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Analyzing the pre- and end-haulage of maritime containers in collaborative networks

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Analyzing the pre- and end-haulage of maritime containers in collaborative networks

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Abstract

Pre- and end-haulage describes the movement of full and empty containers among a number of terminals, depots and customers in a hinterland region. Trucking companies have to serve customers which either receive goods by inbound containers or ship goods by outbound containers. While keeping hard time constraints the total operating time and total mileage of all trucks has to be minimized. Transportation companies strive to reduce empty mileage by exchanging maritime container shipments in the hinterland through collaboration with 'competing' transportation companies. Pioneer in the Netherlands in maritime container exchange, and subject of this project is Truckloadmatch B.V. (TLM), a collaboration of 7 transportation companies of maritime containers.

A matching algorithm and heuristic are defined to develop an insightful model that quantitatively shows the costs and benefits of collaboration. A case study has been performed to analyze the benefits of adding new partners to the existing collaborative partnership, in this case the TLM partners. Computational experiments are performed to analyze the influence of the container matching constraints and several optimizations are proposed.

Management Summary

This thesis studies the challenge of exchanging cargo between road transportation companies. Pioneer in the Netherlands in cargo exchange, and subject of this project is Truckloadmatch[1] (TLM), a collaboration of 7 Dutch container transportation companies who try to identify and match import shipments with export shipments to reduce empty mileage. Truckloadmatch's network is rather dense; with a combined fleet of 392 licensed trucks[2] they complete an average of 11.500 hauls a month.

The collaboration TLM is an example of horizontal collaboration. Horizontal cooperation is about identifying and exploiting win-win situations among companies that are active at the same level of the supply chain in order to increase performance (Cruijssen et al., 2007).

Exchanging cargo

The core of this thesis is about exchanging cargo in pre- and end-haulage, Figure 1 provides a representation of the possible flows between a port and a hinterland composed of importers (consignees) and exporters (consignors). A blue line indicates a full container; a red dashed line illustrates an empty container.

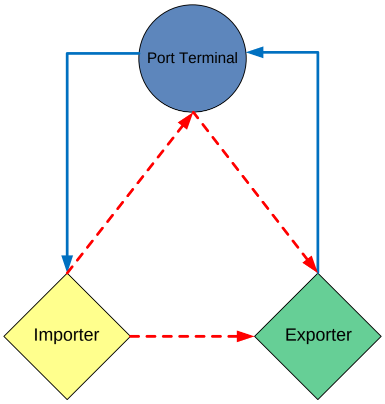

Figure 1. Inland container flows.

Three systems are possible:

- An import loop: a full container is trucked from the port to the importer where it is unloaded and then brought back to the terminal empty.
- An export loop: when an export load is available, an empty container is picked up from the port terminal, brought to the exporter where it is loaded and then moved back to the port terminal.
- And a merged or "matched" flow: in some cases, import and export flows can be combined by bringing an empty container directly from the importer to the exporter. In this case, a full container is trucked from the port to the importer where it is unloaded, the empty container is then brought directly to the exporter where it is loaded with goods and then moved back to the port terminal.

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[1] Truckloadmatch: http://www.truckloadmatch.nl

[2] http://www.niwo.nl/images/html/Lijst/niwo_lijst_wegvervoer.pdf

Transportation management system

PARIS TMS gathers all jobs of the transportation companies that are able to be matched. These jobs are then matched based on location, account booking times, container type, and shipping line (equipment owner).

Benefits

The benefits of matching are not limited to the reduction of empty mileage but also total mileage and thereby reducing CO_2 emissions. The import container will not be returned empty to the terminal thereby reducing container handling at the terminal. The export container that was to be used for the export shipment can now be released for other shipments thus saving handling time at the terminal. The truck and driver that were assigned to the export shipment will now be available for other shipments as the importer generally takes over the export shipment.

Partner selection

The core reason for each company to join a partnership will always be of a 'selfish' nature, meaning that each company's individual goals remain to be the maximization of its own benefit (Cruijssen, 2006). The author found that the most severe impediments are the problems with 1) finding a reliable party that can coordinate the cooperation in such a way that all participants are satisfied and 2) the construction of fair allocation mechanisms for the attained savings.

Objectives

Truckloadmatch had difficulty convincing potential partners into collaboration. Potential partners complained about unclear potential costs and benefits of joining. An insightful model that shows the costs and benefits of collaboration is currently unavailable; such a model would help Truckloadmatch convince other transportation companies to collaborate. The objective of the project was formulated as follows:

Improve the number of successful potential matches between companies, by developing an insightful model that quantitatively shows the costs and benefits of collaboration and uncovers potential synergy opportunities for new partners.

The academic goal of the project can formally be defined as:

Generate knowledge about the benefits of adding new partners to the existing collaborative partnerships, in this case the TLM partners, through the development of management tools that give more insight in FTL truck collaborations.

Model

The problem described was modelled as a *Full Truckload Pickup and Delivery Problem with Time Windows* (FTPDPTW). The model consists of two phases. The first phase considers finding all feasible matches (the same matches that PARIS registers); an algorithm has been made and implemented in visual basic. The second phase consists of finding a near optimal or *good* set of matches, as one shipment can only be assigned once. A heuristic has been made to quickly solve this assignment problem.

Output

Analyses have shown that new partners can greatly benefit from the dense TLM network. In terms of efficiency the collaboration does not seem to perform much more efficient through the addition of the prospect, the additional shipments however result in substantial potential savings. The created model is currently being tested in partner negotiations, addition of partners that are about equally sized as current TLM partners can result in a reduction in empty mileage of 163% for the new party. As the network of TLM is already rather dense, adding shipments of new partners does not greatly influence the fraction of empty mileage for TLM. As the network grows, more shipments are required to achieve same benefits for the collaboration

Optimization

The matching constraints have shown to be of bigger influence than expected. A summary of the influence of all constraining factors in matching is shown in Table 1.

Constraint	***Restricting factor***
Shipping Line	95%
Time window	69%
Equipment type and size	60%
Location	3%

Table 1. Summary of constraint influence.

Clearly, shipping lines are the main bottlenecks; in 95% of all cases the shipping line restricts a match. Collaboration of the members of big liner alliances such as G6 and CKYH in pre- and end-haulage can greatly increase the matching potential and efficiency of TLM; the amounts of feasible matches will more than double and potential savings will increase by approximately 34%.

Another form of optimization is possible through the exchange of empty containers in empty container depots located in the hinterland. Inland terminals have to cope with a plus and surplus of maritime containers of different equipment owners. By extending the current matching problem with empty depots, empty containers can be exchanged in the hinterland instead. Figure 2Figure 6.1 illustrates the alternative matching flow including inland terminals.

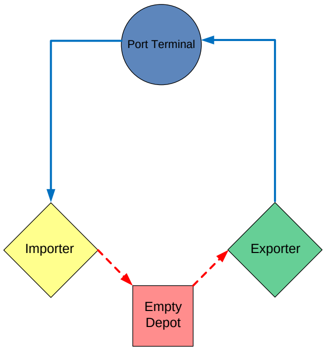

Figure 2. Extension of the business case with empty depots.

The second large restricting factor is the time window constraint. Collaborate with shippers to lengthen time windows and shorten loading times to increase the matching potential; small adjustments i.e. a shortening of loading times or time windows by 30 minutes can increase potential savings by 11%.

A major implication of the matching model is commitment of the current TLM partners. Many matches are still denied; a detailed overview of reasons of denied matches can be viewed in appendix VIII. The major reason of a denied match is that the shipment is already matched with an own shipment. Through interviews it became apparent that own matches have priority over TLM matches, many shipments however have better matching alternatives with partners and the best match should always be prioritized.

Ultimately, matching maritime containers in pre- and end-haulage will increase efficiency of shipments; the same amount of shipments can be performed with a smaller fleet. In the current situation when a shipment can be matched, but the released vehicle cannot be assigned to a new shipment, the match will generally not be performed. When there is an over capacity of vehicles, transporting companies must be willing to reduce their fleet size.

Preface

This thesis is the result of the graduation project for the MSc program Operations Management and Logistics. The project was conducted at Truckloadmatch in Rotterdam.

I would like to thank my supervisors for guiding me through this project. I would like to thank Peter de Langen for his enthusiasm for the project and his effective style of supervision. I enjoyed working with him during the project as his passion for logistics was contagious. I am grateful for his willingness to supervise my MSc project in container logistics and for bringing me into contact with Truckloadmatch. I would like to thank Tom van Woensel for his contributions to this master thesis, especially his feedback on the mathematical model and guidance on the vehicle routing problem and pickup and delivery problem have been of great value. Thanks to Said Dabia for his valuable feedback on the report and taking over the evaluating role of Tom van Woensel at the graduation session on such short notice.

I would also like to thank my supervisors and colleagues at Truckloadmatch. I am especially grateful to Bert van der Heijden and Fred Visser for their continuing support and input throughout the project. Your unlimited belief in the business case has given me the sense that the management tool could be of great value for the collaboration. It was a great pleasure to be able to work at 5 companies, the input of all planners and management have been of great value in understanding the container trucking business.

Thanks to all my friends working in the port of Rotterdam for helping me getting familiarised with the port and its many actors. Thanks to all my ‘not working in the port of Rotterdam’ friends, I greatly value your company, support and understanding whenever I had to pull an all-nighter.

I owe many thanks to my family for their support and interest during the progress of the project. Thanks to my brother Edwin for being my personal Visual Basic expert. A special thanks to my father for always encouraging me and supporting me throughout my studies. Finally the time has come for me to find a real job, dad. Right after I get back from a backpacking trip through Australia.

Table of Contents

1. Introduction

In transportation and supply chain logistics, companies collaborate to improve performance. Collaboration provides opportunities for increased profitability that are impossible to achieve with an internal focus only; reducing costs, decreasing lead times, increasing asset utilization and improving overall service levels are potential goals of collaborations.

Since Sea-Land and Maersk began sharing ships in 1990, alliances have become increasingly common among sea cargo carriers. Similarly, airline carriers collaborate and share seat capacity to increase asset utilization. Also in trucking, several web based collaborative networks save time and money by integrating the network of many shippers and carriers.

Collaboration in road transportation has led to a reduction of empty container freight transport in The Netherlands: in 2005 empty mileage accounted for 33% of total mileage; this figure has decreased by 9% to 25% in 2008 and has been steady at 25% in 2009 and 2010[3]. A spectacular decrease but there is still much to gain.

This thesis specifically studies the challenge of exchanging cargo between road transportation companies. Pioneer in the Netherlands in cargo exchange, and subject of this project is Truckloadmatch[4] (TLM), a collaboration of 7 Dutch container transportation companies who try to identify and match import shipments with export shipments to reduce empty mileage.

All involved companies are trucking companies with their own specialities. Where most are mainly specialized in full truck load (FTL) container transportation; others are also involved in distribution or ADR[5]. The project was performed at the following five stakeholders of TLM: G. van der Heijden & Zonen, Van den Bogerd Transporten, Van der Most Transport, De Jong-Grauss Transport and GTO Group. The other companies, Hebra Containervervoer and Van der Bas transport, are partners and users of the matchmaking transportation management system 'PARIS'[6] which will be discussed in chapter 2.5. All involved companies (see Figure 1.1) are similarly structured consisting of the main departments: administration, drivers, finance, planning and are completed by one or more managing directors.

Figure 1.1. Geographical locations of involved companies of Truckloadmatch.

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[3] EUROSTAT: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=road_go_ta_vm&lang=en

[4] Truckloadmatch: http://www.truckloadmatch.nl

[5] The European Agreement concerning the International *Carriage of Dangerous Goods* by Road

[6] PARIS: http://www.PARIS-tms.com/home.htm

Truckloadmatch's network is rather dense; with a combined fleet of 392 licensed trucks[7] they complete an average of 11.500 hauls a month, thus an average of 532 hauls on workdays; transportation in weekends is negligible. An import/export imbalance exists; on average 61% of the jobs are imports and 39% are exports[8]. The main export and import areas are within The Netherlands, TLM mainly transports from, and to, Rotterdam and Antwerp.

Naturally, demand is not homogeneous divided over the hinterland. Figure 1.3 and Figure 1.2 respectively show the distribution of all matchable import and export shipments for Truckloadmatch's network in the Netherlands; approximately 85% of all shipments are within Dutch boundaries. The highest quantity of import hauls are destined to the area of Rotterdam and Venlo, depicted by the darker colours. Most of the export shipments are within the Rotterdam port area. For a detailed map and graphs on municipality level see Appendix I.

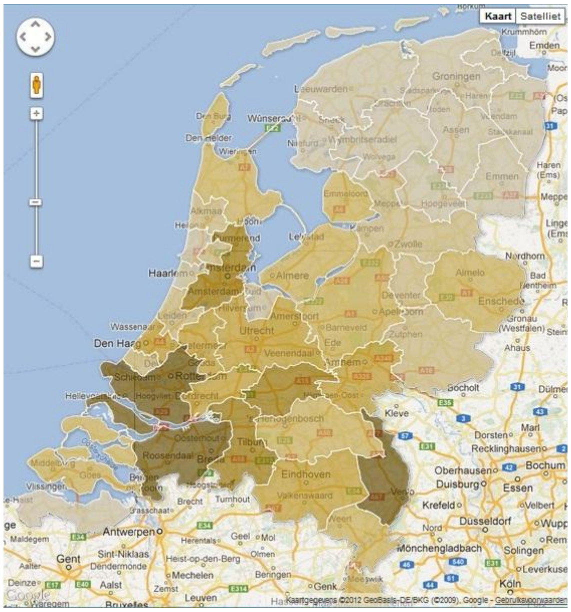

Figure 1.3. Import distribution.

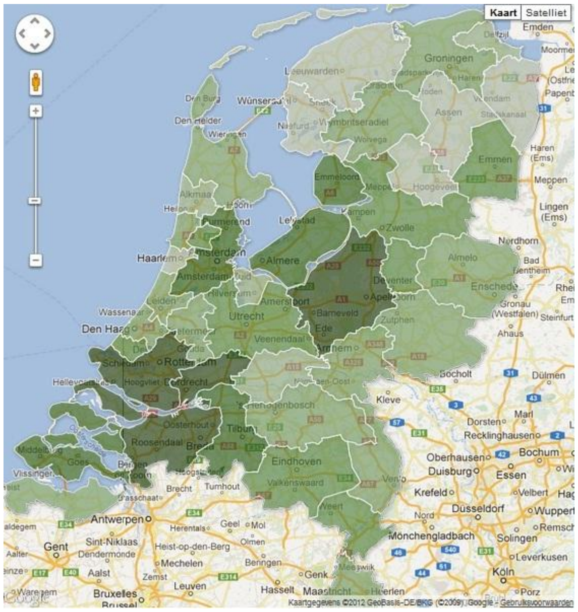

Figure 1.2. Export distribution.

Structure of thesis/ thesis outline

This master thesis project started with two goals, one at the academic level and one with a practical goal. The academic goal of the project is to contribute to the existing body of scientific knowledge. At a practical level, this project is aimed to yield a practical solution to the business problem of the organization.

To accomplish these goals, the project was designed according to the reflective cycle described by van Aken et al. (2007) and illustrated in Figure 1.4. The reflective cycle consists of choosing a type of business problem, solving that problem through the regulative cycle, reflecting on the results with the aim of learning from this project for similar projects and establishing preliminary technological rules (van Aken et al., 2007).

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[7] http://www.niwo.nl/images/html/Lijst/niwo_lijst_wegvervoer.pdf

[8] Data through PARIS over 1-year period: mar2011-feb2012.

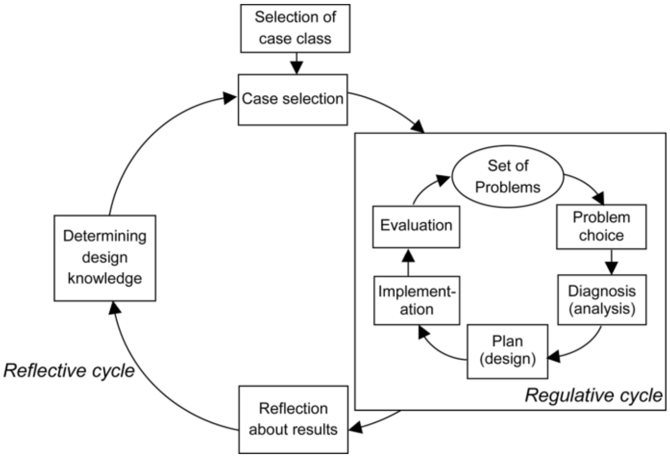

Figure 1.4. Reflective Cycle (van Aken et al., 2007).

Literature is treated first in chapter 2 to fully comprehend the problem statement. In chapter 3 the problem statement and objectives are discussed. The creation of the model is described in chapter 4. The model was tested in a real life partner selection procedure of which the results are described in chapter 5. Chapter 6 will show the determinants of successful matching in a collaborative environment. Finally conclusions and recommendations are drawn in chapter 7.

2. Cooperation in pre- and end-haulage

This chapter elaborates on the actors involved in the hinterland transportation network, specifically those that are involved with Truckloadmatch, and the structure of its collaboration. Furthermore this chapter presents network characteristics and the matching problem.

2.1 Actors

A project on problem solving must be *client-centered;* developing a management tool involves dealing respectfully with the project principles, users and stakeholders (van Aken et al., 2007). This paragraph discusses the most import actors of the project.

Hinterland transport consists of a variety of different firms: e.g. shipping lines, terminal operating companies, forwarders, hinterland transport providers and inland terminal operators. But also public actors such as the port authority, customs and infrastructure managers; Figure 2.1 shows the contractual relations between the involved actors. In order to create effective hinterland transport chains, coordination is required between these actors (Van Der Horst & De Langen, 2008). The most relevant parties in this project will be discussed briefly:

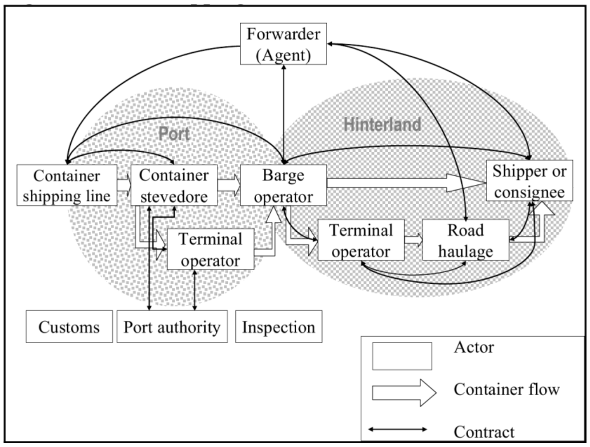

Figure 2.1. Contractual relations of actors in the hinterland chain.

Shipper or Consignee: The shipper is the most important player, the initiator of container shipment. Smaller shippers tend to let freight forwarders handle their shipments; larger shippers may also have contracts with road haulers or carriers.

Carrier or Road hauler: The carrier is responsible for transporting the containers by land using trucks and trailers to carry the containers. Carriers have become professional service providers handling all inland distribution. The majority of containers in the transport chain are still transported by truck.

Terminal operator (container stevedore): The terminal operator is in charge of all terminal handling activities such as loading and unloading of seagoing vessels, and moving containers from stack to inland transport modes such as truck, barge and rail. Terminals can be located in ports or inland.

Container shipping line: The container shipping line is responsible for shipping the container for a specific shipper from one port to another. Shipping lines now also offer shippers door-to-door services and integrated logistic packages.

The Port Authority: The port authority is the organization responsible for leasing sites to port related business and handling the port infrastructure. By investing in development of the existing port locations and newly developed port space they work to maintain a smooth and safe handling of shipping operations.

2.2 Collaboration

In partner selection and acquirement it is important to know what forms, but especially which types of partners are desirable for the collaboration. This paragraph discusses desirable collaboration forms and partners for truck collaborations such as Truckloadmatch.

Collaborations among buyers or among sellers are examples of *horizontal collaboration*, which are comprised of companies with similar characteristics (Agarwal et al., 2009, Cruijssen et al., 2007). "Horizontal cooperation is about identifying and exploiting win-win situations among companies that are active at the same level of the supply chain in order to increase performance" (Cruijssen et al., 2007).

For example, shippers work together for joint procurement of transportation services whereas truckload carriers like Truckloadmatch work together to reduce empty truck movements. A definition of horizontal collaboration is stated by the European Union (2001) as "concerted practices between companies operating at the same level in the market".

Alliance formation among carriers poses various challenges. As carriers form alliances by pooling their ships and integrating their networks, a large scale optimization problem needs to be solved to design the overall service network. In an alliance, carriers work in collaboration with each other, however each carrier's *individual goal* remains to be the maximization of his own benefit. For forming sustainable alliances, the task is not only to design an efficient service network, but also to provide mechanisms to manage the interactions among the alliance members, and share the benefits and costs of the alliance in such a way that all carriers are motivated to collaborate. Figure 2.2 illustrates the different forms that could apply to the collaborative concept; Shipper-Shipper, Carrier-Carrier, and Shipper-Carrier cooperations.

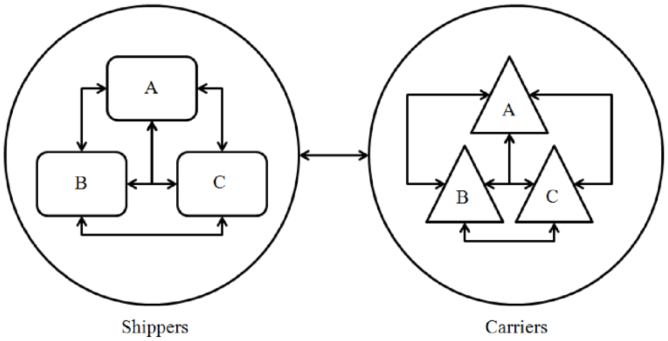

Figure 2.2. Cooperative forms (Peeta & Hernandez, 2011).

The most interesting is *carrier-carrier collaboration.* Truckloadmatch is comprised of carriers only, and wishes to expand by attracting other carriers. This type of collaboration is depending on management of a carrier's relations with shippers; shippers should not mind that a carrier different from their usual contracted carrier ships their goods.

Recent trends in freight transportation indicate that more and more carriers have begun to collaborate to increase profit margins and level of competitiveness (O'Reilly, 2005). Making a profit, especially for a small- to medium sized carriers, lies on its ability to minimize its cost over a collaborative network. The intention of Truckloadmatch is no exception to that.

The second form of collaboration is vertical, *shipper-carrier* collaboration; also referred to as collaborative transportation management (CTM). It is essentially an extension of Collaborative Planning, Forecasting and Replenishment (CPFR). Collaboration between shippers and carriers concerns information sharing about shipment forecasts (Kale et al., 2007). Empirical research of Ha & University (2007) concludes that strategic cooperation with carriers results in both carriers' and shippers' organizational performance improvement. Esper & Williams (2003), Kale et al. (2007) and Lynch (2000) focus on improving the relationship between the shipper and truckload carriers.

Lastly, *shipper-shipper* collaboration is aimed at improving transportation performance of shippers. This model is based on information sharing, when one shipper has extra needs it can negotiate with a second shipper in the collaborative community that has excess contracted capacity. Shipper-shipper collaboration is therefore more attractive for less than truckload (LTL) transport. However, Cruijssen et al. (2010) propose an approach called *insinking*. The logistics service provider selects a group of shippers with a strong synergy potential and whose distribution networks can be merged very efficiently, this would create a situation of 'co-opetition' (Brandenburger & Nalebuff, 1998, Zineldin, 2004).

Insinking is a new phenomenon and a different approach to merging trips and reducing empty mileage, but does not fit the scope of the project. This master thesis project mainly focused on carrier-carrier collaboration as well as carrier-shipper collaboration.

2.3 Network characteristics

Conceptualization of a management model starts with a deeper understanding of the transportation network and the optimization process. This paragraph describes the distribution network of Truckloadmatch and the optimization problem at hand.

The network of Truckloadmatch is typical for the intermodal transportation system (Figure 2.3). In the intermodal transportation system the major part of the cargo's journey is performed by rail, inland waterway or sea, while the initial and final legs; distribution and collection of containers, are typically carried out by road (Crainic et al., 2007, Macharis & Bontekoning, 2004, Vidovi'c et al., 2011). These initial and final legs will be referred to as the pre- and end-haulage of the intermodal transportation system and is the core business of TLM.

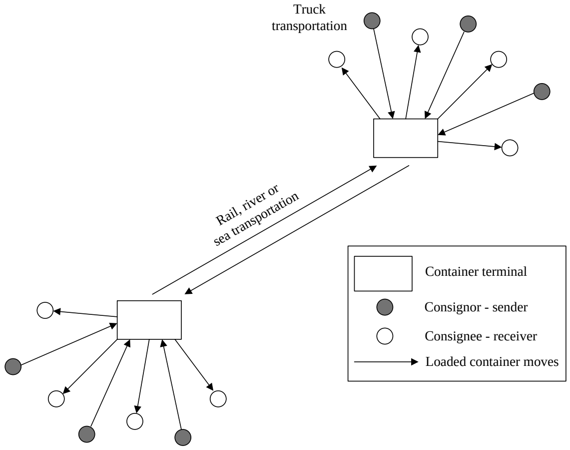

Figure 2.3. Intermodal transportation system.

The network consists of several hubs or gateways such as the port of Rotterdam and the port of Antwerp. A gateway is a pivotal point for the entrance and exit of goods in a region, country or continent and commonly implies a shift from one mode to the other, such as maritime-land. Transport corridors are commonly linking gateways to the inland. A hub is a central point for the collection, sorting, transhipment and distribution of goods for a particular area. It originates from the 'Hub and Spoke' concept from air transport for passengers and freight.

The objective of the optimization process is to select links (connections between origins and destinations) in a network which satisfies the demand for transportation at the lowest possible system cost. This optimization problem is related to the matching or assignment problem, and can be treated as a vehicle routing problem (VRP) (Crainic, 2000, Golden et al., 2008). The routing problem in this project is part of an intermodal transportation system where containers are distributed by trucks to customers in the hinterland; the inland region lying behind a port. Few possible types of inland container moves, also known as drayage operations can be recognized (Macharis & Bontekoning, 2004). These are described in chapter 2.4.

2.4 Exchanging shipments

Matching export hauls with import hauls is the heart of this master thesis, this chapter gives a detailed representation of the possible container flows and give a general overview of the benefits of merging tasks.

Figure 2.4 provides a representation of the possible flows between a port and a hinterland composed of importers (consignees) and exporters (consignors). A blue line indicates a full container; a red dashed line illustrates an empty container.

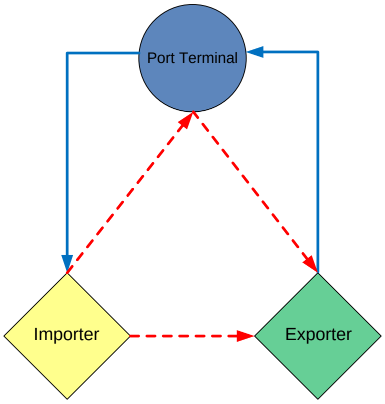

Figure 2.4. Inland container flows.

Knowing where partner's jobs and trucks are provides partnerships savings by merging single pickup and delivery tasks. Three systems are possible:

- An import loop as shown in Figure 2.5: a full container is trucked from the port to the importer where it is unloaded and then brought back to the terminal empty.
- An export loop (Figure 2.6): When an export load is available, an empty container is picked up from the port terminal, brought to the exporter where it is loaded and then moved back to the port terminal.

- And a merged or “matched” flow presented by Figure 2.7: In some cases, import and export flows can be combined by bringing an empty container directly from the importer to the exporter. In this case, a full container is trucked from the port to the importer where it is unloaded, the empty container is then brought directly to the exporter where it is loaded with goods and then moved back to the port terminal. Naturally, the closer the importer is located to the exporter the more efficient the match is. Utilizing this match reduces empty mileage for the alliance and allows carriers to allocate released resources to other jobs.

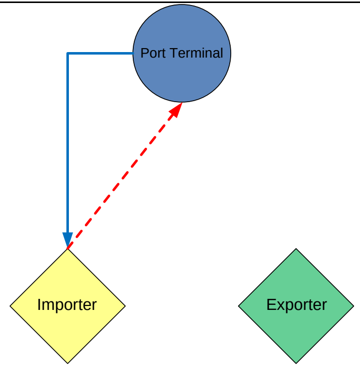

Figure 2.5. Import flow.

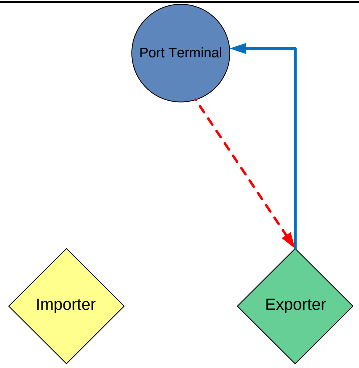

Figure 2.6. Export flow.

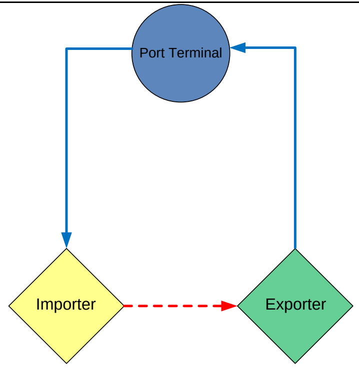

Figure 2.7. Merged tasks, a Match.

Clearly, 50% of the journey of one-way loops (Figure 2.5 and Figure 2.6) is an empty trip. Trips can be matched with other trips within the company or with partners; this project was aimed at improving the collaboration *between* companies i.e. to develop a method to increase the amount of matches between companies. However, matches between companies are not more important than own matches. The best match should always be prioritized.

The benefits of matching are not limited to the reduction of empty mileage, but also total mileage and thereby reducing CO_2 emissions. The import container will not be returned empty to the terminal, thereby reducing container handling at the terminal. The export container that was to be used for the export shipment can now be released for other shipments thus saving handling time at the terminal. The truck and driver that were assigned to the export shipment will now be available for other shipments as the importer generally takes over the export shipment.

In all the above cases the truck is assumed to be in the port area prior to pickup of full or empty containers. In reality, whenever a truck is ‘free’ it may be located at a different terminal or may still be located at the company’s parking. The distance between the location of truck availability and port, i.e. ‘flat’ distance (an empty chassis; no container), has not been incorporated in this project.

Many restrictions for these kinds of merges must be regarded: e.g. container type, container size and shipping line, as well as shipping times. For TLM it is important that importers and exporters allow their goods to be transported by a different company. Detailed constraints are discussed in chapter 4.

2.5 Transportation Management System

Collecting all jobs of the transportation companies and optimizing the network requires a transportation management system. Truckloadmatch employs PARIS TMS to generate potential matches; utilization of PARIS is costly, about 250 Euros per partner per month. This chapter discusses the operational actions leading to a successful match.

PARIS gathers all jobs of the transportation companies that are able to be matched. These jobs are then matched based on location, account booking times, container type, and shipping line (equipment owner). Detailed constraints are declared in chapter 4.1.

An online interface shows the possible matches suggested by PARIS, and planners can decide on further action. When a planner finds an interesting match, he will update the possible match to say ‘yes’, the other party will receive a message and is asked to respond. When the other party also responds a ‘yes’ the trip will be matched and the status is updated to ‘agreed’.
There is no rule on who performs the job but generally the party with the import job will take over the export job. A fair distribution of costs and benefits of coordination is required as an unequal distribution can cause free rider behaviour. Firms may also be reluctant to improve coordination if this also yields benefits for competitors (Van Der Horst & De Langen, 2008). The party who carries out the job will compensate the party who hands the job over with a fixed amount based on the distance of loading address to delivery address. This compensation is set-up as a pace list and can be found in Appendix II.

3. Problem statement

The first paragraph defines the scope and limitations for this project. The research question and the main objectives will be described in paragraph two, and paragraph three discusses the scientific rigor and managerial relevance of the project.

3.1 Scope and limitations

This master thesis conducted at Truckloadmatch's main stakeholders was focused at the operational planning problems of optimizing the pre- and end-haulage of maritime containers in collaborative networks. The project involved all stakeholders and partners; all shipments are included in analyses and model creation.

This project was focused on maritime containers, their transportation and the ability of matching jobs between the involved companies. ADR and reefer containers (refrigerated containers) are not easily matched due to increased transportation requirements as e.g. cleaning and re-adjusting temperatures, and will therefore not be included in the project. 'Flat' distance has not been incorporated in this project.

The analyzed distribution area comprises the Netherlands as shown in Figure 1.3, Belgium and western Germany (specific areas are shown in Appendix III).

3.2 Problems and objectives

In the current situation, the level of collaboration between Truckloadmatch's members is unsatisfactory, measured by the number of successful potential matches. An overview of causes that have been found during the project can be found in appendix IV.

In order to increase the number of successful matches the project was aimed at uncovering potential synergy opportunities for new partners. Expanding the collaboration increases the amount of hauls, increase network density and ultimately increase potential matches. However, when a trustworthy collaboration partner was found, Truckloadmatch had difficulty convincing this potential partner into joining. Potential partners complained about unclear potential costs and benefits of joining. An insightful model that shows the costs and benefits of collaboration is currently unavailable; such a model would help Truckloadmatch convince other transportation companies to collaborate. The objective of the project was formulated as follows:

Improve the number of successful potential matches between companies, by developing an insightful model that quantitatively shows the costs and benefits of collaboration and uncovers potential synergy opportunities for new partners.

The academic goal of the project can formally be defined as:

Generate knowledge about the benefits of adding new partners to the existing collaborative partnerships, in this case the TLM partners, through the development of management tools that give more insight in FTL truck collaborations.

3.3 Scientific and industry relevance

The transportation sector suffers from reduced trade in the current financial crisis and forces managers to work more efficiently. Transportation companies benefit from matching shipments as they can complete the same amount of work with fewer trucks. The competitiveness of transportation companies increases as they are able to undercut competitors; making collaboration not only interesting for transportation companies, but also for shippers.

Although transportation distances on land by trucks are very short compared to maritime transportation by ships, total costs per TEU (twenty-foot equivalent unit) are relatively high (Zhang et al., 2009). Organizing the road segment in the intermodal transport chain more efficiently can increase the attractiveness of intermodal transport.

In 2010 empty mileage accounted for 25% of total mileage[9], i.e. roughly 1 in every 4 containers transported on Dutch highways is empty. Many shippers and transportation companies in the Netherlands have imbalanced goods flows in terms of import and export. This imbalance is often combined with a thin transportation network, resulting in unavoidable empty mileage.

Collaboration with other shippers and transportation companies can result in significant efficiency improvements for the entire collaboration: reducing empty mileage, fuel consumption, emissions and port handling. Another important benefit is reduced traffic; in densely populated areas such as the Netherlands, highways congestion is a great issue.

Due to its importance in intermodal freight transportation, optimization of container drayage operation has received increased attention over the past decade. Publications on intermodal planning problems at the operational level are however limited. An overview of planning issues in intermodal transport and solution methods proposed in scientific literature is given by Caris et al. (2008). A detailed literature review has been made in preparation for this master thesis project (Odijk, 2011).

This project discusses an operational planning problem in intermodal transport, involving the pickup and delivery of Full-Truck-Load (FTL) containers at customer locations in the hinterland.

In order to contribute to scientific literature a solution algorithm and heuristic was created based on current literature on transportation, assignment and transhipment problems (t.a.t.). These algorithms were subsequently tested in the process of real partner selection. The testing phase has uncovered knowledge on the benefits of adding new partners to truck collaborations, in this case TLM. Furthermore this master thesis contributes to scientific literature by uncovering influential determinants of the success rate of matching import and export containers in truck collaborations.

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[9] EUROSTAT: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=road_go_ta_vm&lang=en

4. Modelling

This chapter describes the two phases of modelling the distribution network. The first phase is about finding *all feasible matches* in the network; based on PARIS. The second phase describes the selection of the *good set of matches.* Considering the time constraints of this project and the requirements of the model, algorithms are written in Visual Basic in Excel.

Chapter overview

To get a better understanding of the terminology used in this chapter, a small fictive dataset is used to illustrate the interpretation of the input and output of the algorithms described in this chapter.

The input of the model is a complete list of *matchable* shipments; shipments that collaborating partners are willing to match with other parties. Table 4.1 contains 13 *matchable* shipments of which 5 are imports (yellow) and 8 are exports (green). From left to right, the input data consists of the party that owns the transportation order, its unique shipment ID, shipping line, start and end location, destination location, lower and higher time window constraints and finally the equipment type.

Party	ID	Line	Start/End	Location	Lower	Higher	Eqp
VM	1	OOL	Maasvlakte	Dordrecht	8:30	9:30	40HC
VM	2	MSC	Maasvlakte	Aalsmeer	7:30	8:30	20DV
VM	3	MAE	Maasvlakte	Barneveld	9:45	10:45	20DV
HE	4	CMA	Maasvlakte	Dordrecht	5:30	6:30	40HC
HE	5	MAE	Maasvlakte	Sneek	7:30	8:30	20DV
GT	20	MSC	Maasvlakte	Botlek R'Dam	8:00	16:00	20DV
HE	21	MSC	Antwerpen (BE)	Botlek R'Dam	8:00	16:00	20DV
HE	22	CMA	Maasvlakte	Breda	7:30	8:30	40HC
JT	23	MSK	Maasvlakte	Kudelstaart	13:30	14:30	20DV
JT	24	CMA	Maasvlakte	Barneveld	8:00	9:00	40DV
VH	25	OOL	Maasvlakte	Botlek R'Dam	8:00	16:00	40DV
VH	26	OOL	Maasvlakte	Botlek R'Dam	7:30	8:30	40DV
JT	27	MSC	Eem- en Waalhaven	Uithoorn	14:00	15:00	20DV

Table 4.1. Data input.

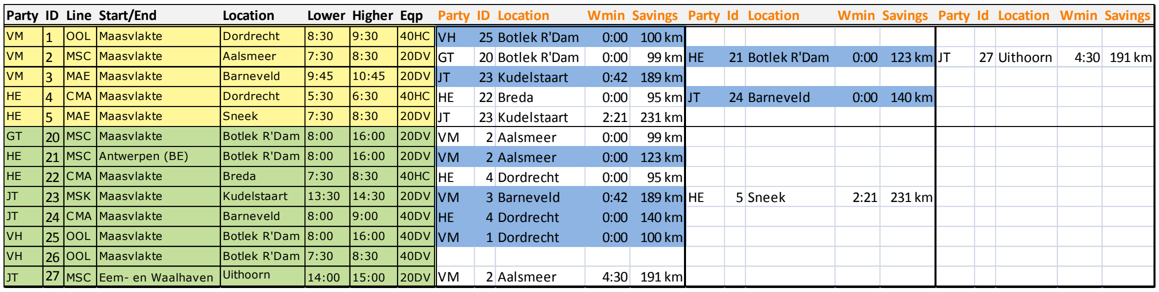
The previous data will be used to generate *feasible* matches; a match is feasible whenever it satisfies the matching constraints, these rules and constraints are discussed in chapter 4.1. The algorithm used to find feasible matches is described in chapter 4.2. The output of the algorithm for this example case is shown in Table 4.2. The algorithm generated 8 feasible matches for this example dataset. One example match is shipment ID 1 with ID 25, resulting in the route: Maasvlakte → Dordrecht → Botlek R'Dam→ Maasvlakte.

Party	ID	Line	Start/End	Location	Lower	Higher	Eqp	Party	ID	Location	Wmin	Savings	Party	Id	Location	Wmin	Savings	Party	Id	Location	Wmin	Savings
VM	1	OOL	Maasvlakte	Dordrecht	8:30	9:30	40HC	VH	25	Botlek R'Dam	0:00	100 km										
VM	2	MSC	Maasvlakte	Aalsmeer	7:30	8:30	20DV	GT	20	Botlek R'Dam	0:00	99 km	HE	21	Botlek R'Dam	0:00	123 km	JT	27	Uithoorn	4:30	191 km
VM	3	MAE	Maasvlakte	Barneveld	9:45	10:45	20DV	JT	23	Kudelstaart	0:42	189 km										
HE	4	CMA	Maasvlakte	Dordrecht	5:30	6:30	40HC	HE	22	Breda	0:00	95 km	JT	24	Barneveld	0:00	140 km					
HE	5	MAE	Maasvlakte	Sneek	7:30	8:30	20DV	JT	23	Kudelstaart	2:21	231 km										
GT	20	MSC	Maasvlakte	Botlek R'Dam	8:00	16:00	20DV	VM	2	Aalsmeer	0:00	99 km										
HE	21	MSC	Antwerpen (BE)	Botlek R'Dam	8:00	16:00	20DV	VM	2	Aalsmeer	0:00	123 km										
HE	22	CMA	Maasvlakte	Breda	7:30	8:30	40HC	HE	4	Dordrecht	0:00	95 km										
JT	23	MSK	Maasvlakte	Kudelstaart	13:30	14:30	20DV	VM	3	Barneveld	0:42	189 km	HE	5	Sneek	2:21	231 km					
JT	24	CMA	Maasvlakte	Barneveld	8:00	9:00	40DV	HE	4	Dordrecht	0:00	140 km										
VH	25	OOL	Maasvlakte	Botlek R'Dam	8:00	16:00	40DV	VM	1	Dordrecht	0:00	100 km										
VH	26	OOL	Maasvlakte	Botlek R'Dam	7:30	8:30	40DV															
JT	27	MSC	Eem- en Waalhaven	Uithoorn	14:00	15:00	20DV	VM	2	Aalsmeer	4:30	191 km										

Table 4.2. Output algorithm 1 - feasible matches.

When this match was to be assigned it would constitute to a mileage reduction of 100km and the driver would not arrive before the 'hard' lower time window; its minimal waiting time is 0 minutes (minimal waiting time is discussed in chapter 4.2.2). However, not all feasible matches can be assigned. For example: 3 feasible shipments have been proposed for shipment ID 2, but only one can be assigned. This decision problem is called 'the assignment problem' and will be discussed in chapter 4.3.

A heuristic has been constructed to solve the assignment problem and to find a *good set of matches*. The output of this heuristic is shown in Table 4.3 and the good matches are highlighted in blue. A detailed description of the construction and functioning of the heuristic is described in chapter 4.3.
The effect of the heuristic can be approximately examined by analyzing shipment 2; the heuristic found the good match to be with shipment 21. Assigning shipment 21 results in higher mileage reduction than assigning shipment 20 (123 vs. 99) and will require no extra waiting time as opposed to shipment 27 (0:00 vs. 4:30 hours). No limitations are set to minimal waiting times as these matches are also shown in PARIS.



Party	ID	Line	Start/End	Location	Lower	Higher	Eqp	Party	ID	Location	Wmin	Savings	Party	Id	Location	Wmin	Savings	Party	Id	Location	Wmin	Savings
VM	1	OOL	Maasvlakte	Dordrecht	8:30	9:30	40HC	VH	25	Botlek R'Dam	0:00	100 km										
VM	2	MSC	Maasvlakte	Aalsmeer	7:30	8:30	20DV	GT	20	Botlek R'Dam	0:00	99 km	HE	21	Botlek R'Dam	0:00	123 km	JT	27	Uithoorn	4:30	191 km
VM	3	MAE	Maasvlakte	Barneveld	9:45	10:45	20DV	JT	23	Kudelstaart	0:42	189 km										
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HE	5	MAE	Maasvlakte	Sneek	7:30	8:30	20DV	JT	23	Kudelstaart	2:21	231 km										
GT	20	MSC	Maasvlakte	Botlek R'Dam	8:00	16:00	20DV	VM	2	Aalsmeer	0:00	99 km										
HE	21	MSC	Antwerpen (BE)	Botlek R'Dam	8:00	16:00	20DV	VM	2	Aalsmeer	0:00	123 km										
HE	22	CMA	Maasvlakte	Breda	7:30	8:30	40HC	HE	4	Dordrecht	0:00	95 km										
JT	23	MSK	Maasvlakte	Kudelstaart	13:30	14:30	20DV	VM	3	Barneveld	0:42	189 km	HE	5	Sneek	2:21	231 km					
JT	24	CMA	Maasvlakte	Barneveld	8:00	9:00	40DV	HE	4	Dordrecht	0:00	140 km										
VH	25	OOL	Maasvlakte	Botlek R'Dam	8:00	16:00	40DV	VM	1	Dordrecht	0:00	100 km										
VH	26	OOL	Maasvlakte	Botlek R'Dam	7:30	8:30	40DV															
JT	27	MSC	Eem- en Waalhaven	Uithoorn	14:00	15:00	20DV	VM	2	Aalsmeer	4:30	191 km										

Table 4.3. Heuristic output - Good match set.

Finally, the managerial tool allows for analyzing the results of the algorithms. Some relevant output is shown in Table 4.4. A detailed description of the used formulas and an analysis of Truckloadmatch's network data are given in chapter 4.4.

Match details	***Current Situation***
Feasible matches	16
Hauls with potential matches	12
# of good matches	4
# of good matches with partners	4
Results	
Mileage reduction	553 km
Reduced # of port handling	8
Reduced handling time	16:00
CO_2 Reduction	486 kg
Potential savings (based on mileage)	€ 829

Every match reduces the amount of handling at the terminal by 2.

2:00 hours per handling activity

0,88kg per km

€1.5 per km

Table 4.4. Matching results.

4.1 Rules and constraints

Several rules apply to matching; this paragraph elaborates on these rules and constraints.

Shipping line

Sea containers are owned by shipping lines and only allow reuse of their own containers. Shipping lines allow reuse of containers as it lowers handling costs; e.g. an import Maersk container can match with a Maersk export container. As usage of containers is combined over a larger fleet, more opportunities arise to find matching loads and equipment repositioning decreases (Gorman, 2005). Shipping lines use different prefixes; a list of equipment owner alternatives is added in appendix V.

Container size and type

ADR[10] and reefer containers (refrigerated containers) are not easily matched due to increased transportation requirements such as cleaning and re-adjusting temperatures, and are therefore not included in the project. Dry Van (DV) containers are the standard general purpose 20ft and 40ft containers, High Cube (HC) containers are about 30 cm taller than standard 40ft DV containers. Containers with equal size and type can be matched, however some additional matches are allowed, these are shown in Table 4.5. A 40ft import haul could physically be matched with a 20ft export haul, however through interviews it became apparent that the benefits of a match do not weigh up to the costs of container size difference.

Container type and size				
* Any type can match with its own type				
45HC	import	can match with	40HC	export
40HC	import	can match with	40DV	export

Table 4.5. Container type matching rules.

Shipping date and time windows

Imports can be matched with exports that are scheduled for the same day. There is one exception: an import shipment with its earliest arrival time after 16.00 can be matched with an export shipment which is scheduled for the next day when its earliest arrival time is before 9:00 am. In this case the trucker will sleep in his cabin.

Time windows are convenient to customers due to the relative certainty of delivery and the ease to schedule the deliveries to suit the work pattern. On the other hand, time windows are inconvenient to transportation companies as they limit flexibility. Companies in the hinterland are generally not operational during the night, leading to peaks of traffic in the early morning and late afternoon. Van Woensel et al. (2008) present a dynamic vehicle routing problem with time-dependent travel times due to traffic congestion. Results showed that the total travel times can be improved significantly when explicitly taking into account congestion during the optimization. Also, a higher number of time zones and road types improves the solution quality. Different road types have been incorporated in the final model. A match is only feasible when the earliest allowed arrival time at the importer plus unloading time and drive time to the exporter is before the latest allowed arrival time at the exporter.

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[10] The European Agreement concerning the International *Carriage of Dangerous Goods* by Road

Loading and unloading times

On arrival at the customer in the hinterland, a trucker has to wait for the shipper to load or unload the container. These turn times are assumed to be 2 hours. Pickup and delivery tasks at the port terminal are also assumed to be 2 hours.

Assumptions

Several constraints can currently not be incorporated in the model as the data was hard to obtain or unavailable. The model assumes that:

- Shippers allow their goods to be trucked by a different company;
  Data analysis and interviews learn that it rarely occurs that shippers deny a match.

- Containers are not already matched with an internal (own) shipment;
  As opposed to PARIS, the created model for this project *does* consider own matches, hence this assumption does not affect the output.

- Containers are not combined with another container on a multi-chassis. 20ft containers are considered to be a full truckload, so no matches will be made for two 20ft containers on one chassis;
  Multi-chassis combining is not pre-determined thus cannot easily be incorporated into a model.

4.2 Feasible matches

Due to computational difficulty of the optimization problem, modelling has been split in to two phases. The first phase of network modelling comprises finding all *feasible matches*.

4.2.1 Vehicle routing literature

The operational planning problem of this project, can be modelled in terms of a *Vehicle Routing Problem* (VRP), the classical VRP consists of designing optimal delivery or collection routes from a central depot to a set of geographically scattered customers, subject to various constraints such as vehicle capacity, route length, time windows and precedence relations between customers (Laporte, 2007). Unlike other well-known combinatorial optimization problems, a single universally accepted definition of the VRP does not exist, because of the diversity of constraints encountered in practice. Most research has concentrated on a standardized version of the problem, called the classical VRP. Many of the algorithms developed for this case, mostly heuristics, can be adapted to suit the more complicated real-life situations.

The VRP belongs to the class of NP-hard combinatorial optimization problems because it includes the *Traveling Salesman Problem* (TSP) as a special case when $m = 1$ and $Q = \infty$ (Laporte, 2007). In practice, the VRP is considerably more difficult to solve than a TSP of the same size. The most sophisticated exact algorithms for the VRP can only solve instances of up to about 100 customers, and with a variable success rate (Baldacci et al., 2008, Laporte & Nobert, 1980). Most research has therefore concentrated on (meta-) heuristics, which are also more flexible than exact algorithms and can be more promptly adapted to deal with changing variants in practice (Bräysy & Gendreau, 2005).

The problem described may be modelled as a *Full Truckload Pickup and Delivery Problem with Time Windows* (FTPDPTW). The *Pickup and Delivery Problem with Time Windows* (PDPTW) is an extension of the classical VRP where customers may both send and receive goods; the general PDP is reviewed by Savelsbergh & Sol (1995). The operational planning problem of this project considers full truckloads as measured by a single container which is described by the *Full Truckload Pickup and Delivery Problem* (FT-PDP) (Currie & Salhi, 2003, 2004).

4.2.2 Problem statement and model formulation

The FTPDPTW can be formulated as a VRP with full container load. The problem is to find an assignment of delivery and pickup customers to a fleet of vehicles, to minimize the total cost of serving all customers. Travelling cost is measured by travelling times, distance and waiting times at the customer locations. All orders are known in advance, so the problem is studied in a static environment.

The structure of the model formulation is based on a lower bound proposed by Caris & Janssens (2010) who modelled their problem as a vehicle routing problem with time windows, as described by Cordeau et al. (2007) and is modified with respect to the characteristics of this project.

The FTPDPTW is defined on a graph $G = (V_0; A)$, where V_0 represents the node set. V is the set of all customers where V^D is the set of delivery customers and V^P is the set of pickup customers. {0} is the singleton (a set with one element) representing the depot. Delivery customers are indicated with index *i* and pickup customers with index *j.* A trip is indicated as a pair (*i,j*). The logic of pickup and delivery customers is incorporated in the definition of travel times t_{ij} (based on distance d_{ij}) of arcs between customer locations. Additional characteristics are listed below:

- Three possible trips occur:
    - (i,0) : only a delivery customer belongs to the trip (see Figure 2.5)
    - (0,j): only a pickup customer belongs to the trip (Figure 2.6)
    - (i,j): a pickup customer is served after a delivery customer (Figure 2.7)
- A truck can only drive from one customer location to the other if a pickup customer is served after a delivery customer, meeting time windows.
- All containers are available at the terminal when orders arrive, the terminal is open 24/7
- When day n: L_i>16.00 and day n+1: E_j<9.00 it is possible for truckers to sleep in their cabin and still match the trip. Overnight (ON) =16.00-9.00.
- Each vehicle starts from the depot and ends at the depot.
- All deliveries start from the depot and all pick-up demands have to be brought back to the depot, so there are no interchanges of goods between the customers.
- A vehicle is allowed to arrive before E_i and wait until the customer becomes available (Wmin), but arrivals after L_j are prohibited.

The mathematical formulation is as follows:

$V_0^D =$ Set of n Delivery nodes $\mathrm{i} = \{0,1,2,\dots,\mathrm{n}\}$ where 0 is the terminal/empty depot
$V_0^P =$ Set of n Pickup nodes $\mathrm{j} = \{0,1,2,\dots,\mathrm{m}\}$ where 0 is the terminal/empty depot
$C_{ij} =$ Cost of travel between i and j, starting and ending at the terminal
$X_{ij} = \begin{cases} 1, & if\ delivery\ node\ i\ and\ pickup\ node\ j\ are\ served\ in\ one\ trip \text{ on the same day} \\ 0, & otherwise \end{cases}$
$Z_{ij} = \begin{cases} 1, & if\ delivery\ node\ i\ and\ pickup\ node\ j\ are\ served\ in\ one\ trip \text{ with overnight} \\ 0, & otherwise \end{cases}$
$m =$ Orderindex of node
$Q_i =$ Amount of delivery orders in node i
$Q_j =$ Amount of pickup orders in node j
$E_i =$ Earliest start time of delivery i
$L_i =$ Latest start time of delivery i
$E_j =$ Earliest start time of pickup j
$L_j =$ Latest start time of pickup j
$t_{0i} =$ Travel time from terminal to delivery i
$t_{ij} =$ Travel time from delivery i to pickup j
$t_{j0} =$ Travel time from pickup j to terminal
$s_i =$ Service time of delivery i (Unloading)
$s_j =$ Service time of pickup j (Loading)
$s_0 =$ Service time of terminal (bring in or collect container)
$ES_{im} =$ Equipment size of order m in node i
$ET_{im} =$ Equipment type of order m in node i
$EL_{im} =$ Equipment line of order m in node i
$ES_{jm} =$ Equipment size of order m in node j
$ET_{jm} =$ Equipment type of order m in node j
$EL_{jm} =$ Equipment line of order m in node j
$TR_{ij} =$ Time required for total trip
$T_i =$ Day of delivery i
$T_j =$ Day of pickup j
$Wmax =$ Maximum wait time
$Wmin_{ij} =$ Minimum wait time for trip i, j

$$Min \sum_{i\in V_0^D} \sum_{j\in V_0^P} C_{ij} \cdot (X_{ij} + Z_{ij}) \tag{1}$$

subject to

$$\sum_{i\in V_0^D} (X_{ij} + Z_{ij}) = Q_j \qquad \forall j \in V^P \tag{2}$$

$$\sum_{j\in V_0^P} (X_{ij} + Z_{ij}) = Q_i \qquad \forall i \in V^D \tag{3}$$

$$X_{ij} \cdot (E_i + s_i + t_{ij} - L_j) \leq 0 \qquad \forall i \in V^D, j \in V^P \tag{4}$$

$$Z_{ij} \cdot (E_i + s_i + t_{ij} - ON - E_j) \geq 0 \qquad \forall i \in V^D, j \in V^P \tag{5}$$

$$Z_{ij} \cdot (T_i + 1 - T_j) = 0 \qquad \forall i \in V_0^D, j \in V_0^P \tag{6}$$

$$X_{ij} \cdot (ES_{im} - ES_{jm}) \cdot (EL_{im} - EL_{jm}) \cdot (ET_{im} - ET_{jm}) = 0 \qquad \forall i \in V^D, j \in V^P \tag{7}$$

$$Z_{ij} \cdot (ES_{im} - ES_{jm}) \cdot (EL_{im} - EL_{jm}) \cdot (ET_{im} - ET_{jm}) = 0 \qquad \forall i \in V^D, j \in V^P \tag{8}$$

$$Wmin_{ij} \leq Wmax \qquad \forall i \in V^D, j \in V^P \tag{9}$$

$$X_{ij} \in \{0,1\} \qquad \forall i \in V_0^D, j \in V_0^P \tag{10}$$

$$Z_{ij} \in \{0,1\} \qquad \forall i \in V_0^D, j \in V_0^P \tag{11}$$

where

$$Wmin_{ij} = \begin{cases} 0, & if\ E_j \leq L_i + s_i + t_{ij} \\ E_j - (L_i + s_i + t_{ij}), & otherwise. \end{cases}$$

$Wmin_{ij}$ represents the minimum waiting time in a trip (*i,j*) and is illustrated by Figure 4.1.

Figure 4.1. Minimum waiting time.

Objective function: Minimize empty mileage; savings are only possible by reducing the amount of empty miles by matching delivery and pickup trips. C_{ijk} represents the total cost of a complete trip (*i,j*) by truck k. X_{ijk} and Z_{ijk} define whether the trip is performed {1} or not {0}.

Considering full truckloads, Constraints (2) guarantee all visited pickup nodes *j* equal the amount of pickup orders of that node, such that all demand is met. Constraints (3) guarantee all delivery nodes *i* visited equal the amount of delivery orders of that node, such that all demand is met.

Constraints (4) make sure when delivery *i* and pickup *j* are performed in the same trip on the same day, the latest allowed arrival time at the pickup location (L_j) is later than or equal to the latest possible arrival time at pickup location *j*. Constraints (5) make sure that when delivery *i* and pickup *j* are performed in the same trip and pickup *j* is on the next day, the overnight time does not exceed the maximum overnight time. Constraints (6) makes sure that in case of an overnight, pickup *j* is performed a day after delivery *i*.

When a delivery *i* and pickup *j* are performed in the same trip; equipment owner, equipment size and equipment type should be equal for *i* and *j*. For instance, when a pickup order requests a 40ft container, a merge cannot be made with delivery order *i* when a 20ft container was unloaded at *i*. Equal type, owner and size is guaranteed by constraints (7) and (8).

Due to hard time windows, arriving early at a customer results in a waiting time, customers maintain hard time windows so arriving early results in extra costs. Truckloadmatch allows matches to occur when the waiting time does not exceed a maximum. This is guaranteed by constraints (9).

4.2.3 Solution method

In this phase all routes are constructed, all of which are feasible. This chapter elaborates on generating all feasible matches respecting the rules and constraints as described in chapter 4.1.

In order to keep the algorithm fast, low-cost and easy to use, all cities have been merged in to specific zones. These zones are constructed based on COROP[11] which divides The Netherlands into 40 areas. Since a great amount of shipments are executed within the Rijnmond area where the port of Rotterdam is located, this area has been divided into 11 smaller areas. Furthermore, Belgium has been divided based on the 11 provinces, while the west of Germany has been divided into 19 areas. Together these areas represent approximately 95% of all TLM's shipments. A detailed map of these areas is shown in Appendix III.

The steps of the procedure are summarized in Algorithm 1.

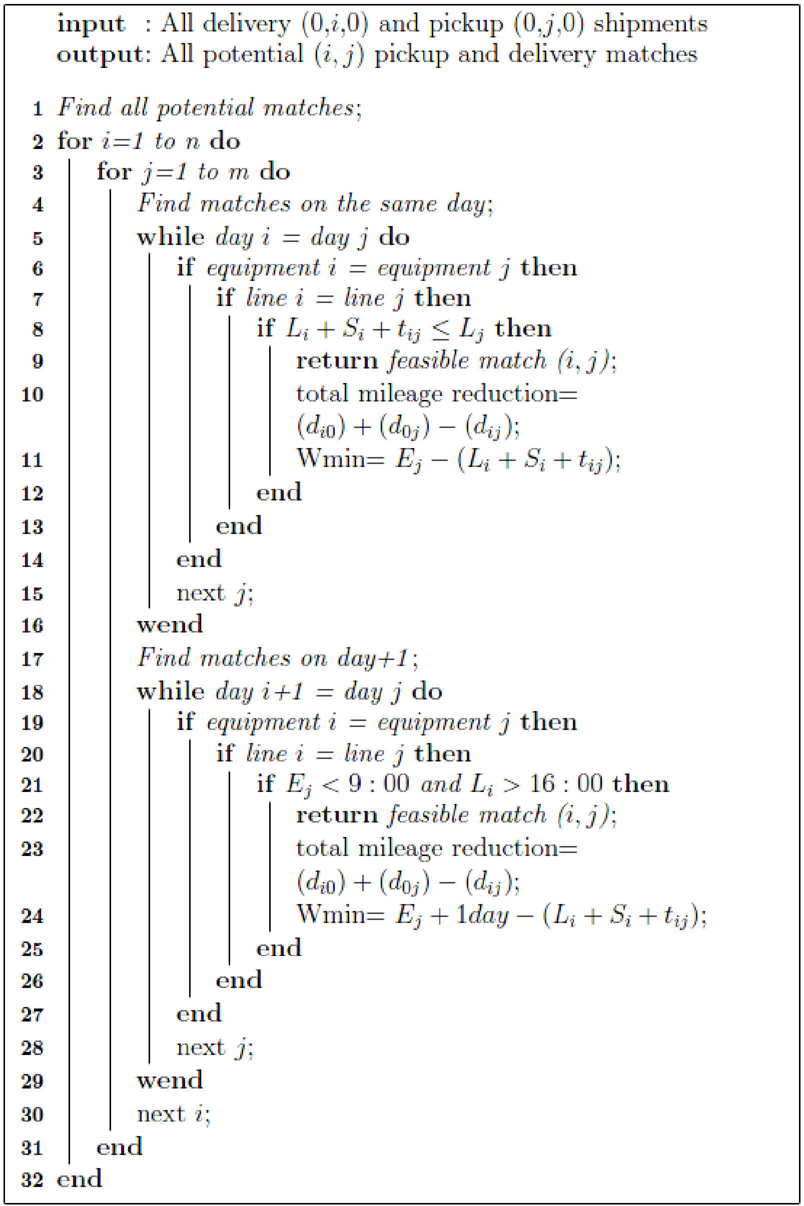
The least time consuming steps are performed first. Whenever a rule is not met, the algorithm moves to the next *i* or *j* and skip the most time consuming constraints. Line 8 is the most time consuming constraint in the search as it has to find the time t_{ij} in the origin destination matrix which is an 81x81 matrix containing the distances and travel times between all described areas.

The d_{ij} distances have been calculated with Microsoft Mappoint[12], different road type travel speeds are found in appendix VI. The calculation time for finding all feasible matches for a dataset of one week of approximately 2500 shipments takes less than a minute.

---

[11] **Co**ördinatie Commissie **R**egionaal **O**nderzoeks**P**rogramma

[12] www.microsoft.com/mappoint/



```
input  : All delivery (0,$i$,0) and pickup (0,$j$,0) shipments
output: All potential ($i$, $j$) pickup and delivery matches

Find all potential matches;
for $i$=1 to $n$ do
    for $j$=1 to $m$ do
        Find matches on the same day;
        while day $i$ = day $j$ do
            if equipment $i$ = equipment $j$ then
                if line $i$ = line $j$ then
                    if $L_i + S_i + t_{ij} \leq L_j$ then
                        return feasible match $(i, j)$;
                        total mileage reduction=
                        $(d_{i0}) + (d_{0j}) - (d_{ij})$;
                        Wmin= $E_j - (L_i + S_i + t_{ij})$;
                    end
                end
            end
            next $j$;
        wend
        Find matches on day+1;
        while day $i$+1 = day $j$ do
            if equipment $i$ = equipment $j$ then
                if line $i$ = line $j$ then
                    if $E_j < 9:00$ and $L_i > 16:00$ then
                        return feasible match $(i, j)$;
                        total mileage reduction=
                        $(d_{i0}) + (d_{0j}) - (d_{ij})$;
                        Wmin= $E_j + 1day - (L_i + S_i + t_{ij})$;
                    end
                end
            end
            next $j$;
        wend
        next $i$;
    end
end
```

Algorithm 1: Find all potential matches

As travel times are incorporated in the algorithm, different time zones and congestion could easily be applied to the model. As congestion is found to not be a big influencing factor (only 2 minutes per hour travel time of congestion), these factors are not incorporated in the model. Adding congestion to the model would increase the complexity of the solution such that the combination of different paths other than the direct t_{ij} path should be considered (thus avoiding the congested areas).

The final output of Algorithm 1 is a complete list of feasible (*i,j*) matches, with its corresponding total reduction of mileage and minimum waiting time. These two values are used in the heuristic to determine the best set of matches.

4.3 Good set of matches

The second phase of the network model concerns the selection of the *good set of matches* from the list of feasible (*i,j*) matches generated with Algorithm 1.

Assignment problem

Not all feasible matches generated by algorithm 1 can be assigned. The challenge is to select a good set of matches that results in the largest efficiency improvement. Algorithm 1 did not filter out matches that result in added mileage, based on handling time a match may still be interesting. The most popular construction heuristic is the Clarke & Wright (1964) savings algorithm and the Hungarian method (Kuhn, 2006). The best variant of the Clarke & Wright algorithm is the parallel version in which the merge yielding the largest savings is implemented at each iteration. For a review of variants of the savings algorithm see Laporte & Semet (2002). While this algorithm is not the best available in terms of accuracy (an average deviation of about 7%), it is rather fast and simple to implement, which explains its popularity (Laporte, 2007).

4.3.1 Problem statement and model formulation

Multiple feasible matches can be found for each pickup or delivery shipment. The insertion heuristic developed by Caris & Janssens (2007) which they use to insert pairs of customers into routes has been adapted to suit the rules and constraints of the network optimization problem of this project.

When forming pairs of pickups and deliveries, both spatial and temporal aspects have to be taken into account. The savings in travel distance from combining delivery *i* and pickup *j* should be as large as possible. The expression for savings in travel distance is given by:

$$(d_{i0} + d_{0j} - d_{ij}) \tag{12}$$

The minimum waiting time (see Figure 4.1) due to hard time windows between customers *i* and *j* should be as small as possible:

$$(E_j - L_i - s_i - t_{ij}) \tag{13}$$

Both aspects (12) and (13) are returned by Algorithm 1 in order to increase the speed of the total procedure. The pair of pickup and delivery customer with the highest value for the following criterion is selected first:

$$w_1 \cdot (d_{i0} + d_{0j} - d_{ij}) - w_2 \cdot \left(E_j - L_i - s_i - t_{ij}\right) \tag{14}$$

This "greedy" approach can be optimized by taking an opportunity cost of not choosing the best combination for a delivery *i* or pickup *j* into account. Gronalt et al. (2003) introduce this approach in order to make the attractiveness of joining two orders not only depend on the savings value associated with these two orders, but also on the values associated with the alternative options these orders have. If opportunity costs are not taken into account, in each step the currently best option is chosen, regardless of the effects on future choices. By giving up some savings in the current iteration, some other savings may be obtainable in subsequent iterations, leading to larger cost savings all together in the end. The authors found that adding such as measure for opportunity cost (a regret value) significantly improved the solution quality. This "regret" approach has also been implemented in this project. The opportunity cost $OC1_i$ (respectively $OC1_j$) can be defined as the difference in savings in travel time achieved by the best combination for delivery *i* (pickup *j*) and the currently selected combination. This results in the following selection criterion:

$$w_1 \cdot (d_{i0} + d_{0j} - d_{ij}) - w_2 \cdot \left(E_j - L_i - s_i - t_{ij}\right) + w_3 \cdot (OC1_i + OC1_j) \tag{15}$$

The same approach can be used to incorporate opportunity cost for minimum waiting time. This opportunity cost is defined by $OC2_i$ as the difference between the minimum waiting time of the current combination and the smallest minimum waiting time of delivery *i* (pickup *j*) in any combination.

$$\begin{gathered} w_1 \cdot (d_{i0} + d_{0j} - d_{ij}) - w_2 \cdot \left(E_j - L_i - s_i - t_{ij}\right) + \\ w_3 \cdot \left(OC1_i + OC1_j\right) + w_4 \cdot \left(OC2_i + OC2_j\right) \end{gathered} \tag{16}$$

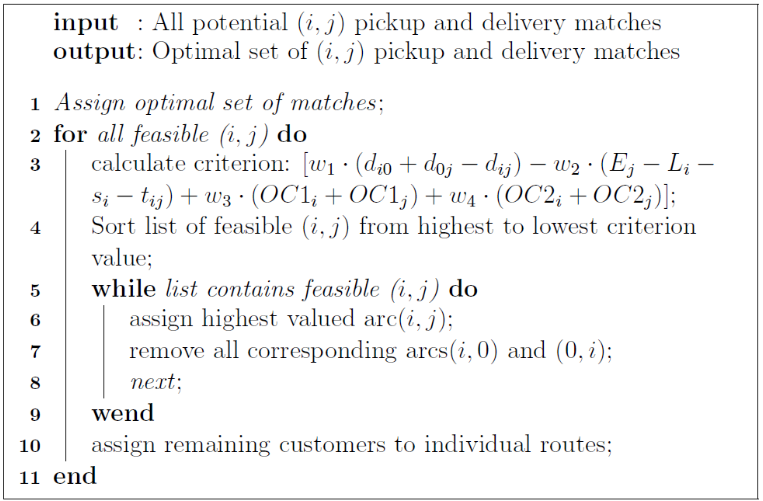
The domain of the weights is not fixed. The weights w_1, w_2, w_3 and w_4 reflect the importance given to each objective and can be weighted depending on the valuation of spatial and temporal aspects.

Routes are constructed sequentially. The pair yielding the largest saving at each iteration is implemented by adding arc (*i,j*) and removing all other arcs (*i*,0) and (0,*j*). The algorithm ends when no more feasible and profitable merges are possible. The remaining customers are inserted in individual routes.

4.3.2 Solution method

The second phase of the algorithm considers generating the good set of matches. This paragraph illustrates the heuristic "regret" approach as discussed in chapter 4.3.1.

The steps of the procedure are summarized in Algorithm 2.



```
input  : All potential $(i, j)$ pickup and delivery matches
output: Optimal set of $(i, j)$ pickup and delivery matches

Assign optimal set of matches;
for all feasible $(i, j)$ do
    calculate criterion: $[w_1 \cdot (d_{i0} + d_{0j} - d_{ij}) - w_2 \cdot (E_j - L_i - s_i - t_{ij}) + w_3 \cdot (OC1_i + OC1_j) + w_4 \cdot (OC2_i + OC2_j)]$;
    Sort list of feasible $(i, j)$ from highest to lowest criterion value;
    while list contains feasible $(i, j)$ do
        assign highest valued arc$(i, j)$;
        remove all corresponding arcs$(i, 0)$ and $(0, i)$;
        next;
    wend
    assign remaining customers to individual routes;
end
```

Algorithm 2: Find optimal set of matches

The list of feasible arcs (*i,j*) is only sorted once, Gronalt et al. (2003) found that an approach that recalculates and sorts the list does not have a favourable effect on the solution quality.

4.4 Managerial tool

The previous chapters lay the groundwork for the managerial tool which can be used to evaluate the value of Truckloadmatch, as well as the value of expanding collaboration with certain partners. The analysis of adding new partners to the collaboration is discussed in Chapter 5. This paragraph shows descriptives of the current Truckloadmatch network; i.e. the value of the network, the amount of matches and its corresponding potential empty mileage reduction.

4.4.1 Descriptives

The created model can be used to discover several statistics of Truckloadmatch's collaboration network. This paragraph gives a detailed description of the formulas used to uncover useful statistics from the network data.

This management tool is developed to evaluate the value of collaboration in different situations, e.g. the value of Truckloadmatch for current partners and new partners, but also to analyze the effects of changing time windows. The value of the collaboration can be expressed in several descriptives; the most important ones are discussed in this chapter. For a full list of all formulas see Appendix X.

Equations (17) and (18) denote total mileage and empty mileage before matching.

$$Total\ Mileage = \sum_{i=1}^{n} d_{0i}\, d_{i0} + \sum_{j=1}^{n} d_{0j}\, d_{j0} \tag{17}$$

$$Empty\ Mileage = \sum_{i=1}^{n} d_{i0} + \sum_{j=1}^{n} d_{j0} \tag{18}$$

Based on the good set of matches generated by executing Algorithm 1 and 2, the mileage reduction of matching these shipments can be calculated with equation (19). Figure 2.7 illustrates how these savings are accomplished.

$$Optimal\ mileage\ reduction = \sum_{i \in V^D} \left(d_{i0} + d_{0j} - d_{ij}\right) \cdot \left(X_{ij} + Z_{ij}\right) \qquad \forall j \in V^P \tag{19}$$

4.4.2 Truckloadmatch network descriptives

This paragraph shows the output of the model based on real Truckloadmatch shipment data of a typical week. Two situations have been analyzed to see the effect of Truckloadmatch on the involved partner's matching. The examined week concerns the following amount of hauls and details (Table 4.6):

TLM Descriptives	
Total Mileage	461.482 km
Total Empty Mileage	216.351 km
Total # imports	1292
Total # exports	898
Total # hauls	2190

Table 4.6. Truckloadmatch's network data.

The following two situations have been analyzed:

- Situation 1: all companies only match their own shipments (within the company)
- Situation 2: shipments can be matched with collaborating partners (between companies).

The following observations can be made from the results in Table 4.7: without the alliance, transportation companies would have been able to match 339 own shipments resulting in 118 matches, resulting in a reduction of approximately 17.088 km. Matching with partners has a substantial positive influence on the amount of matches for the involved companies; the amount of matches almost doubles to 256. The results show that 176 good matches can be made with partners, meaning that 38 (176-138) matches that were previously 'within' matches, are now 'between' matches; the algorithm found more efficient matches for these shipments with collaborative partners. When all these matches would be performed a reduction of approximately 20.385km can be expected.

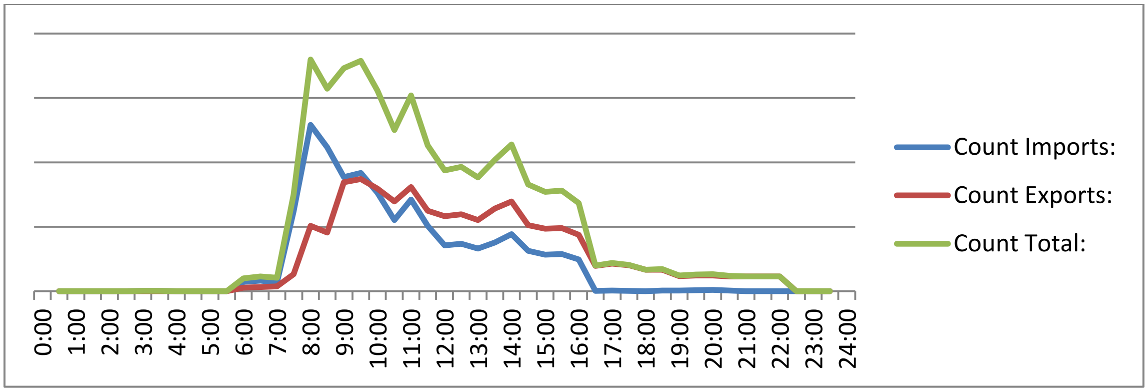
TLM Match details	***Situation 1***	***Situation 2***	***Benefits***
Feasible matches	733	3309	*2576*
Hauls with potential matches	341	812	*471*
# of good matches	118	256	138
# of good matches with partners	0	176	176
All matches			
Mileage reduction	17.088 km	37.473 km	20.385 km
Reduced # of port handling	236	512	276
Reduced handling time	472:00	1024:00	552:00
CO^2 Reduction	15.038 kg	32.976 kg	17.194 kg
Potential savings (mileage)	€ 25.632	€ 56.210	€ 30.577
TLM 'Between' matches			
Mileage reduction	0 km	25.407 km	25.407 km
Reduced # of port handling		352	352
Reduced handling time		352:00	352:00
CO$_2$ Reduction		22.358 kg	22.358 kg
Potential savings (mileage)		€ 38.111	€ 38.111

Table 4.7. Truckloadmatch analysis.

Time windows

The average time window length of the dataset differs for import and export shipments. The average time window length of an export shipment is 2:45h and 1:33h for an import shipment. The average distribution over the duration of a single day is shown in graph Graph 4.1. Clearly, the majority of shipments are scheduled in the morning, and export shipments are better spread across the day than import shipments.

These effects can be explained by several factors. Many companies in the hinterland operate a 9 to 5 work schedule. Due to just-in-time scheduling, customers wish to receive their raw materials or components in the morning and export their finished products during the afternoon. TLM already encourages shippers to allow larger time windows resulting in more feasible matches and possibly lower prices for the shipper.



Graph 4.1. Average distribution of shipments during a day.

Analyses of the effect of different time windows on feasible matches are shown in Chapter 6.1.4.

The management tool has been created in Microsoft Excel and is easy to use and particularly quick at computing the created algorithms by using Excel’s incorporated Visual Basic Editor. More information and some illustrations of the user interface are shown in appendix VII.

5. Case study

This chapter describes the process of partner selection and how the developed model can help in this partner selection process. The study has been performed in two different partner selection processes; one for horizontal collaboration with a transportation company and one for vertical collaboration with a shipper.

5.1 Partner selection

The core reason for each company to join a partnership will always be of a ‘selfish’ nature, meaning that each company’s individual goals remain to be the maximization of its own benefit (Cruijssen, 2006). Companies cannot be assumed to cooperate or sustain a collaborative outcome unless they have the incentive to do so (Figliozzi, 2006). Houghtalen (2007) concludes that the benefit to be gained by collaborating increases with the network and fleet size of a partnering carrier.

Cruijssen (2006) found that the most severe impediments are the problems with 1) finding a reliable party that can coordinate the cooperation in such a way that all participants are satisfied and 2) the construction of fair allocation mechanisms for the attained savings.

Finding the right partner requires careful screening and can be a time-consuming process. Analysing a potential partner’s strategic and organizational capabilities requires knowledge about its physical assets, its intangible assets and organizational capabilities (Bartlett & Ghoshal, 1999). The search costs involved with finding potential trading partners and evaluating their aptness and reliability can be a big hurdle for small and medium sized companies (Bleeke & Ernst, 1995, Hennart, 1993, North, 1990, Williamson, 1991). Many alliances are formed unforeseen, by meetings or through previous experience with the partner.
The detailed literature review conducted by Büyüközkan et al. (2008) resulted in two dimensions of evaluation criteria. *Strategic dimension*: similar values and goals, similar size, financial stability, comparable culture, successful track record, and fit to develop a sustainable relationship. And *Business excellence dimension*: partners’ technical expertise, -performance, -quality, and managerial experience.

5.2 Case study 1 – Transportation Company

The first case study is done for a large transportation company located in the area of Rotterdam. The company was asked to deliver a list of matchable shipments containing the start/end port, destination of the shipment, equipment type and owner, time windows and date. The company delivered a list containing 316 imports and 261 exports of a one week period. TLM shipments of this specific week have been gathered and all shipments were added to the management tool.

Two calculations are performed, one for the situation without the potential partner and one with the prospect’s shipments. The addition of the prospect’s shipments account for 20% added mileage for the collaboration. The benefits for TLM are shown in Table 5.1. Adding another party to the collaboration does not greatly affect the percentage of empty mileage of the collaboration. Addition of the new party results in a reduction of empty mileage for the entire collaboration of 0.28%. To put this figure in perspective, 56 additional good partner matches are found resulting in approximately €13.671 savings and 276 released hours for other shipments.

TLM Match details	***TLM***	***TLM + Prospect***	***Benefits***
Feasible matches	3.309	4513	*1204*
Hauls with potential matches	812	1039	*227*
# of good matches	256	325	69
# of good matches with partners	176	232	56
All matches			
Mileage reduction	37.473 km	46.587 km	9.114 km
Reduced # of port handling	512	650	138
Reduced handling time	1024:00	1300:00	276:00
CO_2 Reduction	32.976 kg	40.997 kg	8.021 kg
Potential savings (mileage)	€ 56.210	€ 69.881	€ 13.671

Table 5.1. Prospect 1 benefits for TLM.

Next, the benefits for the individual prospect have been analyzed. The amount of potential matches for this prospect increases by 61%, resulting in a reduction of empty mileage of 163% (3460km to 9114km) and approximately 115 hours of the individual partner are released for other shipments. More details can be found in appendix IX.

5.3 Case study 2 – Shipper

The second case study is done with a large shipper in Rotterdam. The company delivered a list of shipments; 73 imports and 44 exports. These shipments account for 5% added mileage to the TLM network. Again, empty mileage reduction for the entire collaboration is not influenced a lot; an improvement of 0.15% reduced mileage. 10% of the shipments can be matched with TLM partners resulting in a reduction of 1368km. Details are shown in Table 5.2. The output of the model can ultimately help TLM propose discounts to the shipper if the shipments have great matching potential with TLM partners.

TLM Match details	***TLM***	***TLM + Prospect***	***Benefits***
Feasible matches	3759	3990	*231*
Hauls with potential matches	714	748	*34*
# of good matches	213	221	8
# of good matches with partners	146	156	10
All matches			
Mileage reduction	32809 km	34177 km	1368 km
Reduced # of port handling	426	442	16
Reduced handling time	852:00	884:00	32:00
CO_2 Reduction	28872 kg	30076 kg	1204 kg
Potential savings (mileage)	€ 49214	€ 51266	€ 2052

Table 5.2. Prospect 2 benefits for TLM.

5.4 Conclusion

New partners can greatly benefit from the dense TLM network. In terms of efficiency the collaboration does not seem to perform much more efficient through the addition of the prospect, the additional shipments however result in substantial potential savings. Any extra match is a benefit for the individual partner, but the collaboration is also faced with extra shipments that are not easily matched due to the tough constraints.

As the network grows, more shipments are required to achieve same benefits for the collaboration. The matching constraints were found to be a bigger restricting factor in the matching problem than expected, chapter 6 elaborates on the impact of the constraints on the network, and some optimizations are proposed.

6. Network effects

This chapter discusses the factors that influence matchmaking for full truckloads. The analysis has been performed on Truckloadmatch's real network data.

6.1 Determinants of matching

Factors that influence feasible matches are discussed in this paragraph, and its influence on matchmaking will be analyzed. Knowing which factors have a large influence on matching can be of great value in partner selection processes and price negotiations with large shippers.

6.1.1 Equipment type

Containers with equal size and of equal type can be matched and some additional possibilities are described in chapter 4.1. As discussed earlier in this report, ADR and reefer containers are not easily matched and were disregarded. 5 container type/size combinations are allowed to match, being 20ft and 40ft Dry Van containers and 20, 40 and 45ft High Cube containers.

To analyze the influence of equipment type on matching, the amount of feasible matches has been analyzed when *only* the equipment type constraints as described in chapter 4.1 are considered. All other constraints such as shipping line constraints have been ignored in this analysis.

For example, when considering 2 import shipments and 4 export shipments and all constraints are ignored, 8 feasible matches can be found. The next step is running the algorithm with the equipment constraint to determine how many matches are still feasible. The output is shown in Table 6.1. The analysis has been performed for data of 4 randomly chosen weeks in 2012. From the results can be observed that approximately 40% of all matches are allowed when only equipment type and sizes constraints are considered. Thus, in 60% of the cases a match cannot be allowed as it is restricted by equipment type constraints. The type and size of a maritime container are great constraining factors of matching but are not easily changed to allow for more matches.

	Week 10	***Week 12***	***Week 39***	***Week 42***	***Average***
Total # imports	949	1076	1385	1292	
Total # exports	672	777	924	898	
Total # hauls	1621	1853	2309	2190	
Pre-Count	477206	606232	950364	843796	
Post-Count	187336	239856	395542	342494	
Percentage of success	39%	40%	42%	41%	**40%**

Table 6.1. Influence of equipment constraint.

6.1.2 Shipping line

The second investigated determinant is the shipping line constraint. A match is only allowed when both import and export shipments are of identical shipping lines. A list of alternatives is shown in Appendix II.

The same analysis as with equipment type has been performed for the shipping line constraint. The results are shown in Table 6.2.

	Week 10	*Week 12*	*Week 39*	*Week 42*	*Average*
Pre-Count	477206	606232	950364	843796	
Post-Count	24936	39576	53618	38340	
Percentage of success	5%	7%	6%	5%	**5%**

Table 6.2. Influence of shipping line constraint.

From the analysis can be observed that in approximately 5% of the cases, the shipping line constraint is met. The possibility of finding a feasible match is greatly influenced by the shipping line constraint; this was expected due to the large amount of equipment owners.

Optimization - Liner Alliances

Some possibilities of optimization are possible. Shipping lines form alliances to aggregate cargo volumes and improve asset utilization through sharing of vessels. Members of the two biggest container shipping alliances, the New World Alliance (NWA) and the Grand Alliance (GA) have joined forces creating the G6 Alliance. Currently this alliance does not yet have agreements with TLM about exchanging maritime containers in pre- and end-haulage *between the members of the liner alliance*: APL, Hyundai Merchant Marine (HMM), Mitsui O.S.K Lines (MOL), Hapag-Lloyd AG (HLC), Nippon Yusen Kaisha (NYK) and Orient Overseas Container Line (OOCL). The alliance represents an average of 20% of all TLM shipments.

Table 6.3 shows the impact on match probability when these members would allow matching containers in the pre- and end-haul of intermodal containers.

	Week 10	*Week 12*	*Week 39*	*Week 42*	*Average*
Pre-Count	477206	606232	950364	843796	
Post-Count	46514	68538	90024	75132	
Percentage of success	10%	11%	9%	9%	**10%**

Table 6.3. Influence of G6 alliance.

From the analysis can be concluded that when the G6 Alliance allows TLM to match their members' shipments, the possibility of finding a feasible match doubles; in 10% of all cases, the shipping line constraint is met.

The same analysis (Table 6.4) has been performed for the CKYH alliance consisting of members COSCO, "K" Line, Yang Ming Marine Transport Corp, Hanjin Shipping Co Ltd. and partner Evergreen.

	Week 10	*Week 12*	*Week 39*	*Week 42*	*Average*
Pre-Count	477206	606232	950364	843796	
Post-Count	27344	47232	87636	60334	
Percentage of success	6%	8%	9%	7%	**8%**

Table 6.4. Influence of CKYH Alliance.

It is clear that shipping lines greatly influence the possibility of matching shipments in the hinterland. To better understand the impact when these alliances allow matching, the analysis of chapter 4.4.2 is repeated to see the effect of these adjustments on a real data set.

The output shown in Table 6.5 is a comparison of the current TLM situation (2) with situation 3 where the liner alliances G6 and CKYH allow TLM to match their equipment in the pre- and end-haulage part of the intermodal chain.

TLM Match details	***Current TLM***	***TLM + G6 &CKYH***	***Benefits***
Feasible matches	3.309	7.455	*4.146*
Hauls with potential matches	812	1.156	*344*
# of good matches	256	309	53
# of good matches with partners	176	214	38
All matches			
Mileage reduction	37.473 km	50.389 km	12.916 km
Reduced # of port handling	512	618	106
Reduced handling time	1024:00	1236:00	212:00
CO_2 Reduction	32.976 kg	44.342 kg	11.366 kg
Potential savings (mileage)	€ 56.210	€ 75.583	€ 19.374

Table 6.5. Effect of liner alliances on real data set with all matching constraints.

The amount of feasible matches more than doubled and the TLM partners are able to create an additional 53 matches, resulting in 212 hours of port handling time released for other shipments and total mileage reduction of 12.916km.

Benefits are not only for the transportation companies, the liner alliance also benefits from matching. A match between shipping lines results in less handling of empty containers at the terminal and a reduction of empty container repositioning.

6.1.3 Location of shipments

The location of shipments in the hinterland determines the reduction of mileage when two shipments are matched. The following analysis is performed in a similar way as previous analyses, a match will only be allowed when it satisfies equation (20).

$$d_{i0} + d_{0j} - d_{ij} > 0 \tag{20}$$

A match will only be allowed when its mileage reduction is positive. The results of the analysis are shown in Table 6.6.

	Week 10	***Week 12***	***Week 39***	***Week 42***	***Average***
Pre-Count	477206	606232	950364	843796	
Post-Count	458182	591124	923929	813993	
Percentage of success	96%	98%	97%	96%	**97%**

Table 6.6. Influence of location constraints.

From the analysis can be observed that the location of a pickup or delivery shipment is not a great influencing factor of matching as expected due to triangle inequality. In approximately 97% of the cases, a match is profitable in terms of reduced mileage. Naturally, matches between shipments that are relatively close are more profitable. The cases that are not profitable are mainly trips of which the export destination port is not the same as the origin port of the import haul. For instance, the import haul Rotterdam-> Breda will not be matched with the export haul

Duisburg->Neuss, due to restrictions of the model which does not consider the 'flat' distance to the port.

6.1.4 Time windows

Gronalt et al. (2003) show the impact of time window tightness on solution quality. In general, increasing time window tightness leads to a rapid increase in empty vehicle movements. Throughout interviews with several actors within TLM it became apparent that larger time windows for export shipments, or a shift of export shipments to the afternoon, were expected to dramatically increase the probability of a match. This is tested in a similar way as the previous analyses.

Three scenarios have been analyzed, the first case being the normal situation with current real time windows. In the second situation, time windows for export shipments have been changed to 8:00-18:00. Time windows for export shipments have been changed to 13:00-18:00 in the third case. In all cases, import shipment time windows are kept in their present condition. The time window distribution of the first situation is shown in Graph 4.1.

A match can only be feasible when the earliest arrival time at the importer plus unloading time and drive time to the exporter is before the latest arrival time of the exporter, reflected by equation (21).

$$E_i + s_i + t_{ij} < L_j \tag{21}$$

The analysis has been split up into 'same day' matches and 'next day' matches. Different matching rules apply for these situations as discussed in chapter 4.1.

The results are shown in Table 6.7. It can be observed that in the current situation 31% of the cases can successfully be matched, the percentage of matches for the next day is a lot smaller due to its special constraints.

In the second situation the change of time windows of export shipments to 8:00-18:00 shows to have a great impact on the amount of feasible matches. Shifting export shipment times to the afternoon as in case 3 has no impact on the rate of success as compared to case 2.

	Case 1 ***Normal time windows***		***Case 2*** ***Export 8:00-18:00***		***Case 3*** ***Export 13:00-18:00***	
	same day matches	*Next day matches*	*same day matches*	*Next day matches*	*same day matches*	*Next day matches*
Pre-count	653126	190670	653126	190670	653126	190670
Post-Count	203504	1285	438134	1138	438134	0
Success	**31%**	1%	**67%**	1%	**67%**	0%

Table 6.7. Effect of different export time windows.

The same matches can still be made in case 3, however when the earliest arrival time shifts to the afternoon the average minimum waiting time for these matches increases. To get a better understanding of the effect of the different time windows the analysis of chapter 4.4.2 has been repeated for the different time window cases.

TLM Match details	***Case 1 Normal time windows***	***Case 2 Export 8:00-18:00***	***Case 3 Export 13:00-18:00***
Feasible matches	3.309	7024	7017
Hauls with potential matches	812	1360	1357
# of good matches	256	410	416
# of good matches with partners	176	269	275
All matches			
Mileage reduction	37.473 km	64188 km	60467 km
Reduced # of port handling	512	820	832
Reduced handling time	1024:00	1640:00	1664:00
CO_2 Reduction	32.976 kg	56486 kg	53211 kg
Potential savings (mileage)	€ 56.210	€ 96282	€ 90700

Table 6.8. Impact of different time windows on real data.

Case 3 seems to be the best situation when the different cases in Table 6.8 are compared. However, the average minimal waiting times of the good matches have increased. The minimal waiting times of the different cases are shown in the table below (Table 6.9).

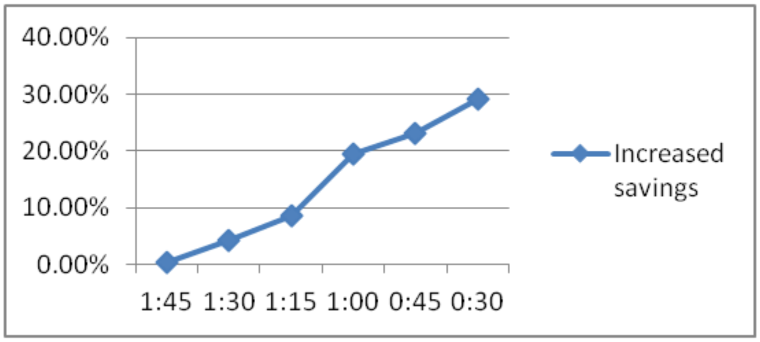
Minimal waiting time	***Case 1 Normal time windows***	***Case 2 Export 8:00-18:00***	***Case 3 Export 13:00-18:00***
Sum of *Wmin* in good set	43:52	0	224:06
Average *Wmin* per match	00:10	0	0:32

Table 6.9. Minimal waiting times in good set.

Naturally, when export shipments can be matched at any time in one period (a working day) as in case 2, minimal waiting times are nonexistent. The shift of export time windows to the afternoon (case 3) results in an increase of minimum waiting time to an average of 32 minutes per match, but still is a much better case than the current time windows.

6.1.5 Load and Unload

Currently load and unload times are assumed to be 2 hours; shorter times naturally have a positive influence on matching. shows the increase of savings when TLM manages to decrease unloading times. These times are dependent of the load and unload speed of the shipper and the type of goods. Port times are not in the scope of this project as there are no restrictions on arrival and departure times at the terminal.



Graph 2. Unloading time influence.

6.2 Conclusion

A summary of the influence of all constraining factors in matching is shown in Table 6.10.

Constraint	***Restricting factor***
Shipping Line	95%
Time window	69%
Equipment type and size	60%
Location	3%

Table 6.10. Summary of constraint influence.

Shipping Lines

Clearly, shipping lines are the main bottlenecks; in 95% of all cases the shipping line restricts a match. Collaboration of the members of big liner alliances such as G6 and CKYH in pre- and end-haulage can greatly increase the matching potential of TLM.

Another form of optimization is possible through the exchange of empty containers in empty container depots located in the hinterland. Inland terminals have to cope with a plus and surplus of maritime containers of different equipment owners. By extending the current matching problem with empty depots, empty containers can be exchanged in the hinterland instead. Figure 6.1 illustrates the alternative matching flow including inland terminals.

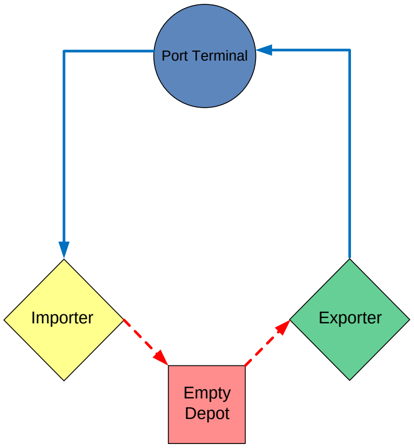
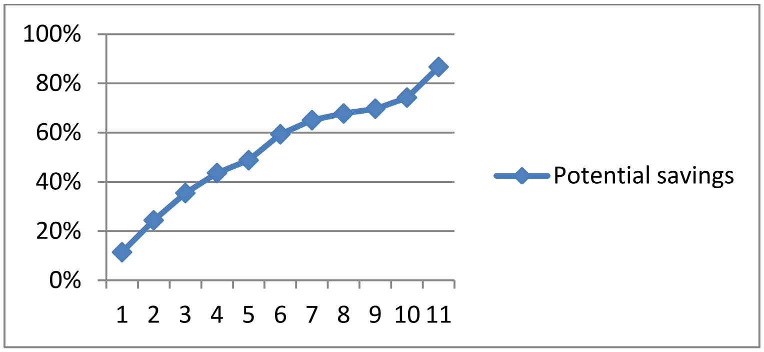


Figure 6.1. Extending the business case with empty depots.

Time windows

The second most restricting factor is the time window of shipments. The average time window length of a TLM export shipment is 2:45h, and 1:33h for an import shipment.

Graph 6.2 shows the effect of lengthening the current time windows, the time windows have been changed by adding 15 minutes to the latest departure time at the customer location and subtracting 15 minutes from the earliest arrival time. Example: the time window 13.00-14.00 changes to 12.30-14.30 in step 1 and to 12.00-15.00 in step 2, etc. The graph shows that lengthening the current time windows by only 30 minutes results in an increase of 11% potential savings.



Graph 6.2. Added mileage reduction.

7. Conclusions and recommendations

The main bottleneck in container exchange within TLM is the shipping line. Currently shipping lines do not allow transportation companies to exchange maritime container with a different equipment owner. Two methods have been proposed to increase matches.

- Collaborate with liner alliances; allowing matches between the G6 and CKYH alliances increases potential savings by approximately 34%.
- Extend the matching model by allowing empty container exchange at inland terminals/empty depots.

The second large restricting factor is the time window constraint. Collaborate with shippers to lengthen time windows and shorten loading times to increase the matching potential; small adjustments i.e. a shortening of loading times or time windows by 30 minutes can increase potential savings by 11%.

The created model is currently being tested in partner negotiations, addition of prospects that are about equally sized as current TLM partners can result in a reduction in empty mileage of 163% for the new party. As the network of TLM is already rather dense, adding shipments of new partners does not greatly influence the fraction of empty mileage for TLM. As the network grows, more shipments are required to achieve same benefits for the collaboration.

A major implication of the matching model is commitment of the current TLM partners. Many matches are still denied; a detailed overview of reasons of denied matches can be viewed in appendix VIII. The major reason of a denied match is that the shipment is already matched with an own shipment. Through interviews it became apparent that own matches have priority over TLM matches, many shipments however have better matching alternatives with partners and should be prioritized.

Moreover, partners should prioritize TLM matches over charters. The ‘selfish’ charter decision is often seen as the best option for the individual company. By prioritizing TLM matches the collaboration benefits through its reduced empty mileage. In the long term the individual company also benefits from this prioritization as the other partners will also prioritize TLM matches. Planners should have incentives and be motivated to match TLM shipments, difficult and specific targets are proven to have a positive influence on work performance.

An origin-destination matrix with travel times and distances between areas on municipality or COROP level can be used to increase PARIS performance. This reduces the accuracy of distance calculations but will have a great influence on the calculation speed of the matching algorithm.

Ultimately, matching maritime containers in pre- and end-haulage increases efficiency of shipments; the same amount customers can be served with a smaller fleet. It often occurs that a shipment can be matched, but the released vehicle cannot be assigned to a new shipment. As the road haulers don’t want their trucks to be idle, generally this match is not ‘agreed’. When there is an over-capacity of vehicles, transporting companies must be willing to reduce their fleet size.

8. References

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Appendices

Appendix I – Import and Export distribution

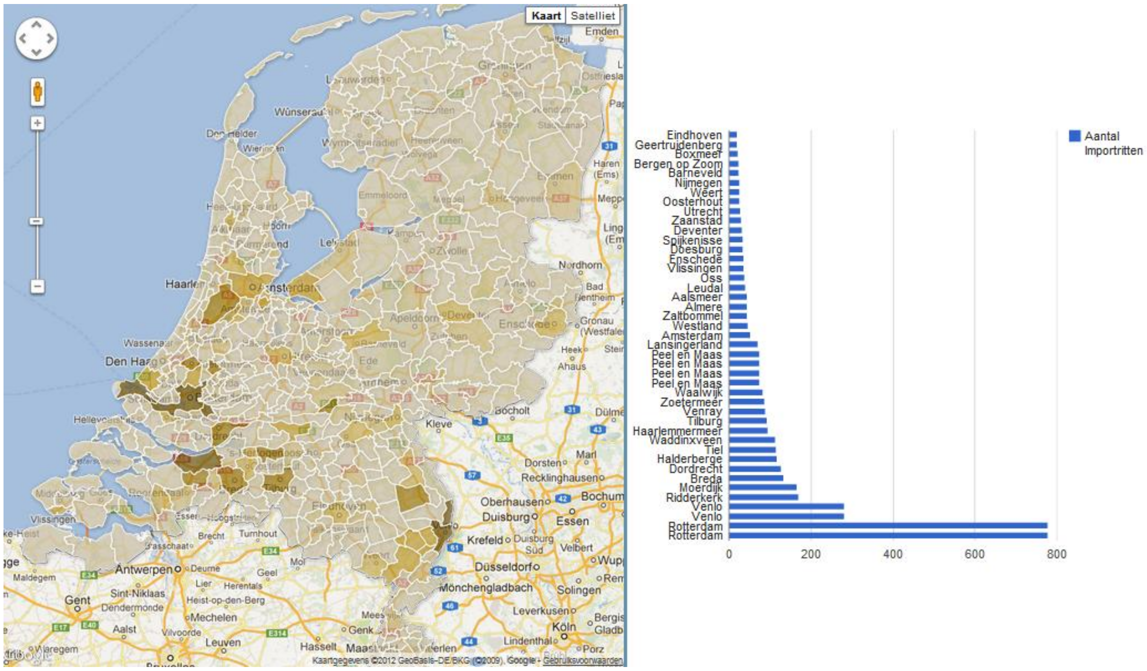


Figure 0.1: Import areas The Netherlands.

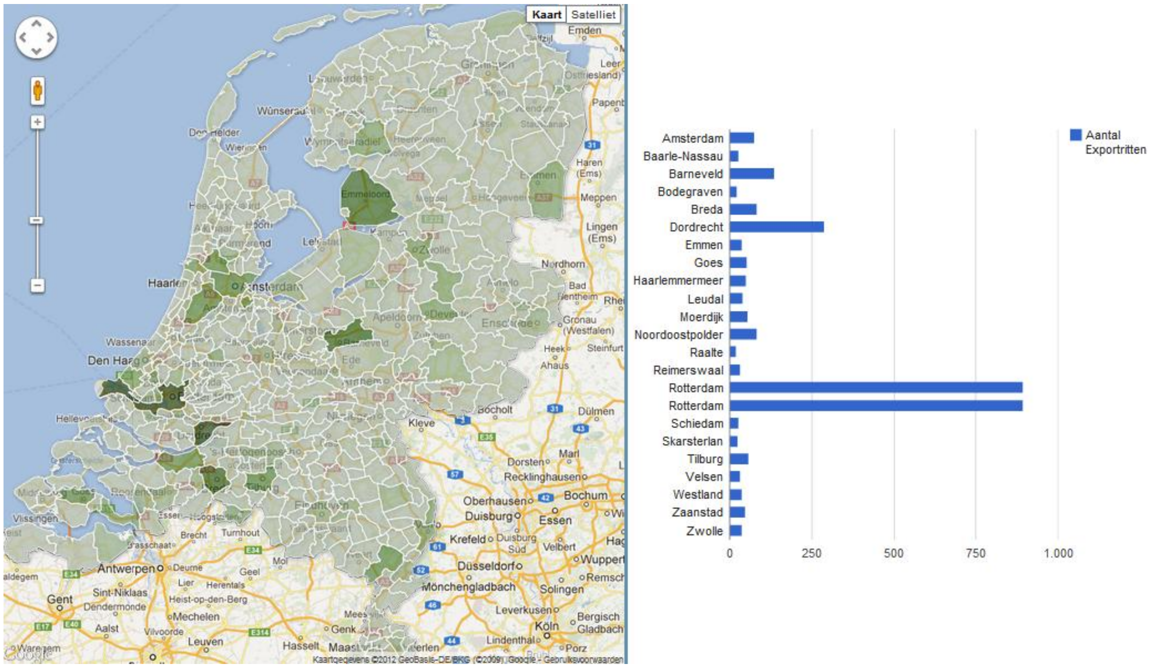


Figure 0.2: Export areas The Netherlands.

Appendix II – TLM pace list

The pace list is used by determining the distance from the loading address to the port area where the container should be brought to. The tariff is paid by the owner of the export shipment to the party that performs the trip (the owner of the import shipment).

Between	***And***	***Tariff***
0 km	25 km	€ 142.0
26 km	50 km	€ 163.0
51 km	75 km	€ 184.0
76 km	100 km	€ 205.0
101 km	125 km	€ 226.0
126 km	150 km	€ 247.0
151 km	175 km	€ 268.0
176 km	200 km	€ 299.0
201 km	225 km	€ 331.0
226 km	250 km	€ 373.0
251 km	275 km	€ 404.0
276 km	300 km	€ 457.0

Table 0.1. TLM Pace list.

Appendix III – Geographical scope

Figure 0.3. Areas Belgium.

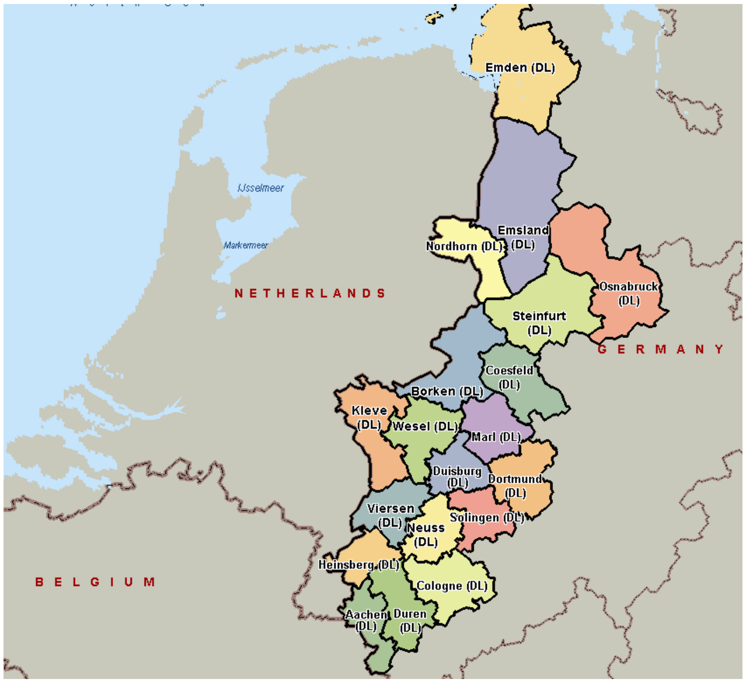


Figure 0.4. Areas Germany.

Appendix IV – Cause and effect diagram

The figure below shows an Ishikawa diagram that shows the causes of the number of potential matches.

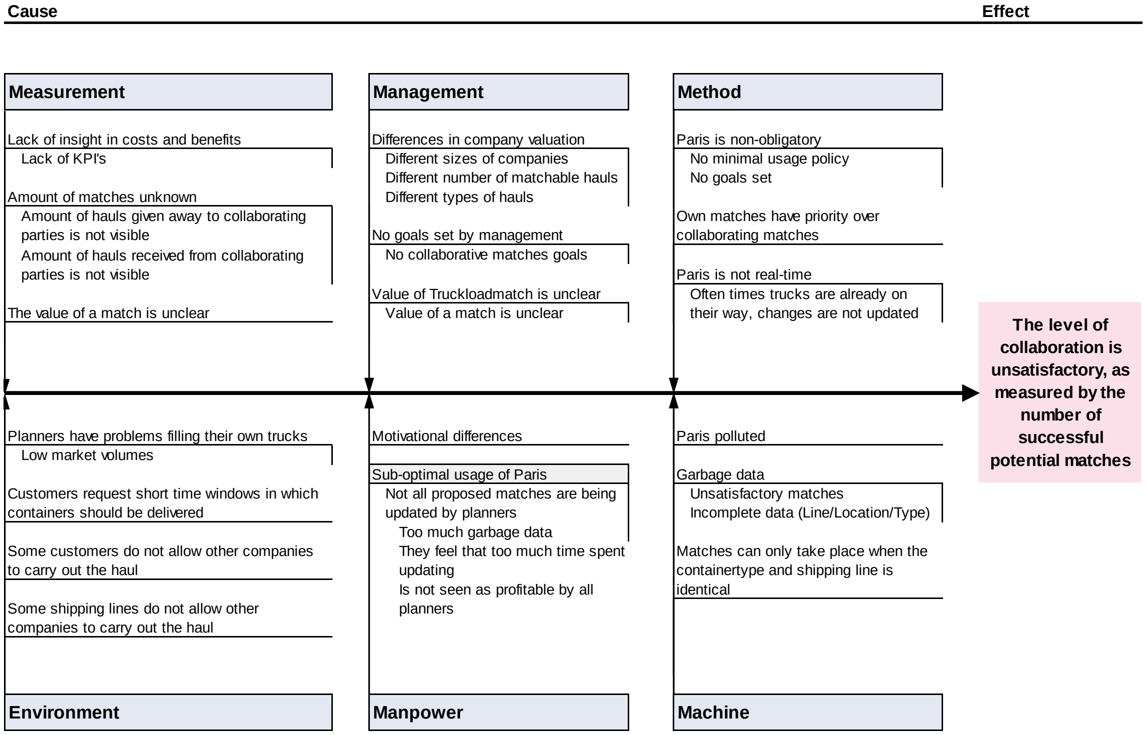


Figure 0.5. Ishikawa diagram.

Appendix V – Equipment owners alternatives

The table below shows the different prefixes of shipping lines. Rules are vice-versa; e.g. an import MAE can match with an MSK export container, and an import MSK container can match with a MAE export container.

Shipping lines		
* Any Line can match with its own line		
MAE	<< >>	MSK
CMA	<< >>	DEL
ACL	<< >>	ACS
ACL	<< >>	ACX
ANL	<< >>	ANN
ANL	<< >>	CMA
ANL	<< >>	DEL
CHI	<< >>	CSC
DAA	<< >>	DEL
ECA	<< >>	EIM
EIS	<< >>	EVG
EIS	<< >>	HML
EIS	<< >>	IM
HAP	<< >>	HLC
KKK	<< >>	KLI
LTE	<< >>	LTN
LYK	<< >>	LYS
MMR	<< >>	MON
NDS	<< >>	NIL
OOC	<< >>	OOCL
OOC	<< >>	OOL
PCI	<< >>	PIL
PLP	<< >>	POR
SCI	<< >>	SCJ
SDG	<< >>	SEA
HJS	<< >>	SEN
HSD	<< >>	SUD
STA	<< >>	STS
UAC	<< >>	UAS
WHL	<< >>	WLH
MAE	<< >>	SAF
MAE	<< >>	SEJJ

Figure 0.6. Shipping line alternatives.

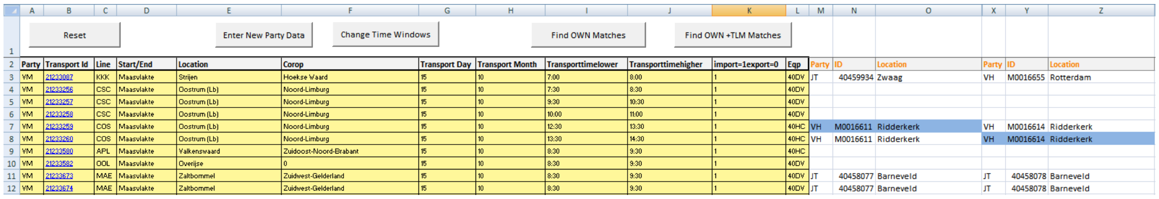
Appendix VI – Road speeds for DriveTimeMatrix

Road speeds for DriveTimeMatrix	
Interstates (motorways)	80 km/h
Limited Access Roads	70 km/h
Other (major) Roads	80 km/h
Arterial (minor) Roads	70 km/h
Streets	30 km/h

Table 0.2. Road speeds.

Appendix VII – User Interface

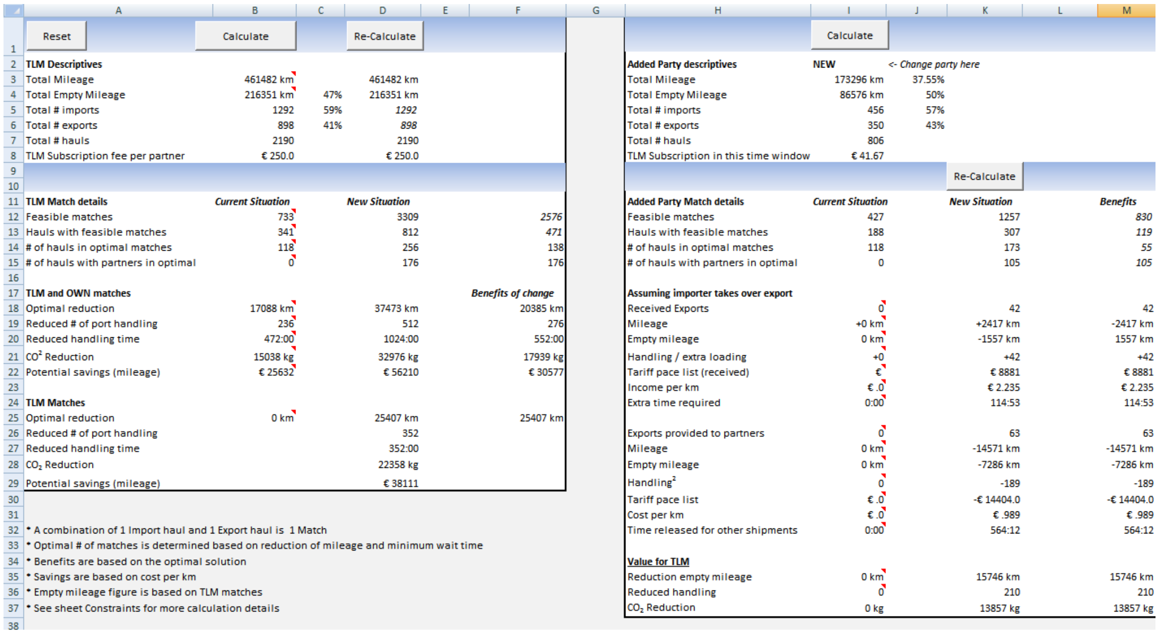
All shipments are located in the data tab (Figure 0.7). New party data can easily be added to the current dataset and time windows can be changed to calculate network effects. 2 different matching algorithms can be used; own matches (the ‘before’ situation without TLM) and between matches (TLM and own matches).



Party	Transport Id	Line	Start/End	Location	Corop	Transport Day	Transport Month	Transporttimelower	Transporttimehigher	import=1export=0	Eqp	Party	ID	Location	Party	ID	Location
VM	21233087	KKK	Maasvlakte	Strijen	Hoekse Waard	15	10	7:00	8:00	1	40DV	JT	40459934	Zwaag	VH	M0016655	Rotterdam
VM	21233256	CSC	Maasvlakte	Oostrum (Lb)	Noord-Limburg	15	10	7:30	8:30	1	40DV						
VM	21233257	CSC	Maasvlakte	Oostrum (Lb)	Noord-Limburg	15	10	9:30	10:30	1	40DV						
VM	21233258	CSC	Maasvlakte	Oostrum (Lb)	Noord-Limburg	15	10	10:00	11:00	1	40DV						
VM	21233259	COS	Maasvlakte	Oostrum (Lb)	Noord-Limburg	15	10	12:30	13:30	1	40HC	VH	M0016611	Ridderkerk	VH	M0016614	Ridderkerk
VM	21233260	COS	Maasvlakte	Oostrum (Lb)	Noord-Limburg	15	10	13:30	14:30	1	40HC	VH	M0016611	Ridderkerk	VH	M0016614	Ridderkerk
VM	21233580	APL	Maasvlakte	Valkenswaard	Zuidoost-Noord-Brabant	15	10	8:30	9:30	1	40HC						
VM	21233582	OOL	Maasvlakte	Overijse	0	15	10	8:30	9:30	1	40DV						
VM	21233673	MAE	Maasvlakte	Zaltbommel	Zuidwest-Gelderland	15	10	8:30	9:30	1	40DV	JT	40458077	Barneveld	JT	40458078	Barneveld
VM	21233674	MAE	Maasvlakte	Zaltbommel	Zuidwest-Gelderland	15	10	8:30	9:30	1	40DV	JT	40458077	Barneveld	JT	40458078	Barneveld

Figure 0.7. Data interface.

The output tab allows for comparisons of multiple analyses (Figure 0.8). The re-calculate buttons perform the exact same calculations but its results are shown in the column below. The box to the right shows a detailed analysis of costs and benefits of a specific partner.

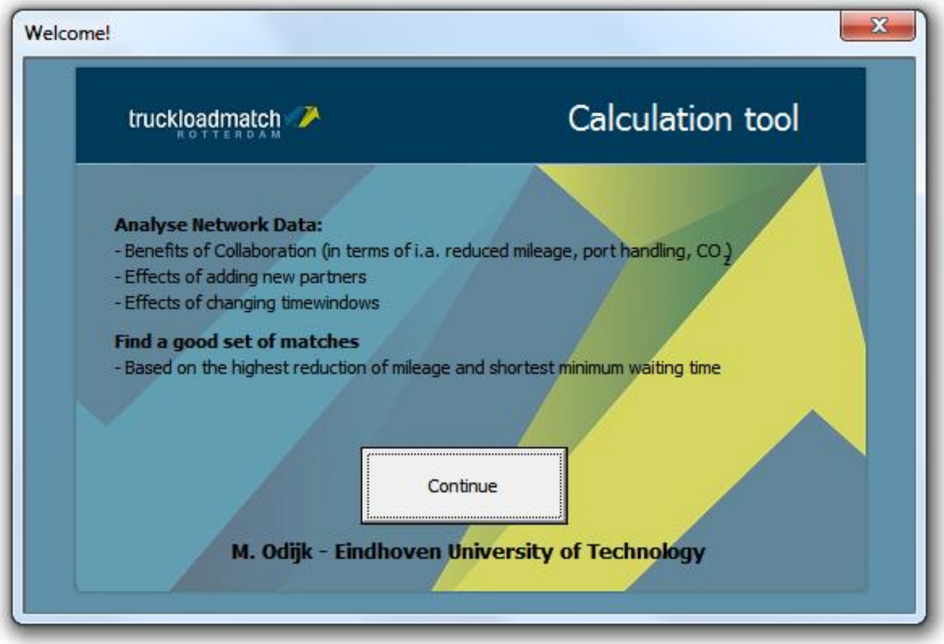


TLM Descriptives				
Total Mileage	461482 km		461482 km	
Total Empty Mileage	216351 km	47%	216351 km	
Total # imports	1292	59%	*1292*	
Total # exports	898	41%	*898*	
Total # hauls	2190		2190	
TLM Subscription fee per partner	€ 250.0		€ 250.0	
TLM Match details	***Current Situation***		***New Situation***	
Feasible matches	733		3309	*2576*
Hauls with feasible matches	341		812	*471*
# of hauls in optimal matches	118		256	138
# of hauls with partners in optimal	0		176	176
TLM and OWN matches				***Benefits of change***
Optimal reduction	17088 km		37473 km	20385 km
Reduced # of port handling	236		512	276
Reduced handling time	472:00		1024:00	552:00
CO^2 Reduction	15038 kg		32976 kg	17939 kg
Potential savings (mileage)	€ 25632		€ 56210	€ 30577
TLM Matches				
Optimal reduction	0 km		25407 km	25407 km
Reduced # of port handling			352	
Reduced handling time			352:00	
CO_2 Reduction			22358 kg	
Potential savings (mileage)			€ 38111	

- A combination of 1 Import haul and 1 Export haul is 1 Match
- Optimal # of matches is determined based on reduction of mileage and minimum wait time
- Benefits are based on the optimal solution
- Savings are based on cost per km
- Empty mileage figure is based on TLM matches
- See sheet Constraints for more calculation details

Added Party descriptives	**NEW**	*<- Change party here*		
Total Mileage	173296 km	37.55%		
Total Empty Mileage	86576 km	50%		
Total # imports	456	57%		
Total # exports	350	43%		
Total # hauls	806			
TLM Subscription in this time window	€ 41.67			
Added Party Match details	***Current Situation***		***New Situation***	***Benefits***
Feasible matches	427		1257	*830*
Hauls with feasible matches	188		307	*119*
# of hauls in optimal matches	118		173	*55*
# of hauls with partners in optimal	0		105	*105*
Assuming importer takes over export				
Received Exports	0		42	42
Mileage	+0 km		+2417 km	-2417 km
Empty mileage	0 km		-1557 km	1557 km
Handling / extra loading	+0		+42	+42
Tariff pace list (received)	€		€ 8881	€ 8881
Income per km	€ .0		€ 2.235	€ 2.235
Extra time required	0:00		114:53	114:53
Exports provided to partners	0		63	63
Mileage	0 km		-14571 km	-14571 km
Empty mileage	0 km		-7286 km	-7286 km
Handling^2	0		-189	-189
Tariff pace list	€ .0		-€ 14404.0	-€ 14404.0
Cost per km	€ .0		€ .989	€ .989
Time released for other shipments	0:00		564:12	564:12
Value for TLM				
Reduction empty mileage	0 km		15746 km	15746 km
Reduced handling	0		210	210
CO_2 Reduction	0 kg		13857 kg	13857 kg

Figure 0.8. Output interface.



Analyse Network Data:

- Benefits of Collaboration (in terms of i.a. reduced mileage, port handling, CO_2)
- Effects of adding new partners
- Effects of changing timewindows

Find a good set of matches

- Based on the highest reduction of mileage and shortest minimum waiting time

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Figure 0.9. Welcome screen.

Appendix VIII – Reasons for denied matches

Denied matches are recorded by PARIS over a one year period, given in by planners.

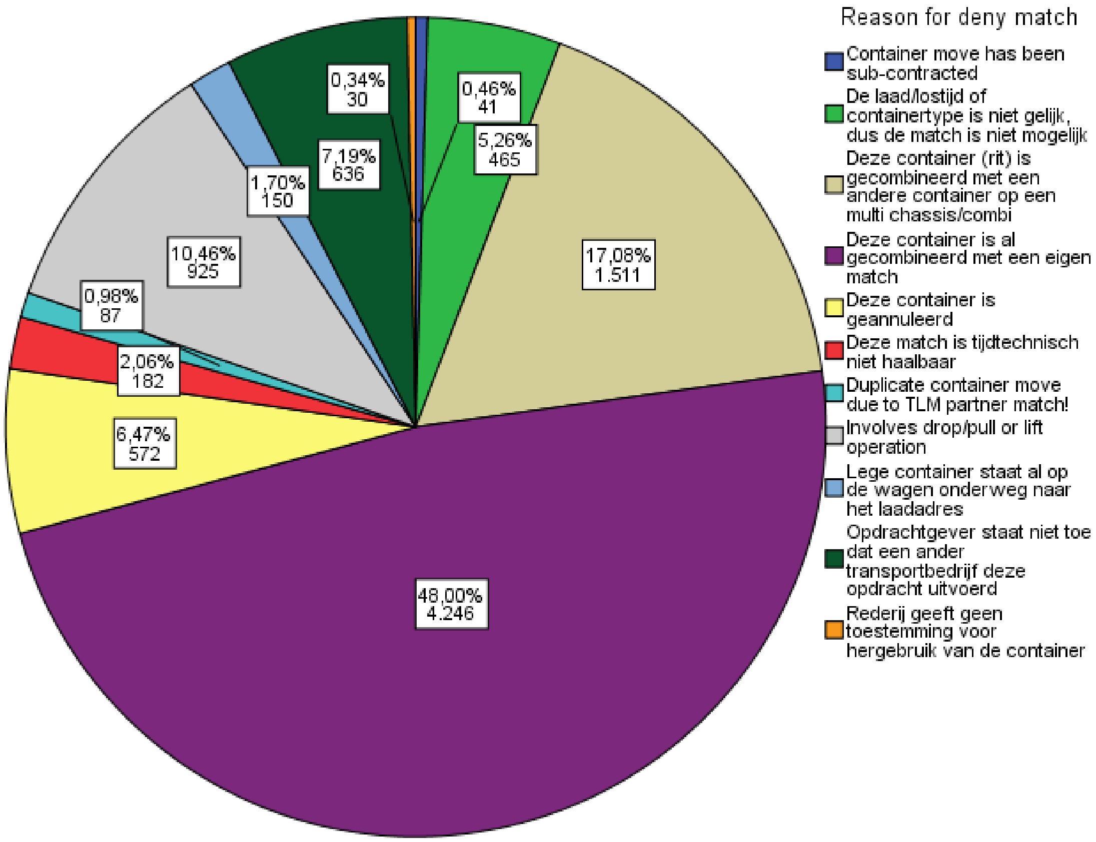

Figure 0.10. Denied matches.

Appendix IX – Case 1 prospect descriptives

Added Party Match details	***Own matches***	***Joined TLM***
Feasible matches	174	690
Hauls with feasible matches	89	177
# of hauls in optimal matches	66	106
# of hauls with partners in optimal	0	66

Table 0.3. Benefits for prospect when joined.

Added Party Match details	***Potential matches***
Received Exports	38
Mileage	+2777 km
Empty mileage	-1286 km
Handling / extra loading	+38
Tariff pace list (received)	€ 8524
Income per km	€ 2.098
Extra time required	111:29
Exports provided to partners	28
Mileage	-4583 km
Empty mileage	-2291 km
Handling	-84
Tariff pace list	-€ 5635.0
Cost per km	€ 1.230
Time released for other shipments	226:33

Table 0.4. Prospect potential exchanges.