question. A literature study has been conducted to place this thesis in the existing literature and examine to what extent the research question could already be answered. The existing literature classifies voluntary order-sharing networks as an operational co-operation in which three topics from the existing literature are combined: vehicle based problems with backhaul (VBPB), joint route planning and auction based mechanisms. In other words, the way how routes can be optimized, how logistics network performance changes when they integrate, and a way to exchange orders are broadly discussed. The added value of this thesis is that it examines network characteristics individually and develops a probabilistic framework to add explanatory power to the existing concepts. Furthermore, occasional exchanges have been studied, rather than full integration of systems.

The theoretical framework used to study network characteristics discussed the introduction of a probabilistic framework to examine network characteristics and their effect on the performance of a network. Given an equal, independent probability of a match between an import and an export, the relationship between network characteristics and the performance of the network have been studied. This led to hypothesis regarding network size (i.e. amount of participants, size of the participants), import/export ratio's, the added value of participants and an ideal network size.

These statements have been tested by means of simulations, mixed-integer linear programming (MILP) and simple- and multiple regression analyses. Simulations have been used to verify the model derived in the theoretical framework for larger order-sharing networks and differing conditions (e.g. matching probabilities) . MILP has been used to calculate the feasibility of every import/export combination of every shipping line of the combined portfolios of the participants. It has also been used to optimize each portfolio to assess the savings that can be made by the network. The regression analyses have been used the outcomes of these simulation to study the effect of network characteristics on the functioning of the network individually.

The results showed that there is indeed a positive, significant relationship between the maximum amount of reloads per order and the size of the network. Assuming that the maximum amount of reloads is a proxy for the actual amount of reloads per order, this means that the performance of the network (in terms of reload) is positively related to its size. The results also showed that the average saving made by a reload increased with the amount of reload opportunities. Combining these observation shows that there are indeed positive scale economies that can be enjoyed by order-sharing networks. They also imply that these networks are more beneficial to small hauliers compared to large hauliers, since small hauliers are less capable of making internal reloads. The importance of a balanced portfolio between imports and exports has also been proven to play a significant role in the functioning of the network. It also showed that new entrants don't, although scale economies are present, necessarily improve the functioning of the network.

The presence of transaction cost has not been studied in this thesis, but given the concave function of network size and performance, it is likely that there is an optimal size, or an optimal range of sizes for the network. That does not mean that the governing body should put an extreme effort in finding the optimum, but rather keep in mind that bigger is not always better.

Chapter 7. Discussion and further research

The main goal of this thesis was to study how network characteristics affect the performance of voluntary order-sharing networks and its participants. Multiple methods have been used to study these type of networks and a theoretical framework has been developed to explain how these network characteristics might affect the performance of a network.

The main limitation of this research is that it is only capable of describing generic relationships, rather than specifying the actual cost reductions that can be achieved. Furthermore, the case study has been based on a one-day sample of the Boxreload network. Although multiple regression analyses are capable of distinguishing the effects of certain network characteristics, the sample might be biased in terms of time restrictions and pick-up/drop-off locations. The type of container (e.g. 20ft, 40ft) is also left out of the analysis and only one port is being considered. These aspects aren't expected to affect the outcomes of this study, but are likely to affect the benefits derived from the network. Adding more ports to the network is expected to improve the functioning of the network, since more reload opportunities will become available, while container type might restrict the system due to equipment requirements.

This thesis is mainly an exploratory type of study. Further research could involve the role of transaction costs and how this affects the "optimal network size". Furthermore, it could be interesting to examine how the Boxreload network evolved; how network characteristics affected the performance of the network and to what extent different hauliers gained benefits for participating. Since shipping lines own the containers, it can also be very interesting to examine their role in the process and how they could be more involved in the network.

Appendix 1. Locations of pick-up and drop-off points

1. De Boer

2. De Rijke

3. HE

4. Htransport

5. JGT

6. OB

7. Van der Heijden

8. Van der Most

9. VTT

Appendix 2. Coordinates and Pythagorean theorem

To calculate the distances between points in the simulation, the Pythagorean theorem has been used in combination with a multiplier to estimate the distance between points. To calculate the distance, the following formula has been used:

Distance A→B: $\sqrt{}((x_a-x_b)^2+(y_a-y_b)^2)$.

Because the units of measurement were unclear (distance was measured in coordinates), 5 outcomes have been compared to actual distances (as the crow flies). The ratio between each pair was constant, meaning that distances could be converted to kilometres. Furthermore, a constant has been used to convert the length of the straight lines to more realistic routes that accounts for deviations in the straight line. To estimate this constant, 50 routes have been entered in google distance and divided by the distances of the straight lines. The average of this ratio has been used as a constant to multiply the length of the straight line with.

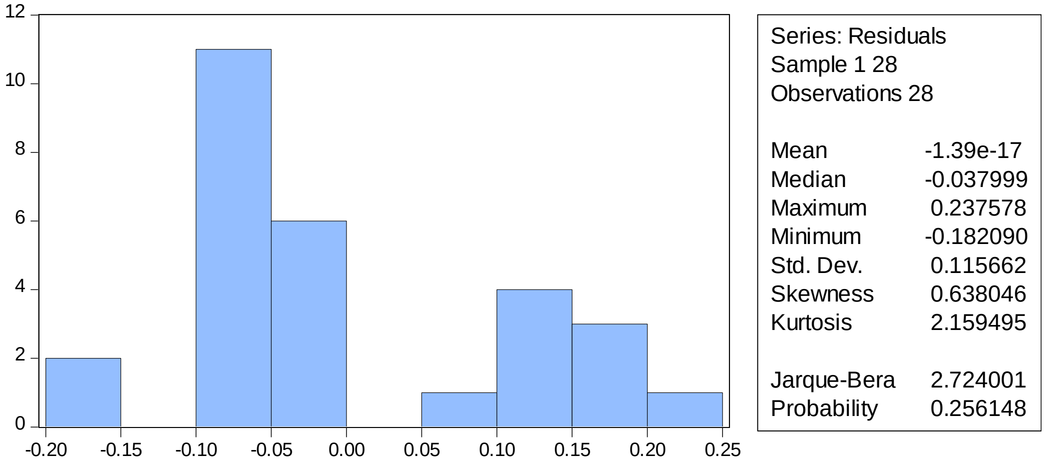
To estimate the length of an empty-return trip, estimated length has been multiplied by two. If a reload has been conducted, the distance has been calculated by adding the distances from port to import, import to export and export to port.

Appendix 3. Outcomes regression analyses

Homoskedasticy test (Breusch-Pagan-Godfrey) regression 1.

F-statistic	2.732371	Prob. F(1,26)	0.1104
Obs*R-squared	2.662725	Prob. Chi-Square(1)	0.1027
Scaled explained SS	1.331054	Prob. Chi-Square(1)	0.2486

Normalization test regression 1.



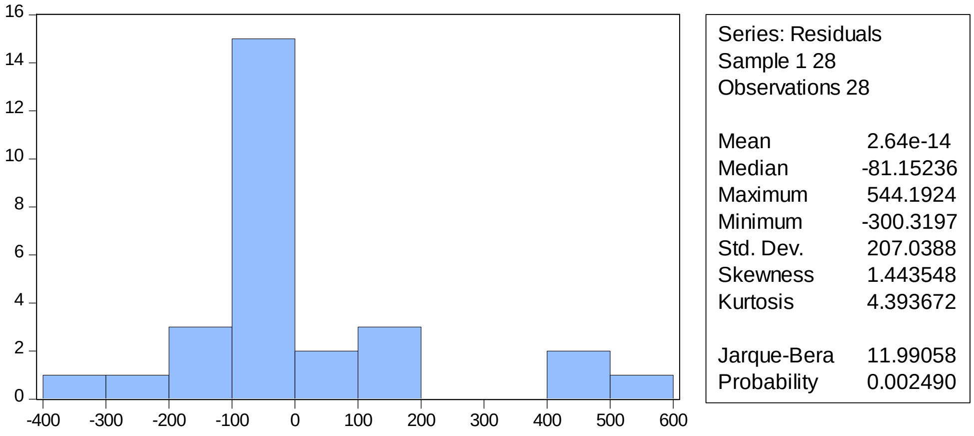
Series: Residuals
Sample 1 28
Observations 28

Mean	-1.39e-17
Median	-0.037999
Maximum	0.237578
Minimum	-0.182090
Std. Dev.	0.115662
Skewness	0.638046
Kurtosis	2.159495
Jarque-Bera	2.724001
Probability	0.256148

Homoskedasticy test (Breusch-Pagan-Godfrey) regression 2.

F-statistic	1.544890	Prob. F(2,25)	0.2330
Obs*R-squared	3.079904	Prob. Chi-Square(2)	0.2144
Scaled explained SS	4.166209	Prob. Chi-Square(2)	0.1245

Normalisation test regression 2.



```
Series: Residuals
Sample 1 28
Observations 28

Mean          2.64e-14
Median       -81.15236
Maximum       544.1924
Minimum      -300.3197
Std. Dev.     207.0388
Skewness      1.443548
Kurtosis      4.393672

Jarque-Bera   11.99058
Probability   0.002490
```

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