Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

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Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach
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This Master Thesis for the TU Delft master program Management of Technology is executed at TNO in association with Statistics Netherlands (CBS). CBS provided valuable data on the commodities transported in road transport done by Dutch companies. This data gained more value, since companies can report shipment data using atomized XML applications. CBS is one of the first statistic bureaus in the Netherlands using such reliable data collection methods. By means of this data I developed a matching model that is able to find collaboration partners on the basis of their shipment data. This matching model has run for specific companies in the CBS database to research the potential for merging road transport activities.

This research project would not had been successful without the help of others. First, I would like to thank TNO and in particular Dr. Igor Davydenko MSc. and Prof. Dr. Ir. Loránt Tavasszy for giving the opportunity to fulfil my research project at TNO. Their constructive feedback and discussion on my work were of great help. Also, Mathijs Jacobs and Wilfred Zentjens who granted access to the complete CBS database. I am very aware of the fact that using this data is a unique opportunity. They were very willing to answer important questions that concern CBS or the database. I hope that the data analysis and recommended changes help to enhance their data. Also, I would like to thank my graduation committee. First of all, Dr. Ron van Duin, for all his support and time he has spent on guiding me through the graduation process. Multiple constructive feedback rounds and advice on for instance clustering helped me a lot. Furthermore, thanks to Dr. Ing. Victor Scholten for his effort for fulfilling the role of second supervisor.

I have learned a lot from Ron, Igor and Lori. Even though it might not be clear in this research, but they did broaden my view on logistics. Their way of positive guiding and steering on the information I gave have had a very positive effect on my work. This will definitely help in my professional career. Looking back, I would have done several things differently: better focus on the research, preparing the data differently and running the model on the full CBS database in an earlier stage. I also would have chosen to make a separate chapter on literature to comply with the usual format of a thesis.

Finally, I would never have come this far without the support of my parents, my dad in particular. Also Saskia Muntz, my girlfriend, never stopped supporting me. Especially in the final stressful days.

Jan Robroeks,
Pijnacker, April 21th 2016
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EXECUTIVE SUMMARY

Fierce competition force companies engaging in road transport to improve their performance. One way to increase performance in order to gain competitive advantage is by horizontal collaboration. This collaboration focusses on combining road transport of two companies. Even though it is accepted that collaboration gives opportunities for improvement by, for example, sharing their fleet and make favourable combinations of shipments, there are still barriers to overcome. One of these barriers is that finding a good collaboration partner is far from easy. Companies have indivisibilities of potential partner’s shipments or do not know that a potential collaboration partner even exists. Furthermore, if companies find each other, they still need to value whether merging their road transport activities improves performance.

The main research objective is to develop a matching model that is able to find collaboration partners for companies that engage in road transport. This model is a supporting tool for companies that are searching for collaboration partners and want to know what partner fits best based on their transported shipments. These transported shipments are provided by Statistics Netherlands (CBS). They keep track on goods transported by vehicles that have a weight capacity of at least 3.5 metric ton. One week of transported goods by one third of all vehicles in the Netherlands provide data. For some years CBS uses an innovative XML application to collect data from companies. This atomized reporting tool reduces survey pressure and increases data quality: the data is directly reported from planning or real time systems in the field. That tool has resulted in significantly more and dense data than the usual internet surveys. This data enhances the value of this research as unique and real data from Dutch companies can be analysed by the developed matching model. The main research question is formulated as follows:

“How can a matching model for finding potential collaboration partners engaging in road transport be modelled based upon their shipment data and what is the effect of matching shipment data on road transport performance?”

As the main research question states, finding potential partners is solely based on shipment data. Therefore, influences like a company strategy that does not leave room for collaboration, costs for aligning IT-systems, knowledge management or cultural differences lay outside the scope of this research. Evaluating these influences come after a match is proposed by the matching model. The shipment data contain the weight transported, locations and date. These shipments fall in three shipment types that are dealt with in different manners for collaboration:

- Pickup shipments (From customer to depot)
  - Collaboration scenario: Hub and spoke network
- Delivery shipments (From depot to customer)
  - Collaboration scenario: Hub and spoke network
- Pickup & Delivery shipments (From customer to customer)
  - Collaboration scenario: Assigned to a depot, without inter-depot transportation

The model outputs are two performance indices for collaboration: the first is an index for the total benefits of the collaboration and the second is an index for the individual companies while collaborating. These indices are based on two scenarios: first the performance for the individual companies without collaboration and thereafter the performance for the merged companies. Performance is measured in schedule costs. These costs are split in fixed, duration and distance and are determined by the tool Kostprijscalculatie (EVO-it, 2016). The lower the costs, the higher the performance. There are three aspects identified that determine matching opportunities: utilizing the backhaul, increasing shipment density and utilizing the available period. This research focuses on increasing the shipment density and utilizing the backhaul. In addition, the type of goods transported constraint the matching possibilities. Oil and living animals might harm the quality of both products, for example.
The matching model first allocates the shipments to the depots. This determines from which depot and by which company the shipments are served. Next, an estimation approach for the schedule costs proposed by Huijink (2016) is extended to make it suitable for inter-depot transportation, pickup and pickup & delivery shipments. This estimation approach is a scalable approach which makes it suitable for large schedules. Tests have shown that the run time complexity is nearly linear (O(n)) and requires 6 ms per shipment. Hence, a 1000 shipment schedule takes 6 seconds to complete.

The matching potential in road transport is more than 20% for a complete merge. This result is even higher for individual companies in an alliance. Some companies are able to realize costs savings of 45%, but these savings are partly beared by the other collaboration partner. Thus one collaboration partner is helping the other company. The differences in shipment sizes between the companies and the company sizes are factors that influence this unbalanced performance gain. Cost schemes on how the profit should be allocated to the companies is an important aspect of collaboration, but is a different field in research.

A match may achieve high levels of performance gain, but that does not necessarily mean that the match suits in practice. Trust is an important concept that determines whether a match is practicable. Trust is influenced by the differences in company size, whether the companies are competitors and unbalanced performance gain. The larger the differences in company size requires higher trust, for example. On the other hand, there are also benefits that are not taken into account like risk sharing, decrease level of dependence in relation to third parties or increase innovation capacity.

The developed matching model enables companies that engage in road transport to find potential collaboration partners. New alliances will help these companies to increase their performance and thereby gain a stronger competitive position in the market. The effects can be observed on a macro level if the majority starts collaborating. In addition, the realized performance increase decreases the CO₂ and NOₓ pollution and therefore is useful for policy makers.

Several applications for the matching model:

- Implementing the matching model as a service (SAAS-solution) for the CBS commodity flow database allows all Dutch companies that engage in road transport to benefit from the tool. Every company is able to search for collaboration partners and benefit from the opportunities. This will result in lowering CO₂ pollution, an increase of capacity utilization and period utilization. Privacy issues can be dealt with by only providing the performance indices and only let the potential partners get into contact when they both agree;
- The matching model can be used for operational planning. In this case, the matching model is used to allocate shipments to the most beneficial collaboration partner. The partner that requests to outsource their shipments can select a specific service area, for example Groningen, and find the best partner for that specific service area for that day. This is done in advance to the final routing phase;
- Policy makers can use the tool to determine the effect of collaboration on performance or capacity utilization. This allows to draw conclusions on a macro level;
- Researchers can use the tool for research on effects of shipment data on logistic performance. For example, the effect of shipment density, transported goods or trade imbalances.

Keywords: supporting model, inter-company collaboration, horizontal collaboration, matching, road transport
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>3PL</td>
<td>Third Party Logistics</td>
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<tr>
<td>CBS</td>
<td>Centraal Bureau voor de Statistiek (Statistics Netherlands)</td>
</tr>
<tr>
<td>DC</td>
<td>Distribution Centre</td>
</tr>
<tr>
<td>EVO</td>
<td>Algemene Verladers en Eigen Vervoerders Organisatie (the Association for companies that transport goods under own account)</td>
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<tr>
<td>Integral</td>
<td>Complete</td>
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<tr>
<td>LRP</td>
<td>Location Routing Problem</td>
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<tr>
<td>LSP</td>
<td>Logistic Service Provider</td>
</tr>
<tr>
<td>LTL</td>
<td>Less Than Truckload</td>
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<tr>
<td>MDLRP</td>
<td>Multi-Depot Location-Routing Problems</td>
</tr>
<tr>
<td>P&amp;D</td>
<td>Pickup and Delivery</td>
</tr>
<tr>
<td>Stem distance</td>
<td>Linehaul distance</td>
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<tr>
<td>TLN</td>
<td>Transport Logistiek Nederland (the Dutch Association for Transport and Logistics)</td>
</tr>
<tr>
<td>TNO</td>
<td>Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (Dutch Association for applied scientific research)</td>
</tr>
<tr>
<td>TSP</td>
<td>Traveling Salesman Problem</td>
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<tr>
<td>VRP</td>
<td>Vehicle Routing Problem</td>
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<tr>
<td>VRPO</td>
<td>Vehicle Routing Problem with order Outsourcing</td>
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**CORE GLOSSARY**

**Cabotage**: the transport of goods or passengers between two places in a foreign country

**CBS tour**: A tour from empty to empty or loaded to empty

**Data point**: Pickup or delivery request of a shipment

**Delivery**: Shipment with an origin at depot and delivery at the customer

**Depot / Vehicle base location**: The location where vehicles start and return

**Destination**: The destination location of a shipment

**Geocoding**: The process of translating an address to a coordinate or location on a map

**Origin**: The pickup location of a shipment

**Pickup**: Shipment with an origin at the customer and delivery at depot

**Pickup and Delivery**: Both the pickup and delivery locations are at customers

**Schedule**: Set of all shipments

**Shipment**: A commodity that has to be transported from an origin to its destination. A shipment is also called an order in Operations Research

**Stop**: A stop within a tour

**The Solution Space**: The feasible region for an optimization

**Trip**: A specific segment in a tour

**Trip Chain / Tour**: Description of vehicle movement involving several stops

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1 INTRODUCTION AND PROBLEM DEFINITION

This introductory chapter first explains the urge for cooperation in road transport. Thereafter an illustrative example of a successful collaboration is given. Next, the collaboration matching problem and associated sub problems found in literature are addressed. After the problem definition, both the societal as well as the scientific contribution are explained. Next the research questions are derived from the problem definition. This research questions are used to build the research framework for this research. Finally, an overview of this thesis is presented.

1.1 THE URGE FOR COOPERATION IN ROAD TRANSPORT

Pressure due to increased competition causes a continuous fight for reducing operational costs, where transportation plays an increasingly crucial part in further improvements. Allowing a few cents cost reduction may already create a stronger competitive position (Adenso-Díaz, et al., 2014). Furthermore, factors like increasing fuel prices and environmental awareness result in an increasing urge for optimizing logistic performance (Guajardo, et al., 2014). The transportation processes involve all stages of production and distribution systems and represent 15 to 20% of the final cost of the product (Toth & Vigo, 2001). Moreover, the overall transport energy consumption in 2014 in the UK accounted for 38 percent of the national energy consumption. Of this 38 percent road transport has a share of 74 percent, illustrating the impact of road transport on an aggregate level (Liz, et al., 2015). Reducing the energy consumption by increasing performance will contribute to the sustainable development goals set by for instance the UN whose main target is to achieve sustainable management and efficient use of natural resources (Hák & Moldan, 2014). Hence increasing logistic performance is important to keep up with the market trends and achieving the sustainable development goals.

Collaboration in transport activities is an opportunity to increase road transport performance. For instance, by joining delivery needs, two companies can use their trucks more efficiently, benefit from economies of scale and achieve greater bargaining power. Especially horizontal collaboration can, among others, improve delivery tours and improve transportation rates (Adenso-Díaz, et al., 2014). Seuring (2004) argues that cooperation is the only way to increase competitiveness of the chain while reducing environmental burdens. Therefore, it is not surprisingly that collaborative transportation planning among different companies has received growing attention in recent years (Guajardo, et al., 2014). Examples of alliances in the Netherlands are Transmission, Network Benelux, Distri-XL and Teamtrans. Every company within an alliance is responsible for their own region within the total area and decides whether to outsource shipments within the alliance (Huijink, et al., 2014).

Collaboration may seem to be the way to go, but it’s not always easy to create an effective collaboration even when companies are willing to cooperate, they face barriers and lack of enablers. Barriers may be asset interconnectedness, partner scarcity, resource indivisibility and different institutional environments (Touboulic & Walker, 2015). A lack of enabling factors such as coordination mechanisms, benefit sharing (Lehoux, et al., 2014) and information sharing (Kache & Seuring, 2014) make collaborations more difficult as well, not to mention cultural differences and willingness to change (Fawcett, et al., 1996).

Lowering the collaboration threshold thus has multiple aspects, of which this research focuses on the partner scarcity barrier by matching commodities of companies. This is made possible because CBS recently granted TNO access to a database containing shipment data of Dutch companies. All shipments transported by companies that used trucks with a loading capacity of 2 metric tons or more are included in this database (Davydenko, 2015). This database currently purposes CBS to deliver statistical data and discover trends in the Dutch trucking sector. CBS is obliged to provide Eurostat with statistical data about the total quantity transported. The value of this database has increased in recent years since CBS developed a new reporting medium: the XML-survey. This XML-survey makes it possible for companies to report data with a push of a button, or even completely atomized. This results in more data of higher quality.

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1.2 AN COLLABORATION EXAMPLE: THE P&G-TUPPERWARE CASE

A clear example of successful collaboration in transport logistics is the P&G–Tupperware case. The case uses inter-modal transport but is still relevant as the line of thought for matching is similar. The train could, in theory, be replaced by truck. This case is also presented by Muylaert & Stofferis (2014).

There are four fundamental characteristics, considering transport logistics only, that play a role in P&G–Tupperware case. First, both companies have manufacturing sites and distribution centres (DC) in Belgium (Figure 1, (1)). Second, they both ship hefty shipments from Belgium to Greece (Figure 1, (1)). Third, the product characteristics of both companies are opposites. P&G ships heavy products while Tupperware ships light and voluminous products (Figure 1, (2)). Fourth, the companies do not compete because they produce different products that cannot substitute each other. These four characteristics are important to determine whether a match creates business opportunities. These characteristics create the opportunity for collaboration: shipment origins match, shipment destinations match and interestingly the product characteristics match as well because of their opposite nature.

Both P&G and Tupperware initially had their transport logistics separate and differently organized, as shown in Figure 2. The transportation flow by Tupperware is shown in orange. They transport their goods directly from their depot in Belgium to their depot in Greece by truck. For the last mile, they use trucks to deliver their products from the depot in Greece to their final customers. P&G on the other hand ships by train for the major part of its 3000 km long trip. Using the train introduces two transshipment locations denoted by the ‘Modal Hub’ circles and splits the full truck loads from depot to depot in two.
Both companies have chosen to bundle their shipments and transport the goods via train (Figure 3). The figure shows the Tupperware parts in orange and the cooperative parts in green. Tupperware first transports their products from their DC in Belgium to the Belgium P&G depot. The consolidation process takes place at the P&G depot where the light Tupperware products are mounted on the heavy P&G products. Doing so increases the handling costs at the P&G depot. The same goes for the P&G depot in Greece, where the Tupperware goods are separated from the P&G goods. The last mile remains the same for both companies.

Even though some parts of the process have increased costs, the overall process shows a significant reduction in costs and emissions, while the load factor increases (Muylaert & Stoffers, 2014):

- 17% cost reduction;
- Capacity utilization increased from 55% to 85%. Based on volume and weight;
- Over 200 tonnes CO₂ reduction;

In conclusion: there are matching criteria that are important to realize performance gain. When destinations and goods of the shipments are matched and the companies do not compete, the result is reduced costs and increased capacity utilization for both companies. The P&G-Tupperware case is
just one example that shows a delivery case with line haul matching. Further explanation of matching forms are explained in the research framework paragraph in this chapter.

1.3 THE MATCHING PROBLEM DEFINITION

The underlying problem that this research addresses is the increasing competitiveness that is experienced by companies that are engaged in road transport. The pressure on price and consumer expectation makes it urgent to improve performance in order to keep up with the market (Adenso-Diaz, et al., 2014). This research focuses on improvement due to collaboration; one of many ways to improve road transport performance. The problem to be tackled lies in lowering the difficulties that organizations experience when finding and selecting potential partners. Two or more companies have to find each other as potential partners before an alliance can be formed. They need to take notice of the overlap in their transport activities, which is far from easy. Building an alliance involves more than finding partners, therefore this paragraph first sketches an overview that a company comes across when building an alliance. Next the general shipment matching problem is explained and an illustrative example is given on how this data can be used to determine performance increase. Thereafter the routing problems involved and the associated constraints to the problem are identified based upon the CBS commodity flow database.

The road to a successful collaboration certainly does not only consist of selecting or finding potential partners. Figure 4 presents a framework that is also used by TNO for developing an alliance. This figure is developed by Tjemkes, et al. (2012) and proposes a breakdown in seven steps: from making a decision to cooperate to finally exit the alliance. This research contributes to step 2: “Select Partner(s)”. Where matching companies is defined as finding the best partners for the company using the matching model. The other steps are not addressed in this thesis. Step 1 is a given, as it supposes the idea that collaboration is a possibility. Step 2 focuses on the operational fit of the companies (Douma, et al., 2000), which is analyse on the basis of the CBS commodity flow database. The other steps consist of the approach of the companies after the technical analysis. This research provides a model for partner selection that can be put into practice. The steps that come after are unique per company and collaboration, therefore they won’t be a part of this research.

![Figure 4, Alliance Development Framework (Tjemkes, et al., 2012)](image)

The matching problem (Step 2) can be described as matching the operational fit (Douma, et al., 2000). The operational fit addresses the operational activities being road transport in this research.
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Operational fit consists of two problems: the performance increase and company boundary conditions. First, performance can be determined in different ways: one or a couple of indicators like capacity utilization, level of service, risk or costs can be used. Therefore, defining the concept performance is quite relevant. Otherwise there is no way to determine to what extent a match increases performance and its impact on the operational fit. Second, not all companies are able to cooperate. There are several boundary conditions when it comes to matching companies. For example, cargo that requires refrigerated transport should not be transported by conventional trucks. Hauling food and oil in the same truck could pose problems for the quality of both products. Determining the performance increase and boundary conditions per company and thus the operational fit is solely derived from shipments and depots from the CBS commodity flow database. This data comes with transported goods, origins, destinations of shipments and depots. The data is thoroughly analysed in chapter [ ].

A simplified representation of the operational matching problem is given in Figure 5. This figure represents shipment data of three different companies identified by the colours green ($C_q$), orange ($C_a$) and yellow ($C_b$). The shipments are indicated by the small nodes and the depots by the larger nodes. All nodes are plotted in a Euclidean space. The left side is the initial scenario ($S_{C_1}$), without collaboration, and right the final scenario ($S_{C_2}$) with collaboration. The figure shows a fit for two companies from the point of view of the querying company ($C_q$), but performs this process in parallel for all companies available in the database. The querying company searches for potential matches. This company can either choose to search for a specific subset ($s_{1...4}$) or all available shipments. One reason to match a subset can be that a company might want to reach a certain market farther away from its service area that is not profitable without a collaboration partner. Another feature for matching a sub set is that it enables to value the match for the querying and the partner company. Thus allowing to present the performance increase for both companies separately for a specific match. The chosen shipment set of the querying company is compared with the shipment data of the other companies. Similarities and opportunities are identified and the superior matches are presented. In the example the orange company increases the performance by 4%, hence a worse fit than the 10% performance increase when an alliance is formed with the yellow company. This increase is realized by a better allocation of the shipments among the companies, increasing density in the service areas of both companies. The increases for the subset ($s_{1...4}$) might find a different outcome than the full order set as the orange company has a higher shipment density in that specific area. How these matches eventually increase performance is an important part of this research. Also how performance increase should be measured in the first place.
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Figure 5. Shipments of the querying company \( C_q \) are compared to the orange \( C_a \) and yellow \( C_b \) companies’ shipments to determine the business opportunities of collaboration in road transport. An example of a subset for matching is denoted by \( s_{1..4} \).

The objective function can be either described as (1.1) or (1.2). An overview of the notation is described below. (1.1) determines the performance increase for the aggregate alliance and (1.2) for the querying company. (1.2) is determined on the input shipment set and therefore can either be a specific subset or a full shipment set of the querying company.

\[
I = \min \left( \frac{P_{SC2i}}{P_{QSC1} + P_{MSC1i}} \right) \quad \forall (i \in 1, \ldots, N) \quad (1.1)
\]

\[
I^q = \min \left( \frac{P_{QSC2i}}{P_{QSC1}} \right) \quad \forall (i \in 1, \ldots, N) \quad (1.2)
\]

<table>
<thead>
<tr>
<th>Output</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I )</td>
<td>( N ) Total number of companies</td>
</tr>
<tr>
<td>( I^q )</td>
<td>( P_{QSC1} ) Performance without collaboration for the querying company</td>
</tr>
<tr>
<td>Indices</td>
<td>( PM_{SC1} ) Performance without collaboration for the partner company</td>
</tr>
<tr>
<td>( i )</td>
<td>( P_{SC2} ) Performance for a complete merge of the querying and partner companies</td>
</tr>
<tr>
<td>Indices</td>
<td>( P_{QSC2} ) Performance for the shipments of the querying company only</td>
</tr>
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Performance of both scenarios should be measured based upon the CBS commodity flow database. Measuring performance of both scenarios comes with planning issues. Since every company organizes its road transport in a different way, the model faces a wide variety of transportation networks for matching:

- Linehaul transportation: full truck loads between hubs or depots;
- Less Than Truckload (LTL) transportation: collection or distribution tours;
- Parcel transportation: pickup and delivery tours;
- International transport: multi day tours;
These transportation networks can contain all types of shipments: delivery, pickup and pickup & delivery. A delivery shipment has a delivery location at the customer and pickup location at depot. A pickup shipment has a pickup location at the customer and deliver location at depot. The delivery or pickup shipments are also known as respectively linehaul and backhaul shipments. Pickup & delivery shipments have both the pickup and delivery location at a customer. Shipments in the CBS commodity flow database can concern either full-truck loads or combinable loads. These shipment types fall in two transportation classes: one-to-many-to-one (1-M-1) and one-to-one (1-1) (Berbeglia, et al., 2007). The remaining class many-to-many (M-M) is not discussed. All classes are described as a static problem, since all shipments are known beforehand. Hence, no shipments are imported during the execution of the model. Furthermore, there is an interesting survey available that addresses and categorizes all types of pickup and delivery problems (Parragh, et al., 2008) (Parragh, et al., 2008). The survey exists of two parts. The first part addresses the 1-M-1 class and the second addresses both the M-M and 1-1 classes. This survey is used for the vehicle routing definitions since there exists many different formulations and abbreviations for equal problems in literature. The routing problems for multiple vehicles that the model comes across based on the provided CBS data are further explained below. First the 1-M-1 problems and thereafter the 1-1 problems.

The 1-M-1 class has shipments that either have their origin or destination at depot. This problem is drawn in Figure 6. The filled nodes represent the pickup shipments (p), the unfilled nodes the delivery shipments (d), the arcs the trip (t) and the green circle the depot (D). The vehicles start and end their tour on depot. This problem is well studied and also known as the vehicle routing problem with mixed linehauls and backhauls (VRPMB) (Parragh, et al., 2008). Thus an extension to the standard VRP where only delivery shipments are considered. Other add-ons, such as the VRP with Clustered Backhauls (VRPCB) where first al deliveries have to be served before the pickups or VRPSDP where locations both have pickup and delivery shipments are not by the data nor the matching process enforced (Parragh, et al., 2008). The CBS commodity flow database simply does not provide such restrictions.

![Figure 6, An example of the one-to-many-to-one (1-M-1) class with delivery (d) and pickup (p) shipments](image)

Many companies in the CBS commodity flow database provide more than one depot or vehicle locations, another 1-M-1 problem. This network design is a classical hub-and-spoke network. Having more depots, which is likely when collaborating, introduces an additional complexity: the Multi-Depot problem. This problem can be referred as the MD-VRPMB and is shown in Figure 7. This comes with a shipment allocation problem and introduces inter-depot transportation (t_{id}). The benefits should outweigh this inter-depot transportation performance decrease. Higher inter-depot transportation costs might worsen the operational fit.
The CBS commodity flow database also contains many pickup and delivery (P&D) shipments where both origin and destination are not located at depot. Hence, these fall in the 1-1 class. An illustration of P&D shipments is given in Figure 8. The P&D shipments combined with multiple depots is described as the multi-depot pickup-and-delivery problem (MD-PDP). This problem is by far the hardest problem that this research deals with. The reason for this complexity is that both the P&D actions should be taken into account when allocating a shipment to a tour. The pickup locations may be close together, but the delivery locations can be geographically far apart (Berbeglia, et al., 2007). Moreover, there are two specific constraints: the coupling constraint and precedence constraint. The coupling constraints ensure that the P&D action are allocated to the same vehicle. The precedence constraint ensures that the delivery action is planned after the pickup action as it is physically impossible to deliver a shipment that is not loaded yet. Because of these constraints, this problem falls in the paired VRPPD category (Parragh, et al., 2008).

The shipments in the CBS commodity flow database do not only require the MD-VRPMB and the MD-PDP but multi-day tours as well. A complete overview of all shipment structures is shown in Figure 9. The P&D trips are coloured orange and the international shipments that require multi-day tours are recognizable by its green colour \( t_{mod} \). Multi-day tours are tours where a driver does not return to depot for more than one day. Therefore, these vehicles are not available every day and shipments that fall in the category P&D can be hauled the upcoming day during the same tour. This increases complexity and is known as the period-VRP (PVRP). Moreover, the use of multi-day tours requires a wider time span than a day when matching shipments. The example given in Figure 9 can represent an input shipment set of the querying company who is searching for potential partners. A shipment set of a single company requiring all explained routing problems is not uncommon in the CBS commodity flow database.
In addition to the routing problems that come along with this research, there are several constraints that the model is subject to. These constraints concern both the vehicles as well as the shipments. Shipments introduce three constraints: good type, quantity and date. First, not all types of goods can be transported together because of physical constraints. Some goods demand a vehicle with specific characteristics such as a crane for transhipment. Second, the quantity transported introduces a constraint in combination with the vehicle capacity and limits the shipments that can be delivered in a tour. Third, shipments should be delivered on a specific day. There are no tight time-windows available, but the execution date is a simplified form of a time-window. The constraints that concern vehicles are capacity and duration. A vehicle can carry a maximum weight or volume and can be physically suitable for transporting specific goods. Duration limitations are at stake since drivers cannot not drive 24 hours a day. Driver constraints are enforced by law as well (EVO, 2016).

Finally, the routing problems are quite complex to solve in an efficient manner. The simplest problem, the VRP, is already identified as NP-hard problem (Wu, et al., 2002). Using heuristics is a usual approach for solving the VRP. Heuristics search for an optimum in a solution space. This solution space increase dramatically with a small increase of the shipments quantity. For this research the problem size is the data quantity provided by the CBS commodity flow database: 85 companies, 3 million shipments and a potential for solving the problem for more than two companies. For this shipment quantity it is not possible to obtain provably optimal solutions and therefore another solution is proposed (Bard & Ahmad, 2009).

In conclusion: the problem is to match the querying company to a collaboration partner with the highest performance gain prospects based on the CBS shipment data. Performance gain is determined by means of two scenario’s: $S_1$ and $S_2$. First without collaboration and second with collaboration. Determining these scenarios requires solving several routing problems: the MD-VRPMB, MD-PDP and multi-day tours. These problems are subject to the following shipment constraints: good type, quantity and date. Also vehicle capacity and tour duration are relevant constraints. Finally, the problem size is 85 companies, 3 million shipments and has to have the potential to be solved for more than two companies.

1.4 RESEARCH OBJECTIVE

The research objective is to design a running model that matches companies’ shipment data by the means of the CBS commodity flow database. A transportation company is defined as a company that is active in transporting goods by road. These can be 3PL or companies who transport goods under own account. The model functions as decision support for companies to discover potential horizontal collaboration partners. The model takes shipment and vehicle constraints into account to determine whether matches are feasible or not. It provides the querying company with several candidates for
combining their road transport activities. Therefore, the main research question is formulated as follows:

How can a matching model for finding potential collaboration partners engaging in road transport be modelled based upon their shipment data and what is the effect of matching shipment data on road transport performance?

The deliverable is this thesis report and the implementation of the matching model in Matlab. A schematic overview of the model with its inputs and outputs is given in Figure 10. The input data is a bag $X$ with a shipment set $s_q$ and a depot or vehicle base set $D_q$. This input data is compared to the shipments and depots of the other companies in the CBS commodity flow database. This comparison results in a bag $Y$ containing the performance ($I_i$) for merging the transport activities per company $i$ and the performance ($I_i^q$) of the input shipment set per company $i$. The lower the performance index, the better the match for the querying company.

$$X = \{s_q, D_q\} \quad Y = \{I_i, I_i^q\}$$

**Figure 10.** The matching model. $X$ is a bag containing the shipment set ($s_q$) and depot set ($D_q$). Bag $Y$ contains a set of performance index of merging ($I_i$) per company $i$ and the performance index of the input shipment set ($I_i^q$) per company $i$.

### 1.5 The Matching Problem Scope

This research addresses the partner selection problem based upon CBS shipment and vehicle data. The data to be matched can either be a complete or a subset of shipments. These shipments only contain road transport thus no inter-modal transport is taken into account. The model runs from the perspective of the querying company, thereby reducing calculation complexity. E.a. only matches for that specific company are evaluated. Only the bilateral matches for the querying company are determined with the associated performance increase perspective.

The partnership for the matched companies can be organized in various forms. For instance, alliances, merging or outsourcing. This research does not refer to specific collaboration forms. Thus what form for a specific match is preferred is not analysed nor is a factor in the final matching model. Moreover, the actual building of a collaboration lies outside the focus. For instance, how costs and profits should be shared or the investment in ICT systems necessary for collaboration.

The CBS commodity flow database provides paper, internet and XML input data of which only the XML input data is used for this research project. This XML input data is more detailed and some companies provide their complete shipment sets, which is not the case for the internet and paper surveys. Moreover, the XML input data provides over 85 companies and 3 Million shipments.

By the nature of the shipments there is need to handle a wide range of routing problems, which is elaborated in the problem definition. The focus lays on the Benelux and therefore only shipments that can be hauled within a day are used for the model building. Thereby making the multi-day tour problem no longer required. A time-span of a single day is therefore sufficient.

In this research depots function as vehicle bases. Vehicles always start and end their tour on the same depot. The fleet available for transportation at a depot is sufficient under all circumstances. Therefore, all shipments can be transported from the optimal depot.

The model runs on a Euclidean space, but will be able to run on road networks as well. The locations are geocoded on a real map. Implementing a road network in Matlab increases development time and
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

costs but adds no value to the final model. The model will run on a real road network just as easy as running on a Euclidean space.

1.6 CONTRIBUTION

The relevance of this research project is distinguished in scientific relevance and social relevance. Scientific relevance focuses on the knowledge gap that the research will cover. The social relevance covers only a small selection of fields that have interest in this research project. There is no space for a full mapping of all relevant aspects.

1.6.1 ACADEMIC CONTRIBUTION

In comparison to collaboration along the supply chain, horizontal collaboration is less explored. Especially when horizontal collaboration is focused on road transport (Adenso-Díaz, et al., 2014). This research builds upon specifically horizontal collaboration of road transport and questions how collaboration opportunities can be identified. To the best knowledge of the researcher, there are no models available that match companies based upon shipment data. Especially because of the scale of the problem (3 million shipments and 85 companies) and that the model is capable of solving a wide range of routing problems: MD-VRPMB and MD-PDP in combination with capacity, good and time constraints.

The matching model provides a high-speed solution for calculating performance of large shipment sets. With the import or shipment generation features, a wide variety of factors on logistic performance can be researched. For example, the effect of shipment density, volume versus weight, trade imbalances or shipment types on logistic performance.

This research is a basis for further research projects on road transport. For example, policy design and evaluation or real time benchmarking. Research on a large dataset with real data provided by road transport companies within the Dutch Trucking sector for company matching is unique.

Furthermore, this research applies the matching model on the CBS commodity database and presents the opportunities for collaboration in the Dutch trucking sector for companies that transport NSTR 0, 7 and 9 goods. Thereby presenting opportunities for collaboration in general.

1.6.2 MANAGERIAL CONTRIBUTION

First, the overall practical relevance is that the model supports the partner selection for horizontal collaboration opportunities in road transport. Lowering the threshold for collaboration will eventually result in more collaboration within the sector and thereby increasing road transport performance. This has potential to increase the Dutch trucking sector competitiveness compared to other countries. These opportunities are quantitatively identified based upon real commodity data for various shipment types. Therefore, the operational fit can be reliably estimated.

The matching model can be implemented as a service that runs on the CBS or other databases. This allows companies to use the model online, without giving insight in their data. A company will receive an email with the matching potential and the notion that another company would like to get in touch. If the companies both agree to further investigate the opportunities, then these companies will receive the contact information and can decide to take the first steps to an alliance.

Another matching tool is to build a service that can match specific shipments. Since the matching model is a high-speed estimation algorithm with a linear time complexity, it can be used to determine what shipments should be executed by what company in seconds. This can be done for complete schedules of all companies, but also for a specific selection. When a company would like to outsource their shipments in a specific service area, they can choose to run the model online to determine what company should serve that shipments.
Collaboration will not only increase logistic performance in terms of costs, but also decrease pollution. This is an effect of increased clustering opportunities which results in a kilometre reduction per shipment. A reduction in CO₂ and NOₓ is one of the sustainable development goals. This reduction is not only a plus for the companies, but for society as well.

The current implementation of the matching model in Matlab features an import function for the shipment, depot and company data. This data can be imported as CSV format. This enables to perform research on, for example, merging companies or shipment allocation. This shipment allocation can be used to determine the service area per company or depot. This option can be used by road transport companies or consultancy firms that solve logistic issues.

The matching model can be used as supporting tool for policy makers. They can analyse the effect of policies on road transport performance. For example, whether they should encourage collaboration to lower the pollution or the effect of policy on road capacity utilization.

Moreover, TNO and TU Delft are interested in the value of the data. This research provides better insight in the CBS commodity flow database for both TU Delft and TNO. Thereby giving the opportunity to determine what other logistic problems can be solved using this data as primary data source.

Finally, companies that spend several days per year (Veelenturf, 2012) providing CBS with data will get relevant tools in return for their effort. It is expected that this will increase commitment and also result in higher data quality (Tee, et al., 2007). Because of this reason, CBS is interested in providing tools for these companies. Not only company matching, but also tools real time benchmarking.

1.7 RESEARCH QUESTIONS

This paragraph presents the main research question and its associated sub questions based upon the matching problem definition and research objective. The main research question, which is also stated in the research objective, is formulated as follows:

*How can a matching model for finding potential collaboration partners engaging in road transport be modelled based upon their shipment data and what is the effect of matching shipment data on road transport performance?*

In order to answer the main research question, the following sub questions are formulated:

a. What are the relevant KPI’s for measuring collaboration potential, how should these KPI’s be measured and how are these KPI’s affected by collaboration?
b. What shipment and schedule characteristics lead to performance increase?
c. To what extent is the CBS commodity flow database capable of providing sufficient data for the matching issues?
d. How can a shipment matching model for companies engaging in road transportation be designed?
e. What results can be expected for merging road transport activities of two companies proposed by the matching model?

Sub question a. on KPI’s determines what (utilization, pollution, costs, level of service), how (max capacity, empty vs loaded trips, cost per stop) and the affect (positive, negative) of collaboration on KPI’s. The model searches for performance increase, but performance should be determined by the right KPI’s. A quote from Michael Braungart fits this issue perfectly: “If you are not doing the right thing, don’t do it efficiently, because then you are doing things efficiently wrong” (Braungart, 2016). Sub question b. defines when specific shipment sets improve performance. For instance, the effect of matching specific goods, shipment size, vehicles or geographical shipment density. Merging a purely pickup up shipment set with a purely delivery set may create better prospects than pickup with pickup. The third sub question conducts a data analysis on the CBS commodity flow database. This analysis
results in a usable dataset for the matching model. Sub question d. uses the prior sub questions to design a model that matches companies’ shipment data to determine the collaboration opportunities and provides the user with several candidates. Sub question e presents results for running the matching model on the CBS database. This results give an indication of the potential when companies merge their transport activities.

1.8 RESEARCH FRAMEWORK

This research falls in the category design science research (DSR) as the deliverable is a newly designed model. There are various methodologies for a DSR. One methodology amongst these is the DSRM Process Model (Peffers, et al., 2014). That model distinguishes the following phases: “Identify Problem & Motivate”, “Define Objectives of a Solution”, “Demonstration”, “Evaluation” and “Communication”. Of this steps the first “Identify Problem & Motive” is already explained in this introductory chapter. The final step “Communication” is this Master Thesis. That leaves four phases for the research framework. This framework, using the DSRM Process Model, is shown in Figure 11. This schematic representation shows how the different phases of the research are interconnected. The first phase defines the optimization goal, model criteria, data quantity and researches performance opportunities for matches. This phase is the “Define Objectives of a Solution”. The “Design & Development” phase prepares a dataset and is the actual building of the matching model. The “Demonstration” phase both applies the model to generated validation data and the to the CBS data. The last phase in the research framework is the last part of the model validation and the final conclusions of this research. The evaluation observes how effective and efficient the model is. Furthermore, the orange feedback loops show the iterative process between the “Evaluation”, “Design & Development” and “Define Objectives”. Especially the findings from the “Evaluation” can force to redesign the matching model.

![Figure 11, Research framework. The letters (a) correspond with the research questions.](image)

The “Define Objectives” phase consists of (a) to (c). (a) Determines the KPI’s and their effect on collaboration by conducting a literature study. This literature study focusses on transport, performance indicators, measures and collaboration. Main sources are the scientific search engines ‘Web of Science’ and ‘Scopus’. In addition, conversations with experts from TNO, TU Delft, Tilburg University and CBS contribute to the findings of (a). Research question (b) is a literature study on factors that affect performance when collaborating. Also here, Scopus and WebOfScience are the main sources for literature. The final research question for the first phase is the CBS commodity flow database analysis (c). (c) is split in two parts. First part maps how the CBS data is collected and analyses the available data fields in the database. Literature provided on how to cope with data inconsistencies like missing data is used. Also, the input and datasheets from CBS are used.
The second part of the data analysis falls in the “Design & Development” phase. This analysis also prepares datasets that are used for the model design. The tools used for this phase are MS SQL server, MS Excel and MS Access. Sub question (d) is split into three parts: the design, implementation and validation. The design of the matching model uses literature on the transportation problem and estimation of VRP’s. Next the design is implemented in Matlab.

The “Demonstration” applies first the model on several test cases to validate the model. The results from this test cases are directly evaluated in the “Evaluation”. This results determine how well the model is able to simulate reality. The design will be adjusted on these findings before sub question (e) addressed. There is no use to apply an untested matching model on real CBS data.

The conclusions are finally drawn after the “Model application” is fulfilled, which means that all sub questions are answered. The evaluation are not only conclusions, but also consists of a discussion and recommendations for feature research.

1.9 CONSISE GUIDE TO THIS MASTER THESIS

The research follows the research framework precisely. First chapter answers sub question (a) on KPI’s. This chapter determines the KPI’s that will be used for the model development. Chapter 2 answers sub question (b) about how the merging of schedules can result in performance increase. Next, chapter 3, analysis the CBS collection process, the available database data fields with its relational structure and the data in the database. The latter results in datasets that are used as input for the matching model. Chapter 4 is the design of the matching model. This chapter explains how the allocation and clustering of the shipments is done. Next, the design is implemented in Matlab. Chapter 5 gives an overview of important decisions taken during the implementation. After the matching model is implemented, the model is tested and evaluated in chapter 6. Several test designs are performed and the outcomes are compared to the professional planning tool Ritplan (EVO-it, 2016). After the model is accepted during the validation phase, the CBS data is used as input for the model in chapter 8. This chapter determines what performance can be gained when companies collaborate. Thereafter the conclusions in chapter 9 and discussion in chapter 10 is elaborated.
2 MEASURING RELEVANT KPI'S AND THEIR EFFECT ON COLLABORATION

[Sub question 1]

What are the relevant KPI's for these companies, how should these be measured and how are these affected by collaboration?

This chapter, highlighted in Figure 12, gives an overview of the relevant KPI’s in road transport and analyses how these indicators are measured in literature. Furthermore, this chapter decides what measures will be used for the matching process. The performance measures are categorized in three categories: utilization, productivity and effectiveness proposed by Caplice & Sheffi (1994).

![Figure 12, Report structure](image)

KPI's and the associated measures for matching road transport are fundamental in the matching process. It is needed to know whether a match will increase performance and how collaboration affects these KPI’s in order to value a possible match. Determining the KPI’s and measures, however, has shown to be rather complex. Various sets of indicators that, for example, focus on costs, capacity utilization, sustainability, risk or service are currently applied in literature. For example, journal articles that tackle questions on effects of technology (Barla, et al., 2010) (Hubbard, 2003), optimization (Calvante & Roorda, 2010) (Toth & Vigo, 2001), level of service (Deflorio, et al., 2012) or collaboration (Adenso-Díaz, et al., 2014) apply different measures on the same KPI’s or even use different KPI’s in their research. These indicators vary from financial indicators and non-financial to non-numerical indicators (Brewer & Speh, 2000). Numerical measures are applied in different angles in literature, but using non-numerical measures is even more ambiguous.

There is not only disagreement in the literature, but also in practise. CBS has been using two KPI’s for years: empty vs loaded tours and gross weight transported between areas of interest. These KPI’s are applied for production statistics, which they report to EUROSTAT. Even though CBS reports their statistics for several decades, their measures are criticized. For example, TLN, the Dutch Association for Transport and Logistics, argues that weight utilization is not a reliable measure when it comes to measuring capacity utilization of transported goods. TLN published a book about capacity utilization of weight and volume to emphasize their vision on this issue (Leewen, 2013). This book also argues that utilization is a derivative of performance. Furthermore, according to Veelenturf (2012) companies operating on a daily basis are more interested in yields than utilization, which again illustrates differences in KPI’s.

This chapter first describes how the literature search is performed. Next the KPI’s and associated measures found are categorized in three sections: productivity, utilization and effectiveness. From
there on these three sections are sequentially explained. Each category introduces the KPI’s first, followed by the measures found to measure a selection of KPI’s. Finally, conclusions are drawn on the KPI’s that will be used for this research and the chosen measurements.

2.1 THE LITERATURE SEARCH

The research method for answering Q1 is done by means of a literature study. Search terms used are the following: transport, optimization, trip, tour, capacity utilization, performance indicators and trucking. In addition, references found in literature are used as well. Also journals on operations research, computer science and logistics are treated with extra attention. Main search engines used are Scopus (Scopus, 2016) and (WebOfScience, 2016).

Criteria for selecting proper articles from the search query results are based on whether they use KPI’s and measurements relevant to road transport. These are for instance articles that research the effects of X on transport performance or develop various models for optimizing logistics performance. Also relevance and citation index are taking into account.

The articles are ordered in a relational structure. Several articles may link to the same search action. For each article comments are added and scored on a 1-10 scale indicating the relevance to performance indicators in road transport. The score is based on the focus on road transport, the number of KPI examples and their argumentation. Every article that scores a 6 or above is used to answer Q1.

2.2 KPI CATEGORIZATION

Not every KPI is directly comparable to one other. Firms may for example desire a high quality or a high level of service (Lai, et al., 2004). Others are interested in cost efficiency or utilization of their fleet. Combinations of several KPI’s is not uncommon as well (Krauth, et al., 2005). These KPI’s are fundamental different and therefore the literature is divided in three categories: utilization, productivity and effectiveness (Caplice & Sheffi, 1994). This categorization is also applied in Veelenturf (2012) and McKinnon (2009) and has proven to cover KPI’s in road transport.

Productivity is defined as “Ratio of inputs to outputs”. This research measures ratio of road transport in terms of costs (C). Lower input while delivering the same shipments results in a higher ratio and therefore increased productivity. Note that costs do not necessarily have to be expressed in a currency, but may also be expressed for example in distance (D), CO₂ or NOₓ emissions (F). Utilization, being “Ratio of actual capacity used to maximum capacity available”, is the exploitation of resources, like capacity utilization (CU). The last category is effectiveness. Effectiveness is defined as “Performance judged to a relative norm”. This category can be explained as level of satisfaction from the point of view of the most important stakeholders: customers, society, employees or the strategy of the firm. How the KPI’s found fall in the different categories is shown in Table 1. In addition, an overview of all KPI’s proposed by Krauth, et al. (2005) is given in appendix A. That overview shows how their KPI’s fall in the three categories proposed.

<table>
<thead>
<tr>
<th>Table 1, Literature categorization</th>
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</thead>
<tbody>
<tr>
<td>C=Costs, P=Pollution, R=Revenue, D=Distance, π=Profit, CU=Capacity Utilization, PU=Period Utilization, ER=Empty Running, LR=Loaded Running, Q=Quantity, LU=Lab Utilization</td>
</tr>
<tr>
<td>Article</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Prod</td>
</tr>
<tr>
<td>(Evans, 1975)</td>
</tr>
<tr>
<td>(McKinnon, 2009)</td>
</tr>
</tbody>
</table>

Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

(Donselaar, et al., 1998)  R / C per tour ↑
(Deflorio, et al., 2012)  D per tour ↓
(Adenso-Díaz, et al., 2014)  C per schedule ↓
(Davydenko, et al., 2014)  C per shipment ↓
(Sun, et al., 2015)  C per shipment ↓
(Huijink, et al., 2014)  C per shipment ↓
(Krauth, et al., 2005)  C per schedule ↓ ; R ↑ ; π ↑ ; P / D ↓
(Wu, et al., 2002)  C per schedule ↓

(Veelenturf, 2012)  CU ↑
(Abate, 2014)  ER ↓ ; CU ↑ ; PU ↑
(Davydenko, et al., 2014)  CU ↑
(McKinnon, 2009)  ER ↓ ; CU ↑ ; PU ↑ ; LU ↑
(CBS)  ER / LR ↓ ; Q ↑
(Barla, et al., 2010)  CU ↑
(Holguín-Veras, et al., 2014)  CU ↑
(Leewen, 2013)  CU ↑
(Davydenko, 2015)  CU ↑
(Hubbard, 2003)  CU ↑
(Krauth, et al., 2005)  ER ↓ ; CU ↑ ; PU ↑ ; LU ↑

(McKinnon, 2009)  [Customer]
(Fisher, 1997)  [Customer]
(Krauth, et al., 2005)  [Society, Customer, Strategy, Employee]
(Fernie & Mckinnon, 2003)  [Customer]

2.3 PRODUCTIVITY KPI’S

Productivity, the ratio of inputs to outputs, is expressed in a ratio of costs. For example, costs per km, schedule or revenue. Other possibilities are to compare costs for outsourcing and insourcing (Huijink, et al., 2014) or determine the correlation of costs and traffic intensity (Evans, 1975). They all share the same objective: minimizing costs. Only profits are maximized which, again, can be done by lowering costs. There is a clear distinction between the transportation costs and the firm’s additional costs. The first costs come down to fixed and variable costs for operating a vehicle. The main focus of this research lays in the transportation costs. Models for determining these costs and how these are used in literature are explained in the following paragraph. The additional costs of the firm, like “Inventories”, “Marketing costs” and “Information System costs” are relevant for collaboration as well, but are difficult to quantify. The literature survey conducted by Krauth, et al. (2005) is used for the KPI’s that involve the firm’s additional costs. See also appendix A. The following table shows the productivity KPI’s and how they are affected by collaboration.
2.3.1 TRANSPORTATION COST MEASURING METHODS

This paragraph explains the following measuring methods: $C_{\text{per tour}}$, $C / R / \text{tour}$, $D / \text{tour}$ and $C / \text{shipment}$. All literature selected that measure transportation costs use solely costs as KPI. The estimated pattern of trips depends in the models found on the travel costs between the various stops. These costs can either be determined per shipment or per tour.

Evans (1975) developed a model for combining trip distribution and assignment to routes depending on the traffic density. Higher traffic density increases driving time and therefore increases driving costs. Their routing optimization is combined with a dynamic network assignment. The total costs is defined as the combination of travel time, distance travelled and the direct monetary costs ($C / \text{tour}$). Where Evans (1975) stops at minimizing costs, Donselaar, Kokke, & Allessie (1998) determine the ratio of revenue versus total costs ($C / R / \text{tour}$). Also they elaborate further on what factors have impact on the duration (wages) and distance costs (fuel, tires and maintenance). Deflorio, Gonzalex-Feliu, Perboli, & Tadei (2012) determine the impact of time-windows on routing. They use travel time in seconds as performance indicator ($D / \text{tour}$). This measurement neglects distance and direct costs that both Evans (1975) and Donselaar, Kokke, & Allessie (1998) included. Ignoring fixed costs will not limit the number of vehicles used, which can result in using more vehicles for shorter routes when optimizing. The lacking the time factor fails to recognize drivers’ costs and time-depended costs like loading and waiting time.

In addition to measuring costs for tours, there are also methods that determine the costs per shipment. Sun, et al., (2015) proposes a model where they use the tour costs and allocate the costs to its shipments ($C / \text{shipment}$). This model is an add on measures that determines the total costs of a tour comparable to Evans (2013). Assumptions are made during the allocation process, for instance the allocation of costs for reaching the service area or the allocation of costs for different loads. Huijink, et al. (2014) proposes a model that estimates costs of a specific shipment without need for a full schedule. They use the costs for driving between the shipments, the front and backhaul and the fixed costs. The basis for the estimates is again distance, time and fixed costs. A different approach is proposed by Davydenko, et. Al (2014) where they determine an allocation weight using the capacity utilization per shipment in a tour. This method uses capacity-related parameters that are appropriate for the selected tour. The costs are then allocated according to the calculated weights. This method is

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Table 2, Productivity KPI’s and how they are affected by collaboration

<table>
<thead>
<tr>
<th>KPI</th>
<th>Affect on collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (Transportation)</td>
<td>↓ (Efficient routing)</td>
</tr>
<tr>
<td>Overhead percentage (Additional)</td>
<td>↑ (Bureaucracy)</td>
</tr>
<tr>
<td>Controllable expenses (Additional)</td>
<td>↓ (Partner Expenses)</td>
</tr>
<tr>
<td>Non-controllable expenses (Additional)</td>
<td>↑ (Partner Expenses)</td>
</tr>
<tr>
<td>Customer service costs (Additional)</td>
<td>↓ (Efficient routing, shared service)</td>
</tr>
<tr>
<td>Order management costs (Additional)</td>
<td>↑ (Decision on outsourcing, Inventory)</td>
</tr>
<tr>
<td>Inventories (Additional)</td>
<td>↑/↓ (Consultation / Warehouse sharing)</td>
</tr>
<tr>
<td>Marketing costs (Additional)</td>
<td>↓ (Economies of scale)</td>
</tr>
<tr>
<td>Total supply chain costs (Additional)</td>
<td>↓ (Efficiency)</td>
</tr>
<tr>
<td>Average delivery planning time (Additional)</td>
<td>↓ (Learning)</td>
</tr>
<tr>
<td>Information system costs (Additional)</td>
<td>↑ (Linking IT systems and processes)</td>
</tr>
<tr>
<td>IT training costs (Additional)</td>
<td>↑ (More complex IT systems)</td>
</tr>
</tbody>
</table>
further explained in paragraph 2.3. They propose the use of OD distances in combination with the allocation weight to incorporate the distance traveled for executing a tour.

In conclusion, the transportation costs are split in fixed, time-related and distance-related. All three factors are required for determining the transportation costs. Each of the three factors can be determined by specific factors such as wage, depreciation or fuel. Determining the factors becomes more detailed when more factors are included in the calculation. Moreover, the ratio between the three has an impact on routing. A lower turning point of variable and fixed costs results in more vehicles used while a higher turning point increases route duration. Also literature found that use costs as main KPI are often focused on the firm and Operations Research. In addition, determining the costs per shipment allows the possibility to measure the performance increase for the companies individually while collaborating. Thus, giving insight in what company benefits the most from the collaboration.

2.4 UTILIZATION KPI’S

Utilization is ratio of actual capacity used to maximum capacity available. In analogy with productivity, there are transportation utilization KPI’s and firm’s utilization KPI’s that do not directly relate to the actual transportation. The KPI’s that concern the additional costs are proposed by Krauth, et al. (2005). Appendix A presents an overview of the additional KPI’s. The other KPI’s are a combination of the other literature found and categorized at the beginning of this chapter. The table below shows the KPI’s relevant for utilization and how these affect collaboration. The upcoming sub paragraph analyses the utilization measuring methods for the transportation utilization KPI’s.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Affect on collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Utilization (Transportation)</td>
<td>↑ (Efficient routing)</td>
</tr>
<tr>
<td>Period Utilization (Transportation)</td>
<td>↑ (Efficient routing)</td>
</tr>
<tr>
<td>Labor Utilization (Transportation)</td>
<td>↑ (Efficient routing)</td>
</tr>
<tr>
<td>Empty Running (Transportation)</td>
<td>↓ (Efficient routing)</td>
</tr>
<tr>
<td>Loaded Running (Transportation)</td>
<td>↑ (Efficient routing)</td>
</tr>
<tr>
<td>IT Utilization (Additional)</td>
<td>↑ (Shared systems)</td>
</tr>
<tr>
<td>Resources (Additional)</td>
<td>↑ (Efficient routing, Shared use)</td>
</tr>
</tbody>
</table>

2.4.1 UTILIZATION MEASURING METHODS

The line of thought for utilization is that a higher utilization ratio is more efficient. Hence, a filled vehicle is performing better than an empty vehicle when concerning CU. Thus the higher CU, the higher the performance. PU measures the share of a vehicle in use in terms of duration in a certain period of time. This measure assumes that vehicles off depot are productive. LU is similar to PU for transportation and is therefore not separately addressed. Measuring the utilization is done in different ways in both literature and practice. This paragraph reviews the following measures: Tonne-km vs vehicle-km, cap-km vs vehicle-km, unit-km vs vehicle-km, loaded vs empty km, loaded vs empty running, maximum capacity utilization and periods of base.

According to the tonne-km vs vehicle-km measurement, the higher tonne-km for a given vehicle-km, the higher CU (Abate, 2014) (McKinnon, 2007) (Abate & Kveiborg, 2010) (Barla, et al., 2010). This formula is given in 2.1 Where tonne-km is the sum of the weight transported (tonne-km) for each trip and the vehicle capacity is the maximum capacity for the whole tour. Hence, a tour containing one full-truck delivery and returning empty has a CU of 50%. Holguín-Veras, et al. (2014) defines this ad the
“black-haul” problem. Using this method does not take the efficiency of a planning into account. For instance, the CU is nearly 1 when a distribution tour unloads a full-truck-load at the end of the tour, but when the tour is reversed the CU will be nearly 0.

\[
CU = \frac{\sum_{i=1}^{N}(T_{\text{trip}}i \times d_{\text{trip}}i)}{T_{\text{max}} \times d_{\text{tour}}}
\]  

(2.1)

Output
\(CU\) Capacity utilization
Indices
\(i\) Index for the trips
Parameters
\(N\) Total number of trips
\(T_{\text{trip}}\) Weight in tonnes for the trip
\(d_{\text{trip}}\) Distance in km for the trip
\(T_{\text{max}}\) Maximum vehicle weight capacity in tonnes
\(d_{\text{tour}}\) Distance in km for the tour

Volume is missing when \(CU\) is based on ton-km vs vehicle-km only. Voluminous goods fill up the physical space before a vehicle reaches its maximum weight capacity (Abate & Kveiborg, 2010) (Leewen, 2013) (Veelenturf, 2012). Therefore, the measure ton-km vs vehicle-km is changed by Leeven (2013) to capacity-km vs vehicle-km where vehicle-km is the capacity measured in different dimensions: volume and weight. An average of volume and weight utilization is used, thus a vehicle is fully loaded when both volume = 100% and weight = 100%. This measure will hold in more circumstances and therefore is preferred over ton-km vs vehicle-km. Moreover, when considering different types of goods, a unit of cargo can be determined based on the good’s characteristics. Some firms use pallets or wheeled containers as capacity measure (Davydenko, 2015). Davydenko et al. (2014) proposes a broader definition of vehicle capacity by combining several capacity-related dimensions into one. The \(U_{\text{trip}}\) (2.3) is substituted for \(T_{\text{trip}}\) in formula 2.1. This add-on is named unit-km vs vehicle-km. In addition, the allocated weight method can be used in other measures to replace weight, volume or averages.

\[
U_{\text{trip}} = \max\left(\frac{\text{sizeP}_i}{\text{sizeP}_{\text{max}}i} \times T_{\text{max}}\right) \quad \forall \ (i \in 1, \ldots, M)
\]  

(2.2)

Output
\(U_{\text{trip}}\) Transported units per trip
Indices
\(i\) Index for the trips
Parameters
\(M\) Total number of parameters
\(\text{sizeP}\) Shipment size in a parameter
Another measuring method is the \textit{loaded vs empty km}, see 2.3 (Hubbard, 2003). In contrast to \textit{cap-km vs vehicle-km}, the travelled load does not take the transported quantity into account. A trip is loaded when the truck contains goods, even though the goods fill 1% of the vehicle capacity. Therefore, two identical trucks transporting respectively 10 and 20 tonnes have the same \textit{CU} when driving the same tour. Therefore, \textit{cap-km vs vehicle-km} is preferred over \textit{loaded vs empty running}. CBS uses a similar method but ignores the distance and only uses the tours for \textit{loaded vs empty running} (2.4). They define a route from empty to empty, thus a distribution tour has two tours and therefore has a \textit{CU} of 50%.

\begin{align*}
    \text{CU} &= \frac{\sum_{i=1}^{N} (d_{\text{trip, loaded}}_i)}{\sum_{i=1}^{N} (d_{\text{trip, empty}}_i)} \quad (2.3) \\
    \text{CU} &= \frac{\text{Trips\_loaded}}{\text{Trips\_empty}} \quad (2.4)
\end{align*}

\begin{center}
\begin{tabular}{|l|l|}
\hline
\textit{sizeP\_max} & Vehicle capacity in a parameter \\
\textit{T\_max} & Maximum vehicle weight capacity in tonnes \\
\hline
\end{tabular}
\end{center}

\textit{CU} can also be determined by the \textit{maximum capacity utilization} along the tour (2.5) (Veelenturf, 2012). This method, however, ignores empty running by vehicles. When the first stop accounts for 99% of the capacity the rest of the tour is merely empty.

\begin{equation}
    \text{CU} = \text{Max}(\text{CU}_{\text{trip}}_i) \quad \forall \ (i \in 1, \ldots, N) \quad (2.5)
\end{equation}

\begin{center}
\begin{tabular}{|l|l|}
\hline
Output & \textit{CU} \\
Indices & Capacity utilization \\
\textit{i} & Index for the trips \\
Parameters & Total number of trips \\
\textit{N} & \\
\textit{d\_trip\_loaded} & Trip distance in km loaded \\
\textit{d\_trip\_empty} & Trip distance in km empty \\
\textit{Trip\_loaded} & Maximum vehicle weight capacity \\
\textit{Trips\_loaded} & Total number of trips loaded \\
\textit{Trips\_empty} & Total number of trips empty \\
\hline
\end{tabular}
\end{center}
To illustrate the differences between the measures an example for a distribution tour is given in Table 4. The vehicle has a maximum weight capacity of 100 kg and a maximum volume of $10 \text{ M}^3$. The vehicle is loaded at stop 1 and returns with empty at stop 5.

<table>
<thead>
<tr>
<th>Stop</th>
<th>Km</th>
<th>kg</th>
<th>M$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Depot)</td>
<td>0</td>
<td>55</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>110</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>5 (Depot)</td>
<td>130</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The differences in CU per measure are significant (Table 5). Loaded vs empty km measures the highest CU rate. The only empty trip is the backhaul from stop 4 to depot. CU would be 1 if the tour contained a pickup prior to stop 4. The maximum capacity measures 0.775 for the average load factor of volume and weight loaded on depot. Replacing the average load factor for Davydenko (2015) would result in a CU rate of 1. Measuring CU along the tour results in a substantially lower performance: 0.448 (Ton-km vs vehicle km), 0.605 (cap-km vs vehicle-km) and 0.763 (unit-km vs vehicle-km). The Ton-km vs vehicle-km obviously fails to recognize that the goods are voluminous. This shows why cap-km vs vehicle-km is preferred.

<table>
<thead>
<tr>
<th>Measure</th>
<th>CU</th>
</tr>
</thead>
<tbody>
<tr>
<td>tonne-km vs vehicle-km</td>
<td>0.448</td>
</tr>
<tr>
<td>cap-km vs vehicle-km</td>
<td>0.605</td>
</tr>
<tr>
<td>unit-km vs vehicle-km</td>
<td>0.762</td>
</tr>
<tr>
<td>loaded vs empty km</td>
<td>0.846</td>
</tr>
<tr>
<td>loaded vs empty running</td>
<td>0.500</td>
</tr>
<tr>
<td>maximum capacity utilization</td>
<td>0.775</td>
</tr>
</tbody>
</table>

PU, in addition to CU, is an important utilization KPI. PU measures the share of a vehicle in use in terms of duration in a certain period of time. When assuming that vehicles off depot are productive, a measure considering the number of time periods can be used (2.6). For instance, the number of days...
in use during a year. This method determines the time in use versus the available time (Hubbard, 2003):

\[ PU = \sum_{i=1}^{N} \frac{\text{duration}_{tour_i}}{\text{duration}_{period}} \]  

(2.6)

<table>
<thead>
<tr>
<th>Output</th>
<th>Capacity utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indices</td>
<td>Index for the tours</td>
</tr>
<tr>
<td>Parameters</td>
<td>Total number of tours</td>
</tr>
</tbody>
</table>

A drawback of this method is that it fails to recognize empty running: a truck driving 600 km without any use has a positive impact on PU. The use of time, however, is an interesting view that should be combined with CU. This view is also shared by (Krauth, et al., 2005), where they argue that equipment utilization rates (hours) are important measurements for performance.

In conclusion, there are two major factors found that determine utilization: utilization of vehicles in terms of time in use and capacity. Capacity measures are merely used for macro statistics. For example, CBS, EUROSTAT or Abate (2014) use these measures. Preferred is to combine both CU and PU. Only CU fails to measure the usage of a vehicle. A fully loaded vehicle used one hour a day could have been utilized the other 23 hours as well. Solely PU is not sufficient either, since a vehicle driving empty for 24 hours a day would be very efficient according to PU. A combination of both helps, but can still rate an inefficient order of shipments higher. Finally, CU should be measured as *unit-km vs vehicle-km*.

### 2.5 Effectiveness

*Effectiveness* is defined as the satisfaction level categorized from the point of view of Society, Customer, Strategy and Employee. The KPI’s found are merely based on Krauth, et al. (2005), of which an overview is given in appendix A. Effectiveness is a dimension that is hard to determine by the CBS commodity flow database, as there is data required of behaviour, processes and experienced processes from each stakeholder. Even though *effectiveness* will not be used further in this research, there is an overview given in the table below since this KPI’s are affected by collaboration.

| Table 6, Effectiveness KPI’s and how they are affected by collaboration |
|---|---|
| KPI | Affect on collaboration |
| **Society** | |
| Employees satisfaction | ↓ (Changing processes) |
| Road maintenance costs | ↓ (Efficient routing) |
| Cooperation with other companies | ↑ (Partner matching) |
| Disaster risk | ↑ (Increasing volumes) |

**Strategy**
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

| Number of deliveries, customers etc. | ↑ (Shared deliveries, new profitable regions) |
| Continuous improvement | ↑ (Learning) |
| Market share width | ↑ (Shared deliveries, new profitable regions) |
| Competitive advantage | ↑ (Cost reduction, flexibility) |
| Product range | ↑ (Product sharing) |
| Data privacy | ↓ (Operations sharing) |

**Employee**

| Attrition of drivers | ↓ (Efficient routing) |
| Working conditions | ↑ ↓ (Depends on processes) |
| Weight to (un)load per labor hour | ↑ (Shared shipments) |
| Salaries and benefits | = (No change) |

**Customer**

| Price | ↓ (Efficient routing) |
| Goods safety | ↑ ↓ (Depends on processes) |
| Product variety | ↑ (Product sharing) |
| Response time | ↑ ↓ (Depends on processes) |
| Transparency for a customer | ↑ ↓ (Depends on IT decisions) |
| Flexibility | ↑ (Resource sharing) |

### 2.6 CONCLUSION

*What are the relevant KPI’s for these companies, how should these be measured and how are these affected by collaboration?*

The measures are categorized in three domains: *productivity, utilization* and *effectiveness*. All KPI’s found in literature that are relevant for companies that engage in road transport are categorized and how these are affected by road transport. This research will focus on the shipment patterns provided by the CBS commodity flow database. Therefore, *effectiveness* and the additional KPI’s on *productivity* and *utilization* are left out of the scope.

The KPI’s proposed for this research are transportation costs. These costs are split in fixed, time-related and distance-related. These three factors cover all transportation costs, excluding the additional overhead costs. Determining the costs per shipment allows the possibility to measure the performance increase for the companies individually while collaborating. Thus, giving insight in what company benefits the most from the collaboration. The fixed costs indirectly measure *PU* and the variable costs *CU*. Leewen (2013) also argues that capacity is a KPI that measures performance indirectly. In addition, costs are often used for optimizing road transport on a micro level. The utilization is merely used on a macro level. Examples are CBS, EUROSTAT and Abate (2014).

If, for other research, measuring capacity utilization is required then methods proposed by Abate (2014) in combination with Davydenko et al. (2014) are preferred (2.1 to 2.2). This combination allows measuring every capacity-related parameter with the distance travelled per tour. Still, there are issues with measuring the *CU*, as inefficient planning can result in higher *CU*. The combination with *PU*, used by Hubbard (2013)(2.6), is even better to correct for stationary vehicles.
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

\[
CU = \frac{\sum_{i=1}^{N}(U_{\text{trip}}_i \times d_{\text{trip}}_i)}{T_{\text{max}} \times d_{\text{tour}}} \quad (2.1)
\]

\[
U_{\text{trip}} = \max \left( \frac{\text{size}P_i}{\text{size}P_{\text{max}}} \times T_{\text{max}} \right) \quad \forall (i \in 1, \ldots, M) \quad (2.2)
\]

<table>
<thead>
<tr>
<th>Output</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(U_{\text{trip}})</td>
<td>Transported units per trip</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>Index for the trips</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(N)</td>
<td>Total number of trips</td>
</tr>
<tr>
<td>(M)</td>
<td>Total number of parameters</td>
</tr>
<tr>
<td>(\text{size}P)</td>
<td>Shipment size in a parameter</td>
</tr>
<tr>
<td>(\text{size}P_{\text{max}})</td>
<td>Vehicle capacity in a parameter</td>
</tr>
<tr>
<td>(d_{\text{trip}})</td>
<td>Distance in km for the trip</td>
</tr>
<tr>
<td>(d_{\text{tour}})</td>
<td>Distance in km for the tour</td>
</tr>
<tr>
<td>(T_{\text{max}})</td>
<td>Maximum vehicle weight capacity</td>
</tr>
</tbody>
</table>

\[
PU = \frac{\sum_{i=1}^{N}(\text{duration}_{\text{tour}}_i)}{\text{duration}_{\text{period}}} \quad (2.6)
\]

<table>
<thead>
<tr>
<th>Output</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(CU)</td>
<td>Capacity utilization</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>Index for the tours</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(N)</td>
<td>Total number of tours</td>
</tr>
</tbody>
</table>
3 PERFORMANCE OPPORTUNITIES IN ROAD TRANSPORT MATCHING

[Sub question 2]

What shipment and schedule characteristics lead to performance increase?

From the previous research question is learned that performance is measured in transportation costs. There are also additional KPI's and KPI's that fall in the category Effectiveness, but these are not applied in this research. This chapter’s analysis when a potential match is promising or not. The goal is to learn how combining shipment patterns add value. The physical sense are the boundary conditions and determines what type of goods can be combined. The economic sense is whether specific matches increase productivity. Note that the matching will be based only on the shipments and depot data. It does not include aligning IT systems, inventories, knowledge and managerial aspects.

![Figure 13, Report structure](image)

First is explained that this research addresses the operational fit but that there are more aspects that are required for a successful collaboration. That paragraph also categorizes the factors that affect business opportunities. The two categories: “Freight” and “Geographic location” are sequentially addressed. The conclusions are drawn in the last paragraph.

3.1 THE OPERATIONAL FIT

The success of a potential match can be valued using the framework shown in Figure 14 (Douma, et al., 2000). The framework is proposed for structuring and supporting the process of alliance building. This framework provides five aspects that require a sufficient fit: strategic, organisational, cultural, human and operational fit. All should be aligned for a successful collaboration. This research problem addresses the operational fit, based on CBS shipment data. The operational fit consists of the economic and physical aspects of the matching. Thus the transportation costs and the boundary conditions. The remaining four fits are not analysed even though they have an impact on the success of a match in practice.
The basis for creating business opportunities is to utilize the backhaul (Tavasszy & Jong de, 2014), increasing the shipment density in the service areas (Huijink, 2016) and increasing the period utilization (PU) (Hubbard, 2003). All three finally lead to lower transportation cost. In fact, the goal is utilizing the slack in road transport.

Achieving high levels of backhaul utilization is not always easy. High backhaul utilization occurs when companies have a consistent demand, back and forth, between two locations. This, however, is in most situations not the case. Most individual companies do not have a balanced demand for the back- and fronthaul and do not always have fully utilized trucks at the fronthaul either. Matching shipments for different companies is a requirement (Hubbard, 2003). In fact, the backhaul is directly influenced by trade imbalance of the commodity flow origin-destination matrices. The higher the trade imbalance, the lower the backhaul utilization (Holguín-Veras, et al., 2014). This symmetry in combination with the complementary nature of the commodity type, volume or weight increases the effect as shown in the P&G-Tupperware. Of course, some goods cannot be combined like oil and vegetables. In addition, not only demand should be aligned, but the time and equipment should be matched as well (Abate, 2012). The depot location, where the vehicles start and end their trip, adds complexity as this location can increase the detour costs. Not only the backhaul is important, but also increasing the shipment density in the service area (Huijink, 2016). Combining shipments by cooperation will decrease costs by decreasing the front- and backhaul trips and the driving between the shipments in the service area. An example in the P&G-Tupperware case is the clustering of the destination shipments in Greece. The density will have less impact when shipping full truck loads. The last factor, period utilization, results merely in decreasing the fixed costs of a schedule. Companies that utilize their fleet during the early morning can be matched to companies that have their peak moments during the evening. Because of data limitations, the time-windows are left out of the scope. Therefore, the business opportunities created by this aspect are not evaluated. An overview of the factors that are relevant for determining the operational fit are shown in Table 7. The factors are categorized in: “Freight” and “Geographical location”.

Figure 14, The generic fit framework (Douma, et al., 2000)
Table 7, Factors that affect business opportunities

<table>
<thead>
<tr>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freight</td>
</tr>
<tr>
<td>Type of goods</td>
</tr>
<tr>
<td>Volume vs Weight</td>
</tr>
<tr>
<td>Geographic location</td>
</tr>
<tr>
<td>Origins vs Destinations</td>
</tr>
</tbody>
</table>

3.2 FREIGHT

This paragraph explains how the “Good type”, “Volume vs Weight” and “Shipment size” create or limit the business opportunities.

3.2.1 TYPE OF GOODS

The type of goods limits the bundling opportunities, not every good can be transported with any other. Some require specific vehicle types and other types may harm the product quality. Vegetables from production to consumption regions, or tanker trucks cannot be used to transport general cargo. The good types provided by CBS are indicated by NSTR codes. NSTR codes are classified in a hierarchical four-digit structure. The first is the highest classification, second is further specified until level four. The highest level is used for this research. The definitions of the first digits are given in appendix B. A matrix of whether the NSTR codes can be bundled or not is shown in Table 7. The goods that allow bundling are indicated by “Y” and if not by “N”. For example, good type “0” cannot be transported together with good type “3”, meaning that living animals and oils cannot be matched. Some NSTR categories require specific vehicle types. Therefore, this matrix indirectly relaxes the use of vehicle types.

Table 8, Good type combinations. (Y = bundling possible, N = bundling impossible)

<table>
<thead>
<tr>
<th>CODE</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>N</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>3</td>
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<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td></td>
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<td>9</td>
<td>N</td>
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<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

3.2.2 VOLUME VS WEIGHT
The P&G-Tupperware case has already shown that voluminous and heavy shipments are complementary. An efficient distribution increases capacity utilization and decreases costs. The example shown in Table 9 for two companies transporting two complementary goods (Plastics and Sodas) illustrates this effect. The vehicles of company A are filled in terms of volume and company B in terms of weight. The companies individually use 17 vehicles. Together the companies save 7 vehicles if they start collaborating.

<table>
<thead>
<tr>
<th>Company</th>
<th>Goods</th>
<th>Weight</th>
<th>Volume</th>
<th>Quantity</th>
<th># goods per vehicle</th>
<th># Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Plastics</td>
<td>1.00%</td>
<td>8.00%</td>
<td>100</td>
<td>12 (12% [W]/ 96% [V])</td>
<td>8</td>
</tr>
<tr>
<td>B</td>
<td>Sodas</td>
<td>9.00%</td>
<td>2.00%</td>
<td>100</td>
<td>11 (99% [W]/ 22% [V])</td>
<td>9</td>
</tr>
<tr>
<td>A+B</td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>10 (100% [W]/ 100% [V])</td>
<td>10</td>
</tr>
</tbody>
</table>

### 3.3 GEOGRAPHICAL LOCATION

This paragraph explains how the “Origins vs Destinations” and “Depot” create or limit the business opportunities.

#### 3.3.1 ORIGINS VS DESTINATIONS

Symmetry is an important factor when matching origins and destinations for creating business opportunities (Holguín-Veras, et al., 2014). The highest opportunities lay in a full backhaul matching shown in Figure 15. The filled nodes are origins (pickup) and unfilled are destination (delivery). The origin of shipment 1 is close to the destination of shipment to and vice versa. Both ends are clusters. It is only beneficial to cluster pickups or deliveries when the shipments are geographically close to one other. The second example in the figure is matching delivery shipments. This results in a pickup and a delivery cluster. This example fails to utilize the backhaul because of the one way commodity flow, but benefits from utilizing the front haul and beneficial combinations in the service area. This beneficial combinations result in a decrease of detour costs for driving between the orders in the service area. At first there are two trucks driving to the service area and back, but in the joint distribution there is one vehicle serving all shipments.

![Figure 15, Origin and destination matching](image)

An illustration of how the increased shipment density by matching shipments create value is shown in Figure 16. Each tour starts at depot, which is denoted by ‘D’. The represent the locations for the shipments. The figures represent the costs for a specific trip and the fixed costs are 12. The unit for costs is not important. The trips of company A are the straight lines and company B are the dashed lines. Company A has three tours that cost 23, 44 and 38. The routing costs for company B are 44 and 28. When the companies start operating, they are able to benefit from the increased shipment density. The number of vehicles decreases from five to four and they do not serve the same area by more than one vehicle (shipments n-f-o). The combined routing costs are 139, compared to 177 when the companies do not cooperate.
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Figure 16, An Illustration of shipment density increase by collaboration (Huijink, 2016)

An operational fit does not only rely on goods and matching origins and destinations. Examples of practical limitations are:

- Goods transported via a hub increase delivery time and handling costs. Even when a cross dock is used.
- Companies may prefer to first deliver all shipments before executing pickup shipments. Loading new shipments in a nearly full truck is often problematic.
- Time-windows should fit. A match with conflicting time windows will likely increase waiting time and decrease performance.

3.4 CONCLUSION

What shipment and schedule characteristics lead to performance increase?

Physically matching is only useful when the good types transported can be bundled. Therefore, a matrix is proposed that gives an overview of which NSTR 0 levels go well with each other. This matrix also includes rough limitations for vehicle types as different NSTR categories require different vehicles. Another limitation is the shipment size. Companies shipping full truck loads to the same service area will not find any performance increase.

Complementarity is an important factor for the economic aspect. Utilizing the backhaul or benefit from increasing shipment density is especially useful when goods are complementary in weight and volume. Also complementary in the sense of creating a balanced demand for the front- and backhaul. In addition, increasing shipment density allows better combinations for both companies, hence business opportunities.

- Type of goods: not all goods can be bundled and some require specific vehicle types;
- Volume vs weight: combining heavy and voluminous goods result in higher capacity utilization;
- Origins vs Destinations: a trade balance is required to fully utilize the backhaul. Origins and destinations close together decreases fronthaul costs and detour costs between shipments;
THE CBS COMMODITY FLOW DATABASE ANALYSIS

To what extent is the CBS commodity flow database capable of providing sufficient data for the matching issues?

This chapter analyses the CBS commodity flow database. The goal is to gather sufficient information about the data for the model development process in the upcoming chapters and process the data in such way that it can function as import for the designed model (Figure 17).

Figure 17, Report structure

This chapter first addresses the literature used on big data. Next, is described why the CBS data meets big data characteristics and proposes how the data analysis should take place. Thereafter the database analysis is conducted in three steps: the data collection process, the data model and finally the data analysis. This data analysis also results in CSV files required for the matching model.

4.1 LITERATURE ON BIG DATA

The data analysis is based on literature found using the search engines Scopus (Scopus, 2016) and WebOfScience (WebOfScience, 2016). Key words used are “Big Data”, “Data Analysis”, “Smoothing”, “Missing Data”, “Analysis”, “Duplicates”, “Entity relation models” and “Database design”. In addition, the citations and references are used for gathering more data. The search first focusses on the background of big data, next the problems that come along with big data and finally how to coop with the problems. Literature used is shown in the table below:

<table>
<thead>
<tr>
<th>Reference</th>
<th>Literature on big data analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Jin, et al., 2015)</td>
<td>Background information on big data and associated complications</td>
</tr>
<tr>
<td>(Laney, 2001)</td>
<td>Background information on big data</td>
</tr>
<tr>
<td>(Rajeshwari, 2015)</td>
<td>State of the art of big data</td>
</tr>
<tr>
<td>(Qin &amp; Li, 2013)</td>
<td>Big data analysis</td>
</tr>
<tr>
<td>(Kolomvatsos, et al., 2015)</td>
<td>Big data analysis</td>
</tr>
<tr>
<td>(Fan &amp; Wang, 1999)</td>
<td>Sampling</td>
</tr>
<tr>
<td>(Teorey, et al., 1986)</td>
<td>Entity relation models</td>
</tr>
</tbody>
</table>
4.2 ANALYSING BIG DATA

Big data has rapidly gained great attention from industry, academia and even governments around the world. Compared to traditional data, big data is characterized by 5V, huge Volume, high Velocity, high Variety, low Veracity and high Value (Jin, et al., 2015). They, however, do not define exact criteria for the 5V’s. How the data fits all V’s is dependent on the data and open for interpretation of the researcher. Earlier definitions only used Volume, Velocity and Variety (Laney, 2001). The two added V’s: Veracity and Value estimate the usability of the data. The CBS commodity flow database falls in the category big data. First, the Volume is high: over 3 million shipments for the XML data only. One third of the shipments transported by Dutch companies is reported to CBS. Processing this data cannot be done in Excel and even MS Access experiences difficulties when analysing data for practical reasons. The data does not take up levels of a 100ts TB’s, but still requires high speed SQL tools like MS SQL. The second criterion, Velocity, is an important factor in this case. The data grows automatically on a daily basis because of direct XML links from IT systems to the database. The more companies that implement the XML format, the higher acceleration of data growth will be observed. Third, the Variety is clearly present. The sources are reported via three different response tools: paper, internet and XML. The sources are filled in by different companies who organize their processes in a different way. Also, the IT tools that provide the data via the XML tools are implemented by the company and are per definition different data sources. More about these sources is explained later in this chapter. Fourth, Veracity, and fifth, high Value, focus on usability. The CBS data complies with both V’s.: the data have been used by CBS for decades for producing influential statistics used by policy makers and other agencies like EUROSTAT (Veelenturf, 2012). This research takes a deeper dive in the database than aggregate statistics and therefore a complete analysis is necessary. It is necessary to decide on what grounds the data should be analysed. Therefore, this paragraph imposes the requirements of the data in order to determine the sufficiency for model development.

Since the CBS data is classified as big data, the data analysis is performed accordingly. The characteristics of big data makes it difficult to distinguish between reliable and unreliable or true and false. In addition, Jin, et al. (2015) argues that the best data cleaning methods experience difficulties to eliminate some inherent unpredictability of data. Nevertheless, the CBS commodity flow database should be analysed and produce usable datasets for the upcoming phases of this research. Qin & Li, (2013) describe aspects on analysing big data. They distinguish three layers for big data: “Input” (1), “Data Warehouse” (2) and “Data Applications” (3). The input data are several sources (Variety) with different characteristics like implementation and data availability. The “Data Warehouse” provides the data. It functions as a hub between the “Data Applications” (3). In this setup the warehouse is the database and the application is the matching model. The application, MS SQL Server, for the data analysis runs directly on the data warehouse server to speed up the process. Qin & Li, (2013) propose to analyse the data model of the data warehouse first. Then analyse the data model of the reporting companies and finally the analysis of the actual data. This research, however, addresses the layers from (1) to (3). The parts of each layer differs per research and therefore specifically determined for this research. In the basis (1) determines the data collection process of the CBS, (2) the data model of the database and (3) the reliability of the data fields, see Table 11.
4.3 INPUT: DATA COLLECTION PROCESS OF CBS

The data collection process gives insight in the completeness of the data samples and whether this process introduces a bias. This paragraph identifies issues that should be taken into account during the model development or when valuing matches. The guidelines proposed by Fan & Wang (1999) are used for evaluating sample designs of which: a clearly specified target population (1), the unit of analysis (2), the sample size (3), the selection procedures (4) and the response rate (5). In addition, the data processing is analysed as well. The schematic overview below represents the data collection process. There are three stages that have impact on the available data: “Initial sample”, “Sample 2” and “Data processing”. “Initial sample” determines all companies and vehicles that are obliged to report data. This raw data is directly imported into the database via the XML format. Next a sample is drawn from the CBS commodity flow database on which the statistics are produced. The data drawn in “Sample 2” is further processed. CBS calls this processing “gaafmaken” or data smoothing. During this process the data is enhanced and enriched both manually and automated. The output from this records is imported into the CBS commodity flow database. Answers on sampling and processing given by CBS are summarized in appendix C. First the sampling processes are explained and thereafter the data smoothing.
4.3.1 INITIAL SAMPLE

CBS keeps track on shipments carried by trucks with a capacity of 3.5 metric tons and above (Davydenko, 2015) or a loading capacity of 2.0 metric tons. Thus their target population is all road transport done by Dutch companies. Companies fill in a week of transported shipments for the vehicle. Therefore, the unit of analysis is vehicle-weeks for trucks with a loading capacity of 2.0 metric tons. The shipments are not complete per company, since the unit of analysis is not on the company level. All vehicles are identified by their license plate. These license plates are used to compose the sample group.

The selection procedure is as follows: the chance of drawing a vehicle depends on 74 strata that are based on the following indicators: company size, vehicle age, vehicle capacity and vehicle type. Each vehicle from the sample group is assigned to a specific week of which all transported shipment data and tours should be reported. The requested data contains shipments with origin, destination, transported good and weight. These shipments are assigned to a specific tour executed by the requested vehicle. Statistics produced by CBS using this data are transported weight, distance traveled loaded, distance traveled empty, ton kilometer and capacity utilization (Veelenturf, 2012). A sample is drawn quarterly. Companies that have over 30 vehicles registered are part of each sample and the remaining companies at most once per year. The chance for drawing a vehicle that has to report their shipments for the requested week is nearly 1:3 per year. Thus the sample size for a year is 1:3*1:52 of the target population. Since it is mandatory to report data and CBS calls companies that forget to report their data, it is assumed that there are no issues with the response rate. Especially when companies have the ability to use the XML interface where the data is provided with a push of a button or even completely automated.

The companies can choose between three survey response tools: paper, internet and a structured XML format. The latter is used for this research as this data is denser and has higher quality due to the atomized input and response groups. Some companies that use the XML format do deliver more data than requested. There are three response categories identified: only the requested vehicles, all vehicles within the requested sample week or all vehicles during the year. This identification is important as companies that fall in a specific category should be processed in a different manner. A company that only provides the requested vehicles should be bundled with more than one sample.
period to ensure a complete shipment set. A company that provides all vehicles of the requested sample week can be used directly. From the third category where all data is supplied, a representative week should be chosen. With this distinction is ensured that a representative complete shipment set per company is used for the model.

The custom implementations of the XML formats use two different main sources: according to CBS roughly 80% is provided by real time systems like board computers and 20% by planning systems such as transport management systems (TMS). Real time systems provide data during the execution of the tours. Most of these systems require interaction with the driver, examples are EVO-it (2016) or Groeneveld (2016). Drivers input per system can be various: from complete time logs to only choosing the next shipment in the tour. A planning system forecasts the tours and therefore might deviate from practice. There are systems that import real time data into planning systems enabling them to steer the planning during the execution. This enrichment improves data quality. Whether a real time system or planning system is able to provide sufficient data depends on the implementation. This implementation depends on the logistic processes and available data. There are several decisions taken during an implementation process that can influence the data quality in a negative way. For example, a planning that is only subject to time constraints does not require to map transported quantity. To make things worse, some companies do not have the knowledge about the actual transported goods and quantities at all. Especially when they transport goods for other companies or usually plan full truck loads. Other decisions like not planning ad hoc shipments or empties will not be part of the reported data for the simple fact that these data are unknown. All steps in the information gathering process can be seen as a funnel: each step the data is further stripped. Not only might the lack of data be an issue, but also the semantics. A shipment can be bundled per stop or provided per good separately. Carrying empty containers counts for some companies as a fully loaded truck, while others argue that the truck is empty. Also the definition of a tour is an issue. CBS defines a tour being from empty to empty or loaded to empty, but others use the definition from depot to depot. Thus there are three issues addressed here: there are two data source categories: planning and real-time systems, the funnel effect because of implementation decisions, missing information and data field semantics.

Currently, 2015, there are 85 companies that have the XML format implemented compared to 40 in 2012 (Veelenturf, 2012). Unfortunately, companies that transport goods under own account fall behind. There is only one company using the XML tool. Furthermore, the investments for implementing the XML format are significant as every implementation is custom build (Veelenturf, 2012). Therefore, the XML tool is only accessible to larger companies that also have a planning or tracking and tracing tool implemented. These companies have already invested in optimizing their road transport processes and thus are likely to find efficiency important. Therefore, this introduces another bias as companies not aware of efficiency are likely to be able to gain relatively more profits. Hence this research can only draw conclusions about the larger transportation companies that have invested in optimizing logistic processes.

### 4.3.2 DATA PROCESSING

CBS begins with the data processing when the data gathering process is fulfilled. Note that only the sample data is used for the data processing. Also not all data processing actions are mapped in this paragraph since the goal is to provide a general insight for the steps CBS takes to enhance and enrich the data. This data processing is called ‘gaafmaken’ or data smoothing. This involves adding and improving location data of tours and shipments. Also companies, of whom the transported quantities are unknown, are derived from the handling time or an average weight per stop. This quantity data is checked on validity and adjusted accordingly. One of the checks CBS performs is whether the transported goods exceed the vehicle capacity. CBS also adds shipments for empties like pallets. Furthermore, CBS splits tours so that a tour is either filled or empty. Hence a tour containing deliveries...
results in two tours: one empty and one filled. Moreover, CBS assumes that a vehicle within a radius of 250km proximity from depot will return that same day.

4.3.3 CONCLUSIONS

The data collection process learns different aspects that influence this research. The target population is clear: all road transport done by Dutch companies. The unit of analysis is vehicle-weeks for vehicles with a capacity of 3.5T or more. The sample size from the target group is nearly 1:3 for one week per year. The selection is based on 74 strata that are based on the following indicators: company size, vehicle age, vehicle capacity and vehicle type. From the target group there are companies that provide more data than requested. Some deliver all shipments of all vehicles during the year, some deliver all vehicles from the requested week and finally, some deliver only the requested vehicles from the requested week. The response rate is not an issue as the surveys are mandatory and companies that fail to report data are contacted by CBS. Furthermore, the impact of using different data sources (real time systems and planning systems), data insufficiency due to custom implementations and aligned semantics should be taken into account. Also, it is important to be aware of the fact that there is a specific group of companies using the XML format. One single company that transports under own account is part of the sample and it is arguable that the sample group is already familiar with road transport process optimization. Finally, the data provided by the companies is partly processed by CBS. Hence the data contains processed and raw data.

4.4 DATA WAREHOUSE: DATA MODEL

This paragraph analysis the data model used by CBS to give an overview of the available data. Note that only the structure from the survey level to the shipment level is addressed as these are required for this research. This relational structure can be described with an entity relation model (Teorey, et al., 1986). Other database tables that, for example contain trailers, are not analysed. First the relational structure of the tables is explained, followed by the relevant data fields per table.

4.4.1 RELATIONAL DATA STRUCTURE

The relational data structure for the required tables ‘Opgave’, ‘Rit’ and ‘Zending’ is shown in Figure 19 and are all classified as a binary degree of relationship. A binary degree is that two single entities (tables) have a relation. These relations are described as connectivity classes. There are three connectivity classes: one-to-one, one-to-many and many-to-many (Teorey, et al., 1986). The figure shows only one-to-many relationships. The highest level is the ‘Opgave’ table. This table contains the vehicles-weeks drawn from the sample. One record therefore contains data about one vehicle for the sample week. The actual tours are records in the table ‘Rit’. There are, in most cases, more ‘Rit’ records linked to a single ‘Opgave’ record. That means that a vehicle is used for several tours in the sample week. The shipments executed in a tour are included in the ‘Zending’ table. This table contains the goods transported from the origin to the destination. All three tables are provided with a foreign key which ensures data integrity. A ‘Zending’ record can only exists if the parent ‘Rit’ exists (Teorey, et al., 1986).
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4.4.1.1 TABLE ‘OPGAVE’

The table “Opgave” contains the licence plate that uniquely identifies the vehicles. This data can be used to find the fleet of a company. Also a specific company code for the data supplier is required for grouping data per company. Unlike CBS, this research is interested in the data of individual companies. On the “Opgave” level is the source: XML, Paper or Internet given, allowing to filter only the XML data. Furthermore, the vehicle base, which will be used for the depot determination is given in either NAW or coordinates. The data field “Status” is useful. This status indicates whether the data is raw (status 5) or processed (status 2) by CBS.

4.4.1.2 TABLE ‘RIT’

A complete tour consists of several ‘Rit’ records. A distribution tour is split in two: from depot to the last delivery and from the last delivery back to depot. A tour that consists of pickup and delivery (P&D) shipments that are sequentially executed counts the number of shipments + 2 ‘Rit’ records. The data used from the ‘Rit’ table is the ‘RitDatumBegin’ field since the ‘Zending’ table doesn’t provide execution time stamps. The remaining data fields from the table ‘Rit’ are not used since this research uses a commodity based approach and therefore doesn’t require the routes executed in practice.

4.4.1.3 TABLE ‘ZENDING’

The table “Zending” contains all shipments that belong to a specific CBS tour. A shipment contains the transported good type and the corresponding weight. Also the origin and destinations are relevant. The pickup and delivery requests are reported on the same record, thereby losing the ability to determine the real execution order within a tour. Therefore, a TSP is needed before any conclusions can be drawn on costs per tour or capacity utilization. CBS could consider adding a planning table for the execution of a tour that links to the ‘Zending’ and ‘Rit’ table. This table should contain the
timestamp and whether the stop is a pickup or delivery request. Possible changes of the hierarchical structure are presented in Figure 20. Also the execution time and time-windows are not provided. Time-windows can be added in another table ‘Time-Window’ that links to the table ‘Zending’. Missing time-windows may limit the matching opportunities (Deflorio, et al., 2012). Another limitation is that a shipment can consist of several products. Some companies report every product separately, while others bundle the goods to one shipment. An option would be to add another one-to-many relation between the shipments and a new table for products. In addition, increased value for capacity utilization can be realized when products contain standardized units, like pallets or wheeled containers. Finally, there are more recommendations that will enhance the database value, but an in-depth recommendation about the database is not part of this research.

Figure 20, Possible revision hierarchical structure data model. Format is the extended entity-relationship model (Touboulc & Walker, 2015)

4.4.2 CONCLUSIONS

The data fields are sufficient for the matching process. The transported shipments are available and the shipment date can be extracted from the “Rit” table. This combined with the company data in the “Opgave” table enables the possibility to create a dataset for the shipments per company.

There are, however, some recommendations. Execution order per tour is not available since both the pickup and delivery requests are on the same record. A table can be added to overcome this issue with at least a shipmentID, timestamp and request type. Also adding a time-window restriction table creates value for the tour data: not every shipment can be delivered during the whole day. Furthermore, table “Products” linked to the “Zending” table enables bundling shipments and thereby prevents the differences between companies that already report bundled shipments per stop and others who report separate products. Finally, there can be thought of adding standardized loading units like pallets or wheeled containers. This helps determining the capacity utilization for voluminous goods.
4.5 DATA APPLICATIONS: DATA ANALYSIS

This paragraph performs a complete data analysis necessary to arrive at a usable dataset that can be imported in the model. First, a basic overview about the data quantity, international transportation is given to create an impression about the records in the database. Next the fields necessary for the match model about companies, transported goods and locations are analysed and enriched. Main issues are missing data, for example when location fields are empty, and duplicate or ungrouped records. This process is called data cleansing. Data cleansing can be done on the server side while reporting data (Lee, et al., 2005), but this research uses MS SQL server for the analysis. First is explained how to cope with duplicate records and thereafter the methods for solving missing data.

Duplicate record detection is the process of identifying different or multiple records that refer to one unique object. There are two basic steps for finding such objects: data preparation and determining the similarity of fields (Bharambe, et al., 2012). First, data preparation is the process of preparing the dataset in such way that the fields can be compared. This preparation contains steps like ensuring the same data types, the data range and determine the fields that should be compared. Matching individual string fields is harder than numeric fields because of typographical errors or abbreviations. “Rotterdam” may be the same as “Rotterdaam”. For matching strings are many techniques available like determining the “Jaro-Winkler distance”, “Smith-Waterman distance”, Q-gram distance” that all use algorithms for determining how well the fields match. When dealing with dynamic data, there are sophisticated methods like “Active-Learning Based Techniques” or “Probabilistic Matching Models” available. Since the data will be imported in Matlab, this research does not go beyond static data matching for string or numeric records. This research uses only the numeric comparison techniques with a “Rule based technique” which means that specific rules are set to determine whether records are duplicates.

Coping with missing values can be done with several methods. For instance interpolation of data, using a probability distribution, deleting the records, Bayesian or decision trees (Qin & Li, 2013). Also nearest neighbour algorithms are applied for filling missing values. A less sophisticated, or even naive, method is using the mean or mode of all observed values (Anagnostopoulos & Triantafillou, 2014). For simplicity, computational power and available tools (MS SQL Server) is chosen to use a mean value or modus for the missing values.

4.5.1.1 DATA QUANTITY OPGAVE

The number of ‘Opgave’ records and how these are distributed amongst the different sources (XML, Paper and Internet) is shown in Figure 21. A yearly increase of XML surveys is expected, but the figure shows a stable data quantity. Some XML companies no longer report because of bankruptcy or company take-overs. These quantities appear to be in balance with new XML companies. CBS also experiences difficulties to introduce new XML companies. An extra survey on vans in 2012 has led to the significantly higher quantity in that year. The statistics for the year 2015 were not finished at the time of producing the chart and therefore show less reports. An unexpected difference is the high quantity of internet surveys in 2013. The explanation is duplication of raw records during the data processing phase. This copying applies to the XML surveys as well. Since the processed records account for almost 10% of the total records, this is further analysed for the XML. Eventually, the observed duplicate records in the XML data are below 2% and therefore ignored. The analysis on these duplicates is given in appendix D.
4.5.1.2 INTERNATIONAL TRANSPORTATION

The distribution of shipments amongst the nations for the XML companies is shown in Figure 22. Note that the different report groups are not corrected. Thus the companies that report all shipments have a higher stake than the ones that only report the requested week. The figure shows that around 75% of the shipments are transported within the Netherlands. Around five percent of the shipments consists of cabotage, see “Share cabotage per country”. Germany and Belgium account for the major share of cabotage. This pattern is also found for the shipments that either have their origin (“Origin per country”) or their destination (“Destination per country”) in Germany or Belgium. The Netherlands, Germany and Belgium together with France account for 97% of the aggregate transportation done by Dutch vehicles. The origins and destination also show that the Netherlands has an export surplus. This is can be seen in more detail in “Share import vs export per country”. The XML companies export almost 65% from the Netherlands to other countries. All other countries, apart from Italy, have an import surplus. This imbalance limits the business opportunities for matching, because there is no way to utilize the backhaul completely. Therefore, cooperation between other countries would gain more performance for international transportation.
The database contains 93 unique XML company codes. Of which an empty code and the company code: “1234”. These two do not fit the description of the other companies that consists of at least four characters. Amongst the remaining 91 unique codes are 6 from different divisions belonging to one company, which leaves a total of 85 unique companies. From these companies are 2 that reported all shipments during the year and one company all shipments for a week in 2015. Thus, most companies only report the requested sample and, therefore, introduce a significant bias: the matching can only be done on the sampled data for the majority of companies. The complete dataset is used for the remaining companies. Figure 40 shows the number of companies per number of shipments for all XML shipments and all years. The orange line is the cumulative shipment count and the bars are the frequency per interval. Most companies serve between 1000 to 10000 shipments. Even though this companies do not have a complete overview, the shipment quantity is sufficient to run the matching model on. Of course, with the limitation that the shipment sets may not be complete. Determining the costs for incomplete shipment sets will undershoot. Companies that have less than 10 shipments will not be used for the matching.
The modus of the NSTR code is calculated for each company based upon all available shipments (Anagnostopoulos & Triantafillou, 2014). This modus is used to meet the good constraints using the NSTR matrix proposed in chapter 0. Most companies fall in category 9 (Vehicles, machinery and other goods), see Figure 24. For every company is a potential partner according to the NSTR matrix, but the number of possibilities are limited. For example, there are 9 companies that can be matched for oils (NSTR code 3). Figure 25 shows the average weight per company (Anagnostopoulos & Triantafillou, 2014). This weight is used for all shipment records that do not report data about the transported weight. Most companies transport between 1 and 10 tonnes. The companies that fall in the 10T to 100T group report at most 40 tonnes per shipment. There is no reliable data available about volume in the CBS commodity flow database. CBS even removed the volume field from the surveys.
Finally, all companies are processed and exported to a CSV format as shown in Table 12. The company ID is unique to comply with the CBS restrictions. The average weight, NSTR, maximum volume and weight per company are given. For this research the maxima are equal amongst the companies, since there is chosen for a large semi-trailer truck. The loading capacity of the semi-truck-trailer is 30 tonnes and 85 $M^3$. Thus the modal can run for weight and volume. This size is set by analysing the large shipments in the database. Most shipments can be transported by this vehicle type. The remaining shipments are set to the max 85 $M^3$ and 30 tonnes. The sizes are common for large semi-truck-trailers in road transport (RDW, 2012) (CretenBelgium, 2016).

<table>
<thead>
<tr>
<th>ID</th>
<th>Average weight</th>
<th>Average NSTR</th>
<th>Max $M^3$</th>
<th>Max kg</th>
</tr>
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<td>85</td>
<td>30000</td>
</tr>
<tr>
<td>4</td>
<td>1987.32</td>
<td>9</td>
<td>85</td>
<td>30000</td>
</tr>
<tr>
<td>5</td>
<td>14345.52</td>
<td>9</td>
<td>85</td>
<td>30000</td>
</tr>
<tr>
<td>6</td>
<td>7919.47</td>
<td>9</td>
<td>85</td>
<td>30000</td>
</tr>
</tbody>
</table>

4.5.2 TOURS

The tours are not relevant for this research because of the commodity based approach. Nevertheless, tours are interesting for other research purposes, like benchmarking or can function as test to find out whether companies report complete lists of shipments. The shipment count per tour is an important factor as this partly determines whether the tours are complete. Completeness of tours is vital for benchmarking. The shipment count per ‘Rit’ according to the CBS commodity flow database for Benelux, Germany and France is given in Figure 26. This overview addresses two issues: even though not significant, but there are 7,091 ‘Rit’ records (<1%) that contain over 30 shipments (1) and more importantly over 90% contain 1 or 0 shipments (2). The latter suggests that the majority of tours or have been empty or have just one shipment implying a full truck load.
The issue with the large quantity of shipments per tour is a result of the different XML implementations amongst the companies. Some companies count every banana separately as shipment and others bundle these in pallets. Resulting in respectively 300 and 1 'Zending' record in the CBS commodity flow database. This shows that aggregation of the shipments per stop is necessary. This limitation can be solved to introduce a new level 'Products' as earlier proposed. This is necessary for using the Huijink (2015) estimation model as this model determines the insertion costs based on the surrounding five orders. The insertion costs for five shipments on the same location is 0. Bundling also helps lowering the complexity of the optimization problem as the number of stops are reduced. Moreover, comparing the number of shipments per tour is an issue at this stage because of this misbalance. A simplified example of the bundling to overcome this limitation is given in Figure 27.

---

**CBS commodity flow database unbundled example**

<table>
<thead>
<tr>
<th>RtrID</th>
<th>ZendingID</th>
<th>Origin</th>
<th>Destination</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>5645 AB</td>
<td>7588 AC</td>
<td>1 banana</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>5645 AB</td>
<td>7588 AC</td>
<td>1 apple</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>5645 AB</td>
<td>7588 AC</td>
<td>5 peaches</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>5645 AB</td>
<td>9684 EV</td>
<td>10 bananas</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>5645 AB</td>
<td>3423 EB</td>
<td>20 bananas</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5645 AB</td>
<td>3423 EB</td>
<td>1 apple</td>
</tr>
</tbody>
</table>

**Bundled example**

<table>
<thead>
<tr>
<th>RtrID</th>
<th>ZendingID</th>
<th>Origin</th>
<th>Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>5645 AB</td>
<td>7588 AC</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>5645 AB</td>
<td>9684 EV</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>5645 AB</td>
<td>3423 EB</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5645 AB</td>
<td>3423 EB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ZendingID</th>
<th>ZendingID</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1 banana</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1 apple</td>
</tr>
</tbody>
</table>
The figure shows that the first three shipments have the same origin and destination and are allocated to the same tour: 1 banana, 1 apple and 5 peaches. Moreover, these three shipments delivered in a sequence: there is no shipment to another location in between. Therefore, these shipments should be bundled in one shipment as this certainly is one stop in this tour.

The stochastic matching index is determined and then filtered on the following criteria (Bharambe, et al., 2012):

1. Shipments sort by ritID, zendingvolgnummer;
2. Get all shipments where the location data of the next record differs from to the current record;
   - Origin and destination ZIP and country;
   - Origin and destination coordinates;
   - RitID;

Executing the query on the XML database reduces the shipment count from 3,037,044 to 2,246,303 and for Benelux + De + Fr a reduction from 2,959,210 to 2,174,959 is realised (Figure 28). A significant reduction of nearly 30%. The empty tours remain unchanged and the single shipments per tour increased as expected. Tours with one shipment cannot be bundled and at least 30,000 shipments were bundled resulting in one shipment within a tour.

Example tours origin and destinations from the CBS commodity flow database are shown in Figure 29. The upper two screenshots are two CBS tours. The left starts west from Eindhoven and ends the tour in Hannover. The second tour starts in Hannover and arrives in Eindhoven. This is a typical example of a split front- and backhaul due to CBS’s definition of a tour. The third screenshot shows a tour from another company that is split in four CBS tours. This tours should be combined, for research on benchmarking.
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

4.5.3 LOCATIONS

The location data provided by the CBS commodity flow database is required for the matching model are: depot locations and shipment locations. Depot locations determine the vehicle departure and arrival location. The shipments determine the origin and destination of the goods.

4.5.3.1 DEPOT

The depot data is based upon ‘Standplaats’ in the ‘Opgave’ table. How well the depots are filled is presented in Figure 30. The coordinates are very poorly provided, only 8% of the records has a coordinate filled in. The only positive factor is that all coordinates fall within the Benelux and therefore are all marked as valid. The country codes are missing for 10%. Thus the country can be used quite well for the determination of depot, especially since the empty fields are uniformly distributed amongst the companies. The country code should be combined with ZIP codes or city names. Unfortunately, combining the ZIP codes with the coordinates still does not reach more than 20% fill rate. That leaves only the combination for the country code and city name. This is not desired, since city names are spelled differently by companies and harder to geocode (Bharambe, et al., 2012).
Another way for determining the depot location is the share of shipments that have their origin or destination at a specific location. Figure 31 shows a graph of four companies. Company 2 has one location that accounts for 35% of the shipments and is likely a depot. From the third location it becomes fuzzier. This fuzzy area is even bigger for Company 4. The first to 10th location have a comparable share of shipments: between 4 and 8%. Therefore, the only way to determine the depot locations is manually using the city name and countries per company. An example of the final depot locations is given in Table 13.
4.5.3.2 SHIPMENT

Similar to the depots, the origin and destination locations can be determined on coordinates, city name or ZIP. The city name, however, is practically impossible to geocode for this research. There are more than 3 million shipments and thus over 6 million city names that have to be converted. Fortunately, the country and ZIP codes are sufficiently available (Figure 32). Combining those increases the fill rate to a little over 90%. Two companies account for 74% of the remaining 10% invalid locations. Filtering these companies together with the companies that have less than 20% valid locations increases the 74% to 91%. Hence, after filtering these companies a total of 98.6% of the shipments are sufficient. An example of processed shipment data is shown in Table 14.

Table 13, Sample depot data

<table>
<thead>
<tr>
<th>DepotID</th>
<th>ZIP</th>
<th>CompanyID</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>668</td>
<td>1</td>
<td>NL</td>
</tr>
<tr>
<td>2</td>
<td>845</td>
<td>3</td>
<td>NL</td>
</tr>
<tr>
<td>3</td>
<td>803</td>
<td>4</td>
<td>NL</td>
</tr>
<tr>
<td>4</td>
<td>605</td>
<td>5</td>
<td>NL</td>
</tr>
<tr>
<td>5</td>
<td>669</td>
<td>6</td>
<td>NL</td>
</tr>
<tr>
<td>6</td>
<td>784</td>
<td>7</td>
<td>NL</td>
</tr>
<tr>
<td>7</td>
<td>753</td>
<td>8</td>
<td>NL</td>
</tr>
<tr>
<td>8</td>
<td>695</td>
<td>9</td>
<td>NL</td>
</tr>
<tr>
<td>10</td>
<td>491</td>
<td>10</td>
<td>NL</td>
</tr>
<tr>
<td>11</td>
<td>488</td>
<td>11</td>
<td>NL</td>
</tr>
<tr>
<td>12</td>
<td>943</td>
<td>11</td>
<td>NL</td>
</tr>
<tr>
<td>13</td>
<td>602</td>
<td>11</td>
<td>NL</td>
</tr>
</tbody>
</table>

![Figure 32, Charts shipment location availability](image)
Table 14, Sample shipment data

<table>
<thead>
<tr>
<th>CompanyID</th>
<th>LoadZIP</th>
<th>LoadCountry</th>
<th>DelZIP</th>
<th>Delcountry</th>
<th>NSTR</th>
<th>Weight</th>
<th>Volume</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>266</td>
<td>NL</td>
<td>90431</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>4</td>
</tr>
<tr>
<td>23</td>
<td>266</td>
<td>NL</td>
<td>90431</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>4</td>
</tr>
<tr>
<td>23</td>
<td>74564</td>
<td>DE</td>
<td>592</td>
<td>NL</td>
<td>3</td>
<td>23100</td>
<td>25.66</td>
<td>4</td>
</tr>
<tr>
<td>23</td>
<td>592</td>
<td>NL</td>
<td>89275</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>592</td>
<td>NL</td>
<td>89275</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>118</td>
<td>NL</td>
<td>76137</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>118</td>
<td>NL</td>
<td>70825</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>6</td>
</tr>
<tr>
<td>23</td>
<td>592</td>
<td>NL</td>
<td>52249</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>592</td>
<td>NL</td>
<td>50171</td>
<td>DE</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>592</td>
<td>NL</td>
<td>446</td>
<td>NL</td>
<td>3</td>
<td>390</td>
<td>0.43</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>592</td>
<td>NL</td>
<td>446</td>
<td>NL</td>
<td>3</td>
<td>3600</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>2030</td>
<td>BE</td>
<td>592</td>
<td>NL</td>
<td>3</td>
<td>840</td>
<td>0.93</td>
<td>2</td>
</tr>
<tr>
<td>23</td>
<td>481</td>
<td>NL</td>
<td>592</td>
<td>NL</td>
<td>3</td>
<td>2920.71</td>
<td>3.24</td>
<td>2</td>
</tr>
</tbody>
</table>

4.5.3.3 GOODS TRANSPORTED

The final aspect is the type of goods and weight transported. Analysed is again how well the data fields are available. Both weight and NSTR codes are reasonably filled (Figure 33). Weight has a fill rate of 75% and NSTR 78%. There is no company that has no single records filled in as CBS smoothen the data before producing their statistics. The empty fields are enriched using the earlier explained averages per company explained by Anagnostopoulos & Triantafillou, (2014). The average weight of the corresponding company is filled in when data is missing.

![Weight count and NSTR](image)

Figure 33, Good availability

4.5.4 CONCLUSIONS
Most companies deliver only the sample data requested by CBS. This limits the final results as incomplete shipment sets can miss potential matches. Still, the model can run on sample data as well (1:3 of the vehicles each year is reported), but this limitation should be taken into account.

The shipments are bundled per stop to overcome the differences between companies that already bundle their shipment data and those who do not. This decreases the shipment quantity by 30% and therefore decreases the complexity. In addition, not bundling results in 0 costs for detour costs per shipment because driving between the same location is free.

The depot locations are manually determined on the city name because the coordinates and ZIP codes are poorly available. The location for the shipments are determined on coordinates and ZIP together. The companies that have a large share of unfilled location data are filtered. Finally, 100% of the depot data is processed and 98.6% of the shipment data.

The good types and weight transported have a fill rate of more than 75%. The remaining empty fields are filled with the average weight and NSTR codes per company. In addition, the volumes are determined using a conversion table for weight to volume. The processed data of all shipments have 100% NSTR, weight and volume filled in.

The processed data overwrites in some cases the raw data and in other cases adds new records to the CBS commodity flow database. There are two solution proposed for this issue: adding a parentID that links to the raw data in the same table (1) adding processed fields in the databases (2).

Finally, the data could also be processed during the import of XML data. From geocoding the data with NAW data and coordinates to correcting volumes. It is recommended to either have solution (1) or (2) incorporated.

4.6 CONCLUSION

To what extent is the CBS commodity flow database capable of providing sufficient data for the matching issues?

The data is sufficient for this research, even though there are some concerns. Majority of the companies only report the requested sample. Other issues are solved by, for example, using average weight per company if fields are not filled or by filtering companies that report unreliable data. In Table 15 are remarks per aspect of data sufficiency given. There are three data files processed: company data, depot data and shipment data. These files are used as input for the matching model.

Recommended to CBS is to evaluate their data model. There are some recommendations given as result of the analysis: a new child table for products, a tour table and adding fields for processed data. Also automatic data processing during the import can save manual processing time, like geocoding and evaluate good quantities.
### Table 15, Conclusions on the aspects of data sufficiency

<table>
<thead>
<tr>
<th><strong>Data collection process</strong></th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample CBS</strong></td>
<td></td>
</tr>
<tr>
<td>Trucks &gt;3.5 tonnes. Sample chance 1:3.</td>
<td></td>
</tr>
<tr>
<td>Response rate is no issue.</td>
<td></td>
</tr>
<tr>
<td>Different report categories: only sample, all or all vehicles in the sample week.</td>
<td></td>
</tr>
<tr>
<td>Different sources: real-time systems (80%), planning systems (20%).</td>
<td></td>
</tr>
<tr>
<td>XML-companies are large companies that are likely to be aware of process optimization.</td>
<td></td>
</tr>
<tr>
<td>All but 1 company are LSP’s.</td>
<td></td>
</tr>
<tr>
<td><strong>Processing CBS</strong></td>
<td>Combination of processed data and raw data</td>
</tr>
<tr>
<td>CBS tour definition: from empty to empty or loaded to empty.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Data model</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
</tr>
<tr>
<td>Some stops consist of multiple ‘Zending’ records while others are bundled.</td>
</tr>
<tr>
<td>No data about ‘Zending’ order available</td>
</tr>
<tr>
<td><strong>Availability data fields</strong></td>
</tr>
<tr>
<td>No timestamp in the ‘Zending’ table available</td>
</tr>
<tr>
<td>No time-windows in the ‘Zending’ table available</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Data analysis</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipments per company</strong></td>
</tr>
<tr>
<td>2 companies have reported all records, 1 a complete week and the remaining only the requested data in 2015</td>
</tr>
<tr>
<td>Most companies have reported between 1000 and 100000 shipments in the complete database</td>
</tr>
<tr>
<td>CBS overwrites the data during the processing phase in some cases</td>
</tr>
<tr>
<td><strong>Average weight per company</strong></td>
</tr>
<tr>
<td><strong>Average NSTR per company</strong></td>
</tr>
<tr>
<td><strong>Shipments per tour</strong></td>
</tr>
<tr>
<td><strong>Depot locations</strong></td>
</tr>
<tr>
<td>The coordinates and ZIPS are poorly available. The city present for most records.</td>
</tr>
<tr>
<td>Determining depots by the shipment origin and destinations is not easy</td>
</tr>
<tr>
<td><strong>Shipment locations</strong></td>
</tr>
<tr>
<td>The coordinates and ZIPS are sufficient.</td>
</tr>
<tr>
<td>2 Companies account for 74% of the invalid ZIPS</td>
</tr>
<tr>
<td><strong>NSTR per shipment</strong></td>
</tr>
<tr>
<td>78% is available for at least the first level the rest is, for this research, filled with the average weight per company</td>
</tr>
<tr>
<td><strong>Weight per shipment</strong></td>
</tr>
<tr>
<td>75% is available for at least the first level the rest is, for this research, filled with the average weight per company</td>
</tr>
</tbody>
</table>
5 DESIGN OF THE MATCHING MODEL

[Sub question 4]

How can the matching model be designed for 2 companies?

The model design phase follows up from the literature research of the performance indicators, the boundary conditions set by the company characteristics and the data analysis. The problem definition in the introductory chapter has explained various planning problems in detail. How the model is designed for two companies (N=2) and the mathematical formulations are given in this chapter.

From the problem definition in the introductory chapter it has been learned that the performance gain is determined by the ratio between two scenarios: the companies separately thus without collaboration (SC1) and the scenario with collaboration (SC2). The MD-VRPMB and MD-PDP routing problems have to be solved due to the nature of the various shipment types. Note that the multi-day tours are left out of the scope. The routing problems are subject to the following shipment constraints: type of good, quantity and date. Also vehicle capacity and tour duration are relevant constraints. In addition, the problem size is \( \frac{N(N-1)}{2} \). Where N = 85 companies. The complete dataset is 3 million shipments divided over multiple days and has to have the potential to be solved for more than two companies. The number of possible matches for two companies is

From RQ1 is learned that costs should be used as KPI for the model development phase. The total road transport costs of a company should be lowered by collaboration and thereby increasing performance. These costs are split in three main factors: fixed, distance and duration. Cooperation should thus focus on minimizing a predefined ratio of these factors. In addition to the performance measures, RQ1 also learned that capacity utilization is a derivative of performance. Capacity utilization, however, should only be measured to determine the feasibility of a tour. Capacity utilization becomes critical when a schedule is bounded by the transported goods. For example, when there is physically no possibility to bundle shipments. Ignoring capacity will allow no limit on combinations of
full truck loads. Resulting in unrealistic patterns where, for example, one truck is sufficient to fully supply DC’s under all circumstances.

RQ2 has shown that certain type of goods cannot be combined and therefore form a restraint for matching. Especially complementary goods and demand are important factors. Voluminous and heavy goods are good candidates for bundling. Performance increase can be realized by utilizing the backhaul by decreasing trade imbalances or increasing the shipment density by combining more shipments in the service area.

5.2 MODEL OVERVIEW

This paragraph explains the model phases. There are two models identified that are arranged in series: “Initial Selection” and “Performance Gain Estimation”. These concatenated models are shown in Figure 35. The input data is a bag $X$ with a shipment set $s_q$ {ShipmentID, CompanyID, PickupZIP, PickupCountry, PickupLongitude, PickupLatitude, DeliverZIP, DeliverCountry, DeliverLongitude, DeliverLatitude, NSTR, Weight, Volume, Day} and a depot set $D_q$ {DepotID, CompanyID, ZIP, Country}. This input data is compared to the shipments and depots of the other companies in the CBS commodity flow database. This comparison results in a bag $Y$ containing the performance ($P_i$) for merging the transport activities per company $i$ and the performance ($P_i^Q$) of the input shipment set per company $i$. The lower the performance index, the better the match for the querying company.

![Figure 35, Model overview](image)

The first selection procedure is performed during the “Initial selection”. This selection filters the matches that are not worthwhile to explore. These are companies that transport goods that cannot be bundled. These companies will be ignored and only the promising companies are send to “Performance Gain Estimation” for further exploration. Since the “Initial selection” is not very sophisticated, it is not further elaborated in this chapter. These companies are separately matched with the input bag $X$. A performance gain estimation is determined for each alliance separately. The moderating variable $a$ is a $\mathbb{R}$ parameter that determines the weight of inter-depot transportation. Where $0$ calculates the full costs of an inter-depot vehicle per shipment and $1$ only the share of the capacity utilization of that vehicle. The variables $C_f, C_d, C_d$ are respectively the fixed costs per day, costs per hour and costs per km for a vehicle. A predefined number of top scoring companies is the output of the “Performance gain estimation” model.

5.3 PERFORMANCE GAIN ESTIMATION

The remaining shipment set per company as output from the “Initial Selection” is used as input for the performance gain estimation. The performance gain estimation stage estimates the value of the collaboration and determines the performance gain using costs as performance indicator. The lower the costs, the higher the performance. The estimation output is two performance indices. First an index for a complete merge of the transport activities per company. Second a performance index for the input shipment set only. Thus whether the input shipments reduce in costs ignoring the costs of all other shipments. The performance gain estimation consists of the following phases:
The figure describes three steps for $S_{c1}$ and $S_{c2}$: “Shipment Allocation”, “Shipment clustering” and “Performance”. The “Shipment Allocation” step determines from which depots and by which companies the shipments are served. The cluster allocation step is done prior to both scenarios. This prevents a bias due to a possible inefficient allocation in the CBS commodity flow database. A ratio between a sub-optimal $S_{c1}$ and an optimal shipment distribution $S_{c2}$ results in an incorrect low performance index. The cause of a sub-optimal distribution cannot be derived in most cases from the data. The “Shipment Clustering” step clusters the shipments in such way that these can be reliably served by one vehicle. Clustering ensures that the relation between the shipments is taken into account. The “Performance” step of both scenarios determines the performance index ($I$). This index varies from 0 to 1. An alliance cannot perform worse than the companies separately, assuming an optimal distribution of the shipments. An alliance is a collaboration between the querying company and one of the input companies. In worst case there is no exchange between the companies, hence $S_{c1} = S_{c2}$. The performance index is determined for all alliances and the lowest performance indices are chosen. The estimation process is executed for each alliance in parallel. An input of 30 companies therefore results in 30 separate alliances. A predefined number of best scoring companies is the final output of the matching model. The formulas for the performance index ($I$) are given in 5.1.1 (complete merge), 5.1.2 (performance index for company $i$) and 5.1.3 (performance index for company $j$). The matching for all companies can be formatted in a matrix, see the table below. The model design of three steps are explained in the upcoming sub paragraphs.

<table>
<thead>
<tr>
<th>$I_{i,j}$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>0.96</td>
<td>0.94</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td>X</td>
<td>0.81</td>
<td>0.92</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>0.78</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

$\begin{align*}
I_{i,j} &= \frac{c_{i,j}}{c_i + c_j} \quad \forall (i \in 1, \ldots, N, j \in 1, \ldots, N) \\
I_{i,j}^* &= \frac{c_{i,j}}{c_i} \quad \forall (i \in 1, \ldots, N, j \in 1, \ldots, N) \\
I_{i,j}^j &= \frac{c_{i,j}}{c_j} \quad \forall (i \in 1, \ldots, N, j \in 1, \ldots, N)
\end{align*}$
5.3.1 SHIPMENT ALLOCATION

The shipment or demand allocation to the depots, for arriving at $SC_1$ and $SC_2$, is also known as the transportation problem (TP) (Winston & Venkataramanan, 2016). It is concerned with finding the minimum cost of transporting a commodity from a given number of sources to a given number of destinations. TP has the ability to serve the destination locations by multiple sources. Meaning that one shipment can be served by different depots. This, however, is not allowed in this research and therefore simplifies the problem dramatically. With this constraints, the model shows similar characteristics to the gravity model (GM). The surrounding shipments tend to be forced to the closest depot. There are two issues that go beyond the standard TP solutions: first there are P&D shipments and second inter-depot transportation is needed when shipments are swapped between vehicle bases. With that said, first the TP is further addressed and the constraints that this research has to deal with are identified. Then a solution method is presented.

The following figure represents the TP problem. There are $M$ vehicle locations (sources) and $N$ shipments (destinations) shown as $a$ and $b$. The vehicle locations and shipments are represented by a node and the trip is represented by the arc joining the two nodes. The tour costs of transporting one unit from source $i$ to destination $j$ is identified as $c_{ij}$ and is determined by the distance, or a combination of distance and time. The quantity is $x_{ij}$. In addition, the blue arrows represent the inter-depot flows that are associated with delivering shipments from another depot. The new depot acts as a hub, which can be defined as a hub-and-spoke design.

Determining $c_{ij}$ for P&D shipments is done by determining the costs for all three segments (Figure 38). From depot ($a_i$) to pickup location ($b_1$), from pickup location ($b_2$) to delivery location ($b_n$) and finally back from delivery location ($b_n$) back to depot ($a_i$). Adding these three segments is presented
Note that a P&D shipment does not introduce inter-depot costs as both pickup and delivery locations are not at depot.

\[ c_{ij} = c_{ia} + c_{ab} + c_{bi} \]  
(5.2.1)

**Outputs**

- \( c_{ij} \): Estimated distance for driving to the next order in the shipment

**Parameters**

- \( c_{ia} \): Costs from depot to pickup location
- \( c_{ab} \): Costs from pickup to delivery location
- \( c_{bi} \): Costs from delivery location to depot

---

**Figure 38, Determining the P&D shipment unit cost**

The objective is to allocate the shipments efficiently to the depots to reach an optimal solution. Since performance is expressed in costs, the goal is to minimize costs and therefore the objective function of the demand allocation algorithm is (5.3.1). The first part are the shipment costs, the second part are the inter-depot costs for the duration and distance of the inter-depot trip and the third part are the fixed costs for the inter-depot trip. The parameters a and b allows to give a weight on the inter-depot costs, based upon the capacity utilization of the vehicle. The minimization algorithm is subject to several constraints. First of all the total transported quantity may not exceed the fleet capacity per vehicle base (5.3.2). Second, the demand for each shipment must be met, thus in this case all shipments should be allocated to a vehicle base (5.3.3). For every shipment may be allocated to one and only one vehicle base (5.3.4). And finally the costs and quantities are positive values (5.3.5).

\[ \sum_{i=1}^{M} \sum_{j=1}^{N} (c_{ij}x_{ij}) + \]

**Minimize**

\[ \sum_{i_1=1}^{M} \sum_{i_2=1}^{M} \left( c_{i_1i_2} \left( a \frac{x_{i_1i_2}}{X} + (1 - a) \right) \right) + \]  
(5.3.1)
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

\[
\sum_{i_1=1}^{M} \sum_{i_2=1}^{M} \left( F \times \frac{t_{i_1i_2}}{t_{\text{max}}} \left( b \left( \frac{x_{i_1i_2}}{X} \right) + (1 - b) \right) \right)
\]

subject to

\[
\sum_{j=1}^{N} x_{ij} \leq a_i \quad \forall \ (i \in 1, ..., N) \quad (5.3.2)
\]

\[
\sum_{i=1}^{M} x_{ij} \geq b_j \quad \forall \ (i \in 1, ..., N) \quad (5.3.3)
\]

\[
\sum_{j=1}^{M} ((x_{ij} > 0) \rightarrow 1) = 1 \quad \forall \ (i \in 1, ..., M) \quad (5.3.4)
\]

\[
(x_{ij} \geq 0) \text{ and } (c_{ij} \geq 0) \quad \forall \ (i \in 1, ..., N \land j \in 1, ..., M) \quad (5.3.5)
\]

Indices

\(i\)  
Index for the depots

\(j\)  
Index for the shipments

Parameters

\(M\)  
Total number of depots

\(N\)  
Total number of shipments

\(c\)  
Costs

\(X\)  
Capacity

\(x\)  
Quantity

\(a\)  
Weight parameter trip costs

\(b\)  
Weight parameter fixed costs

\(F\)  
Daily fixed costs for a vehicle

\(t\)  
Duration for the trip in hours

\(t_{\text{max}}\)  
Maximum duration for a tour

5.3.1.1 SOLVING THE SHIPMENT ALLOCATION

For the shipment allocation is assumed that the fleet bases have access to sufficient vehicles. Therefore restraint (5.3.2) is relaxed. This makes the cluster allocation problem easier. There are two approaches given: one that takes the interdependency of orders into account, while the second solution only takes the selected shipment into account:

Cluster allocation approach (1):

- Select a shipment;
- Build a cluster (for example the 5 closest shipments);
- Determine the inter-depot costs for all shipments in the cluster for all depots;
- Determine the distance from the centroid of the cluster to all depots;
- Allocate the shipment to the depot with the lowest costs;
- Select another shipment;

The shipment allocation approach (2):

- Select a shipment;
- Determine inter-depot costs per shipment for all depots;
- Determine distance from customer to all depots;
- Allocate the shipment to depot with the lowest costs;
- Select another shipment;

5.3.2 SHIPMENT CLUSTERING

Shipments clustering is primarily concerned with geographically partitioning shipments into different clusters. The clusters are constraint by both time and physical capacity. The problem is to group the shipments into a minimum number of clusters such that each cluster can be served by a single vehicle. Clustering the shipments ensures the geographical relation among the shipments. The clustering problem is another example of a NP-hard problem (Bard & Ahmad, 2009). Like Bard & Ahmad (2009) this research concerns large-scale instances for 6000 on a single day. They have developed a clustering algorithm for delivery and pickup operations for a given set of customers in a service area. Hence, VRPMB characteristics. They and many others (Wassan, et al., 2008) (Mitra, 2008) (Ganesh & Narendran, 2007), however, do not provide a solution for the PDP. Therefore research of (Ratliff, 1981) is used to complement Bard & Ahmad (2009). The various types of shipments and the associated routing problems are explained in the introduction of this thesis report.

The clustering problem definition of this research is inspired by Bard & Ahmad (2009). The problem has a set of \( N \) shipments, each having \( c \) attributes. Each of the shipments is required to be assigned to exactly one of \( p \) clusters. The objective is to minimize the squared costs between the shipments and the centroid of the clusters to which they are assigned. The distribution problem of Bard & Ahmad (2009) is identified as the Vehicle Routing Problem with Clustered Backhauls (VRPCB) (Parragh, et al., 2008). The VRPCB requires the deliveries to be served first. Therefore they split the costs: one for deliveries and one for pickups. This line of thought is helpful for the PDP clustering as well. Clustering P&D shipments has effect when the origins are close together and the destinations are close together (Ratliff, 1981). For utilizing the backhaul, it can be benificial to cluster shipments that are mirrored, thus an origin with a destination from another P&D shipment. There are also circumstances where both the origin and destination of one shipment can be allocated to the same cluster. Ratliff (1981) proposes a method for building two clusters using both centroids: one for the origins and one for the destinations. These centroids are shown in blue in Figure 39. The surrogate distances for this cluster is an approximation \( 2(a + b + c) + 2(d + e + f) + g \). Clustering is only useful when the surrogate distance is lower than the distance of \( 1 + 2 + 3 \). An example of clustering ten P&D (black nodes), five delivery (yellow unfilled nodes) and six pickup (yellow filled nodes) shipments in eight clusters is shown in Figure 8. There are three destination clusters \( (c_1 \ldots c_3) \) that are close together. This shows the effect of the geographically location of the origins. When these shipments were delivery instead of P&D shipments, these clusters would form one cluster instead of three. The yellow clusters are allocated to a depot. In addition, the origin and destination of shipment \( s_j \) are located in one cluster. Note that P&D shipments have to be served by the same vehicle and in the right order: first the origin, than the destination.
The formulation from Bard & Ahmad (2009) used for the clustering problem. The objective function (5.4.1) minimizes the sum of the total distance from the centroid of the cluster to the shipment node. Constraint (5.4.2) ensures that a datapoint is assigned to exactly one cluster, (5.4.3) defines the capacity constraint and (5.4.4) the time constraints. (5.4.6) and (5.4.7) ensure that the decision variable is logical. There is no fuzzy area allowed, a shipment cannot be allocated partially to a depot. Furthermore, the objective function for clustering with inter-depot transportation is given in appendix E, but will not be used for this research.

\[
\begin{align*}
\text{Minimize} & \quad \sum_{i=1}^{N} \sum_{k=1}^{P} x_{ik} d_{i,k} \\
\text{subject to} & \quad \sum_{k=1}^{P} x_{ik} = 1 \quad \forall (i \in 1, \ldots, N) \\
& \quad \sum_{i=1}^{N} D_i x_{ik} \leq Q, \quad \sum_{i=1}^{N} P_i x_{ik} \leq Q \quad \forall (k \in 1, \ldots, P) \\
& \quad \sum_{k=1}^{P} x_{ik}(\tau_i) \leq TOT - STEM_k, \quad \forall (k \in 1, \ldots, P) \\
& \quad x_{ik} \in \{0,1\}, \quad \forall (i \in 1, \ldots, N^k, k \in 1, \ldots, P)
\end{align*}
\]
Indices
\[ a \in [0,1] \]

\begin{align*}
    i & : \text{Index for datapoints (origin and destination points)} \\
    k & : \text{Index for clusters} \\
\end{align*}

Parameters

\begin{align*}
    P & : \text{Total number of clusters} \\
    N & : \text{Total number of shipments requests. Can either be a pickup or delivery action.} \\
    d_{i,k} & : \text{Distance from centroid of cluster } k \text{ to shipment location} \\
    q_i & : \text{Transportation quantity of datapoint } i \\
    d_{i,t} & : \text{Inter-transportation distance for datapoint } i \\
    a & : \text{Share inter-depot distance based on capacity utilization} \\
    Q & : \text{Cluster capacity} \\
    TOT & : \text{Total time available in a day} \\
    STEM_k & : \text{Estimated time to drive to and from depot to cluster } k \\
    BREAK & : \text{Time allocated for breaks} \\
    \tau_i & : \text{Estimated drive time from } i \text{ to the next customer} \\
\end{align*}

Decision variables

\begin{align*}
    \zeta_k & : \text{Centroid of cluster } k \\
    x_{ik} & : 1 \text{ if customer } i \text{ is assigned to cluster } k; \text{ otherwise } 0 \\
\end{align*}

5.3.2.1 BUILDING THE CLUSTERS

Since the performance estimation is based on an estimation theory developed by Huijink (2016), the clustering will be done per shipment individually. This is also an estimation method, which makes optimization heuristics obsolete. The clustering approach is as follows:

- Select a shipment;
- Determine the marginal costs for all shipments that can be added to the cluster (paragraph 5.3.2.1.1);
- Building the cluster:
  - Add the cheapest shipment first if the capacity and time constraints are not violated (paragraph 5.3.2.1.2);
  - Repeat until the capacity or time constraints are utilized or no shipment is left;

5.3.2.1.1 THE MARGINAL COSTS FOR ADDING A SHIPMENT

The marginal costs for adding a shipment to a cluster is vital for the cluster building. There are two factors that determine the extra costs: the stem and inter-order costs. The stem is the linehaul costs and inter-order the costs for driving to the next shipment. There are four scenario’s distinguished for determining the detour costs for adding shipments to the querying order in Figure 41:

- Adding a P&D shipment to a delivery shipment;
• Adding a P&D shipment to a delivery shipment where the origin and destination fall in the cluster of the delivery shipment;
• Adding a P&D shipment to another P&D shipment where the origin and destinations are mirrored;
• Adding a delivery shipment to a delivery shipment;

All other scenarios are dealt with in the same way as the proposed four examples. For example, adding a delivery to a P&D is similar to adding a delivery shipment to a delivery cluster. Same holds for substituting pickup shipments with delivery shipments. The blue arrows represent the trip from the querying shipment to the new shipment within the cluster. In most cases are the initial stem costs equal to the new stem costs to prevent adding shipments along the tour (see appendix F).

<table>
<thead>
<tr>
<th>Querying shipment (old)</th>
<th>Adding a shipment (new)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagrams" /></td>
<td><img src="image2" alt="Diagrams" /></td>
</tr>
</tbody>
</table>

**Figure 41.** Marginal detour costs per shipment. Left is the querying shipment, right is the added shipment.

The marginal shipment costs are denoted by (5.5.1). Note that only a part of the inter-depot costs is allocated to the marginal costs of the selected shipment.

\[
MC = STEM_{new} - STEM_{old} + IO
\]  

(5.5.1)
Marginal costs for adding a shipment to a cluster

Stem costs for the querying shipment and the new shipment combined

Stem costs for the querying shipment only

The costs for driving between the shipments in the clusters

5.3.2.1.2 ESTIMATING UTILIZATION CONSTRAINTS

After each shipment allocation to a cluster two constraints are checked: the capacity constraint and the time constraint. It is rather easy to meet the capacity constraint. The shipments have several attributes of which volume and weight. This capacity utilization changes along the tour. There will be more free space after a delivery and thus leave extra space for another pickup. The time utilization, on the other hand, is harder to determine. There are approaches that are so called a “rules of thumb” that gives an indication of the real routing costs. The time utilization is a part of these methods. Using an indication algorithm with a linear time complexity ensures an acceptable duration for large shipment sets. Both Huijink (2016) and Bard & Ahmad (2009) use a similar algorithm to determine the time constraint. The cost estimation method developed by Huijink (2016) is designed for a Vehicle Routing Problem with Order outsourcing (VRPO). His method is proven to be accurate and therefore preferred over Bard & Ahmad (2009).

Huijink (2016) based his method on (Fleischmann, 1998) and (Goudvis, 2001) who distinguish three separate parts: the fixed ($F_i$), the stem ($STEM_i$) and the inter-order ($IO_i$) costs (5.6.1). The fixed estimates the fixed costs of a shipment. The stem estimates the line haul costs for reaching the area. The inter-order part estimates the detour costs for driving to the next stop. All three are interchangeable among the methods. Ignoring the fixed costs and replacing the cost by time gives the estimated time of a cluster (5.6.2). The estimated time is used for the time constraint. Huijink (2016) distinguishes his method from other literature by determining the insertion costs of the order and its five neighbouring orders. The other two fixed and stem costs are used from Fleischmann, (1998). The sum of the three separate parts is the estimated cost per shipment. The full schedule costs is the sum of the complete shipment set.

\[
\text{EstCosts} = \sum_{i=1}^{N} (F_i + STEM_i + IO_i) \quad (5.6.1)
\]

\[
\text{EstTime} = \sum_{i=1}^{N} (STEM_i \cdot v_i) + \sum_{i=1}^{N} (IO_i \cdot v_i) \quad (5.6.2)
\]
An example schedule in a Euclidian space is given in Figure 42. The querying shipment is represented by yellow node \(i\). The duration is determined for this specific shipment. The neighbouring shipments allocated to the cluster are indicated by \(j_1 \ldots 4\). This is the cluster for which the time and capacity constraints are checked. Depot, the location from which the vehicles depart and arrive, is indicated by \(D\). The stem is indicated by the two arrows between the vehicle base and querying order. The inter-order time, the time for driving from \(i\) to the next shipment, are only based on the shipments in the cluster. How the stem, inter order durations are calculated are explained below.

![Figure 42, VRP cost estimation example (i=querying shipment, b=vehicle base, \(S_i\) = stem costs, \(IO_i\) = insertion costs for shipments \(j\))](image)

**STEM duration – HUJINK (2016)**

The stem costs or time, as explained in the previous figure, is the sum of \(N\) stem trips multiplied by the vehicle velocity \((5.7.1)\). The line haul duration for delivery or pickup shipments is from depot to the cluster. For P&D shipments there are either three or four stem trips (Figure 43).

\[
\text{Est Stem Time} = \sum_{i=1}^{N} (STEM_i \times v_i)
\]  

(5.7.1)

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Est Stem Time</th>
<th>Estimated stem time for the cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indices</td>
<td>(i)</td>
<td>Index for datapoints (origin and destination points)</td>
</tr>
<tr>
<td>Parameters</td>
<td>(N)</td>
<td>Total number STEM trips (2 to 4)</td>
</tr>
<tr>
<td>Parameters</td>
<td>(v)</td>
<td>Vehicle velocity</td>
</tr>
<tr>
<td>Parameters</td>
<td>(STEM_i)</td>
<td>Stem distance for shipment (i)</td>
</tr>
</tbody>
</table>
Inter-Order duration – HUIJINK (2016)

The inter-order duration is the duration for driving from the querying shipment to the next shipment in the cluster. This inter-order duration is determined by the insertion costs proposed by Huijink (2016). This model assumes that the probability of visiting any location is independent and that the likelihood that the next customer visited after stopping at customer \( i \) is a decreasing function of the distance to that customer. In particular, the closer customer \( j \) is to \( i \), the higher the likelihood that \( j \) will be the next stop in the schedule. This research uses all shipments in the cluster for the inter-order duration. Figure 44 gives an example for four neighbouring shipments in a cluster. The \( k, l, i \) from the figure match 5.8.1. Note that the inter-order distances can be substituted by costs or time. When there are two shipments available in the cluster, the inter-order costs are \( d_{ki} \). The sum of all inter-order distances multiplied by the vehicle velocity in the cluster is the total time for driving between the shipments (5.8.2).

\[
IO_i = \frac{1}{\sum_{k=1}^{M} \sum_{l=1}^{M} 1 + d_{kl} + d_{il} - d_{kl}} \sum_{k=1}^{M} \sum_{l=1}^{M} \frac{d_{ki} + d_{il} - d_{kl}}{1 + d_{kl} + d_{il} - d_{kl}}
\]

\[
\text{EstIOTime} = \sum_{i=1}^{N} (IO_i \times v_i)
\]

<table>
<thead>
<tr>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>( IO )</td>
</tr>
<tr>
<td>( \text{EstIOTime} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>( i, k, l )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d )</td>
</tr>
</tbody>
</table>
$N$  Total number shipments in a cluster

$M$  Total number shipments in a cluster, excluding the querying shipment

$v$  Vehicle velocity

### 5.3.3 PERFORMANCE ESTIMATION PER SCENARIO

After the cluster is completely build, the performance estimation per shipment can be determined. Determining the costs for this shipment is done using the estimation model from Huijink, (2016). The formula used is (5.9.1). The total cost for the complete schedule is the sum of all individual shipments. The stem (5.9.2) and fixed (5.9.3) costs are divided over the shipments based on the capacity share of the shipment relatively to the total capacity of the cluster.

\[
\text{EstCosts} = \sum_{i=1}^{N} (F_i + STEM_i + IO_i)
\]  \hspace{1cm} (5.9.1)

\[
F_i = F \cdot \frac{q_i}{Q}
\]  \hspace{1cm} (5.9.2)

\[
STEM_i = STEM \cdot \frac{q_i}{Q}
\]  \hspace{1cm} (5.9.3)

**Outputs**
- **EstCosts**: Estimated costs for the shipment
- **$F_i$**: Fixed costs for shipment $i$
- **$STEM_i$**: Stem costs for shipment $i$

**Indices**
- **$i$**: Index for the shipments

**Parameters**
- $l$
- $k$
- $Q$

---

Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach
The complete approach for the performance estimation is as follows:

- Select a shipment;
- Determine the marginal costs for all shipments that can be added to the cluster;
- Building the cluster:
  - Add the cheapest shipment first if the capacity and time constraints are not violated;
  - Repeat until the capacity or time constraints are utilized or no shipment is left;
- Estimate the shipment costs:
  - Determine the share of the STEM costs using capacity utilization;
  - Determine the share of the fixed costs using capacity utilization;
  - Determine the IO costs;
- Select another shipment. Repeat until the full schedule costs are estimated;

### 5.4 CONCLUSION

*How can the matching model be designed for 2 companies?*

The matching model determines the performance index by the ratio of two scenarios: the companies individually (SC1) and the performance when cooperating (SC2), where SC1 = 100%. The matching model consists of two phases: the “Initial selection” and “Performance gain estimation”. The “Initial selection” groups the companies in NSTR groups. This ensures that only the companies that have matching potential are used for the second phase “Performance gain estimation”. The second phase consists of two steps: “Shipment Allocation” and “Performance”.

The shipment allocation is described as a variation on the transportation problem. The allocation process is concerned with allocating the shipments to the depots as efficient as possible. All depots have infinite capacity: there are no limitations on the fleet size. Also the customers cannot be served by different fleets. The delivery and pickup shipments are served via a hub-and-spoke network, when the shipments are allocated to a different depot than their initial depot. Thus the costs for the delivery and pickup shipments include inter-depot costs plus the distance between depot and the customer. The P&Dshipments do not introduce inter-depot transportation as both the pickup and delivery locations are not at depot. The costs for a P&Dshipment is only the distance from both customers to depot. The total allocation costs for all shipments are minimized. In order to do so there are two solving methods proposed:

- Cluster allocation:
  - Select a shipment;
  - Build a cluster (for example the 5 closest shipments);
  - Determine the inter-depot costs for all shipments in the cluster for all depots;
  - Determine the distance from the centroid of the cluster to all depots;
  - Allocate the shipment to the depot with the lowest costs;
  - Select another shipment. Repeat until all shipments are allocated;
- Shipment allocation;
The performance gain estimation is based on the estimation model proposed by Huijink, (2016). This model is combined with the cluster techniques developed by Ratliff, (1981). The final model estimates the costs per shipment individually. The following steps should be taken for the performance gain estimation:

- Performance gain estimation:
  - Select a shipment;
  - Determine the marginal costs for all shipments that can be added to the cluster;
  - Building the cluster:
    - Add the cheapest shipment first if the capacity and time constraints are not violated;
    - Repeat until the capacity or time constraints are utilized or no shipment is left;
  - Estimate the shipment costs:
    - Determine the share of the STEM costs using capacity utilization;
    - Determine the share of the fixed costs using capacity utilization;
    - Determine the IO costs;
  - Select another shipment. Repeat until the full schedule costs are estimated;


The goal of this chapter is to present an overview of the essential decisions during the implementation of matching model in Matlab. The implementation of the algorithms for solving the matching model is not explained as solving the problem is already elaborated in the previous chapter.

### 6.1 THE ROAD NETWORK

The geographical locations determine the distance and duration for driving between the shipments. Using a predefined road network with geographical locations enables the possibility to use a matrix for all distances and durations. This research uses Euclidean distances, but such matrix could also be substituted for real time and distances. In addition, another key function of a road network is that shipments location data can be translated to the road network.

#### 6.1.1 LEVEL OF DETAIL ROAD NETWORK

The shipment location data is geocoded to the road network nodes while importing the shipment data. This location data provides ZIP codes, municipality or city description and coordinates. There are software companies that provide full detailed road networks like TomTom, Google Maps and OpenStreetMaps. TomTom is costly and requires licences, Google Maps limits the number of requests and OpenStreetMaps only allows no limitations for private servers. Furthermore, CBS does not allow an internet connection for Matlab. In addition to the associated costs of such road networks, the implementation is not straight forward and therefore is chosen to build a Euclidean network of predefined nodes. The nodes are the centres of predefined areas. These centres are based on NUTS3\(^1\) areas for Europe and PC3 (ZIP) codes for The Netherlands. There are three relational NUTS areas from NUTS1 to the deepest level NUTS3. According to EUROSTAT the different areas are defined as:

- **NUTS1**: major socio-economic regions;
- **NUTS2**: basic regions for the application of regional policies;

---

\(^1\) Nomenclature of territorial units for statistics
• NUTS3: small regions for specific diagnoses;

All NUTS properties for Europe are publically available at EUROSTAT (EUROSTAT, 2016). These properties, among others, are code description, hierarchical relations and coordinates. Figure 46 shows the level of detail for the different NUTS levels and ZIP levels. In contrast to the foreign countries, the level of detail chosen for the Netherlands is PC3. The level of detail for PC3 (800) is higher than NUTS3 (40). This is necessary as the major share of road transport activities are located within the Netherlands. Higher detail decreases the chance of undesired shipment bundling after geocoding. Shipments geocoded to the same node implies no inter-order costs.

Figure 46, Detail road network locations. Above: NUTS1, NUTS2, NUTS3. Below: PC2, PC3

6.2 SHIPMENT GEOCODING

Geocoding, or forward geocoding, is a process of converting address or geographical data to usable geographic coordinates. Common practice for geocoding is converting a postal address or city names to coordinates. This is not as straight forward as it might suggest since the given names are quite ambiguous. City names can be spelled differently (“Den Haag” or “’s Gravenhage”), abbreviation (Street, Str.) may be used or simply be misspelled. Therefore algorithms are needed that allow faulty characters with a certain margin (Bharambe, et al., 2012). Preferably checked in combination with other data, such as street name, zip or coordinates to ensure geocoding quality. For this research the origin-destination (OD) pairs of each shipment and depot of a given dataset are located to the closest node in the road network. The CBS commodity flow database provides three matching opportunities for geocoding:

• Coordinates;
• ZIP / postcodes + Country;
• City names + Country;

The data analysis has proven that the use of coordinates and ZIP codes are sufficient and therefore only these are used for geocoding. Both require a different approach and are explained below.

6.2.1 GEOCODING COORDINATES
Geocoding coordinates is done by using the k-Nearest-Neighbour algorithm (k-NN) provided by Matlab. Where k is the number of closest neighbours to the evaluated object. This searching approach finds the nearest (K=1) nodes (neighbours) for the shipment coordinates (object). Figure 47 shows an example where shipment $S_a$ is connected to a node in the road network (black nodes). Thus $S_a$ has to be geocoded to $l$. Note that the coordinates of $S_a$ are not included in the road network.

![Figure 47, Geocoding the yellow location $S_a$ to the closest road network node $l$](image)

### 6.2.2 Geocoding ZIP Codes

Geocoding ZIP codes is done by mapping the ZIP codes to the ZIP codes of the road network. Thus a pickup location of a shipment with ZIP “241” is mapped to the road network node that has the same ZIP “241”. Same is done for shipments with location outside the Netherlands, only an extra mapping is done from ZIP to NUTS3.

### 6.3 Approximation Real Distances

The implemented road network in Matlab uses the Euclidean distances. Since the earth is a sphere, this distances are calculated using geometric formulas. These formulas are widely available (Wikipedia, sd). The calculated Euclidean distances deviate from reality since vehicles drive on roads that are all but straight over the whole trip. Therefore, a correction factor of 1.3 is used to approximate real distances. This factor is found by determining the ratio between real distances from the planning tool Ritplan (EVO-it, 2016), see appendix G.

### 6.4 Vehicle Velocity

The vehicle velocity is dependent on the distance travelled. A trip of 1 km has a lower average speed than a trip of 80 km. The proposed vehicle velocity calculations by Bard & Ahmad, (2009) are used:

<table>
<thead>
<tr>
<th>Miles</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>$MPH = \min(18.285 + 0.45159 \times \text{Miles},50)$</td>
</tr>
<tr>
<td>&gt;=20</td>
<td>$MPH = \min(5.447 \times \log_e(\text{Miles}) + 11.11,50)$</td>
</tr>
</tbody>
</table>

### 6.5 Vehicle Costs

The costs for a vehicle consists of duration, distance and fixed costs. Each of these factors are dependent on other factors, like purchase price, vehicle size, days in use, tyres and fuel. EVO-it has developed a software tool Kostprijscalculatie (EVO-it, 2016) that produces the costs for every vehicle type available. These costs are based on costs that EVO publishes yearly. The standard settings in Kostprijscalculatie for a 28 Tonnes semi-trailer truck are used for this research. The output is shown in appendix G. The output of the tariffs is per hour, per km or day individually. Thus when €56.45 per hour is charged, no additional costs for distance or fixed costs are needed. This research applies all
three factors. In a real road-network there are differences between time and distances that are used to calculate the cheapest trips. Determining the cheapest trips is done by shortest path algorithms like Dijkstra’s algorithm (Jonker & Volgenant, 1988). These algorithms find the shortest path for a specific trip. If these algorithms are focussed on time, most trips will prefer highways. When these are focussed on distance, the distance is minimized which will result in short cuts and increase the use of less important roads than highways. This research, however, uses Euclidean distances. Therefore, there are no roads that are categorized by a specific speed and no shortest path calculations are needed. Therefore, is chosen to allocate equal share of costs to distance and duration. The final factor, fixed costs, are also chosen to have an equal share in costs. These costs cannot be too low, as the use of an extra vehicle will not be significant. When, for example, the fixed costs are equal to the costs per hour, then the turning point for using an extra vehicle is only one hour. This will result to using many vehicles and decreases period utilization. All costs are shown below:

- €56.45 / 3 = €19 per hour;
- €1.69 / 3 = €0.56 per km;
- €541.95 / 3 = €181 per day;

The inter-depot transportation costs are determined by the shipment allocation phase of the model. This inter-depot costs assume that these vehicles are filled to its potential, both the linehaul as well as the backhaul. Therefore, only a small part of the inter-depot costs per shipment are allocated to a shipment. More explanation is given in the model design of this thesis.

6.6 MATLAB CODE

This paragraph briefly describes the implementation in Matlab. This implementation consists of the following important steps:

- Initialization: location data;
- Import the company, depot and shipment data;
- Allocate the shipments to the depots;
- Determine the costs for the alliance;

The implementation for the matching algorithm first loads the location data. These data are the ZIPs with the associated coordinates. From this location data a Kd-tree is generated that is used for geocoding. In addition, a complete distance matrix is generated between all locations. Thus $N^2$ distances. This only has to be generated once, as the road network will not change. This matrix can also be substituted by real distances and times. The Matlab code:

```matlab
oDataModule.LoadData;
oDataModule.LocationList.LoadLocations;
oDataModule.LocationList.GenerateKdTree;
```

The datasets should be imported via the datamodule object. This datamodule contains all available data in cell arrays. The datamodule loads the company data, depot data and shipment data with the following statements:

```matlab
handles.oDatamodule.LoadCompanyData('CompanyData.mat');
handles.oDatamodule.LoadDepotData('DepotData.mat', 'Depot');
handles.oDatamodule.LoadZendingdata(ZendingData.mat', 'Zending');
```

Now all the data is available, the matching process can begin. First the shipments are allocated to the depots to determine from what depot the shipments will be served. This is done by the function “AllocateDemand” from the object “CompanyList”. The first input parameter of this function are the companies that should be merged: “CompanyIDs”. The parameter should be provided in the form of
an array. Hence, if companies 3 and 5 are requested, then the input is “[3,5]”. From “MaxVolumeM3” to “CostFixed” are input parameters for the vehicles used. “Alpha” determines the weight for the inter-depot distance and time. “Beta” determines the weight of the fixed inter-depot costs. Note that there are no inter-depot costs charged for P&D shipments. Furthermore, the shipment allocation algorithm is used, thus not the cluster allocation algorithm. The shipment allocation algorithm is faster in terms of calculation power and easier to implement. The Matlab code is as follows:

```matlab
[Alliance, InterDepot_Fixed, InterDepot_Distance, InterDepot_Duration] = handles.oDatamodule.CompanyList.AllocateDemand(CompanyIDs, MaxVolumeM3, MaxWeightKg, MaxDuration, CostPerKm, CostPerHour, CostFixed, Alpha, Beta);
```

The final step is determining the costs for this collaboration:

```matlab
[TotalCosts , FixedCosts , STEMCosts , IOC costs , CompanyCosts ] = Alliance.DetermineCostCompleteShipmentListViaDepots(MaxVolume, MaxWeight, MaxDuration, CostKm, CostH, CostFixed);
```

### 6.7 CONCLUSION

This chapter has explained all decisions made that relate to the road network. This road network is built using the centroids of the PC3 areas in the Netherlands and NUTS3 for the foreign areas. The shipment locations are geocoded to the road network using a k-NN algorithm or the available ZIPs. The distances between coordinates are calculated using geometric formulas (Wikipedia, sd) as the world is a sphere. In addition, these distances are corrected to approximate reality with a factor 1.3. The speed for driving between two locations is depend on the distance travelled and is based on Bard & Ahmad, (2009). Finally the vehicle costs are determined using the software tool Kostprijscalculatie (EVO-it, 2016). That result in:

- €19 per hour;
- €0.56 per km;
- €181 per day;

In addition to the road network, a brief explanation is given on the highest level functions build in Matlab. These functions perform the initialization, data import, shipment allocation and shipment cost determination.
7 VALIDATION OF THE MATCHING MODEL

The last step for developing the matching model is the validation step (Figure 48). This process determines how well the matching model reflects reality. This chapter analyses the face validity and the comparison to other models. These two validation techniques eventually lead to accepting or rejecting the model. The paper by Sargent, (2013) about simulation model validation is used for the validation.

This chapter is organized as follows: first model validation is introduced and elaborated what techniques are used. This paragraph also explains the tests that are performed and that these are validated using techniques for face validity and comparison to other models. Next, all tests are sequentially explained, performed and analysed. Finally, an overview of the results is given in the conclusion of this chapter.

7.1 MODEL VALIDATION

Simulation model validation is the last part of the model development. Validation is the process of determining that the model on which the simulation is based, is an acceptably accurate representation of reality (Giannanasi, et al., 2001). Even though the term validation is criticized: “Failing a test helps to reject a wrong hypothesis, but passing is no guarantee that the model is valid” (Sushil, 1993), there is need to accept a model before it can be reliably used. Sargent, (2013) describes seventeen validation techniques that are commonly used for model validation. Not all techniques can be applied to this research. Techniques like “Historical data validation” are not applicable as there is no real historical data available for this research. The two selected techniques are face validity and a comparison to other models. The face validity is chosen to determine whether the model behaves as expected. Similar shipments in close proximity to depot should be less expensive than the shipments farther away or increasing the weight per shipment may not decrease costs. Ensuring that the model behaves reasonable is not sufficient. There is need to know wheter the output reflects reality as well. Thus whether the clusters build can be realiably served by one vehicle and that the output costs are correspond with reality. To ensure this, the comparison to other models is chosen. These tests analyse the differences in output costs between the validated model Ritplan and matching model. How the two techniques are applied is sequentially elaborated in the following two sub paragraphs. Thereafter is explained what scenarios are performed and why these are chosen.
The two validation techniques:

- "Face validity: Individuals knowledgeable about the system are asked whether the model and/or its behavior are reasonable" (Sargent, 2013);
- "Comparison to other models: Various results (e.g., outputs) of the simulation model are compared to results of other valid models." (Sargent, 2013);

7.1.1 FACE VALIDITY

The face validity, which determines whether the model behavior is reasonable, consists of three steps: formulating the expected behavior (1), running the tests (2) and finally compare the test results to the expected behavior (3). The face validity is performed by means of optical verification or sensitivity analyses. The optical verification determines whether the model is able to find obvious matches or whether the clusters build is logical. Logical clusters are clusters where the shipments are geographically close together. For the sensitivity analysis, only one parameter that influences the schedule costs is chosen for each test. Examples of parameters are the proximity of the service area, the weight per shipment or the number of shipments. For each parameter is a parameter-sweep performed and the results are plotted and analyzed. The results are split in fixed, stem and inter-order costs that are explained in the model development phase of this thesis. In addition, also the average shipment costs and total costs are analyzed. All graphs are presented in the appendix.

7.1.2 COMPARISION TO OTHER MODELS

The comparison to other models is only done for the sensitivity analysis tests. These tests are performed to determine whether the results of the matching model are similar to the validated models. The other model used is the planning tool Ritplan (EVO-it, 2016). Ritplan is a professional planning tool that is part of the daily logistic processes of many companies in the Benelux. This tool can solve more planning problems than this research deals with. Ritplan constructs real tours and calculates the associated costs. Hence, Ritplan does not make use of an estimation approach but solves a complete VRP. The aim for the estimation part of the matching model is to approach the Ritplan schedule costs while requiring less processing power. An example comparison between Ritplan and the matching model is given in Figure 49. This figure shows that the matching model overshoots 2% for the presented shipments.

![Example shipment set that shows the results for the matching model (left) and Ritplan (right). Ratio 576/564 = 1.02. The matching model overshoots 2%.

Figure 49, Example shipment set that shows the results for the matching model (left) and Ritplan (right). Ratio 576/564 = 1.02. The matching model overshoots 2%.}
The comparison procedure per test is as follows:

- Generate a shipment set;
- Use the shipment set as input for the matching model and determine the costs;
- Use the shipment set as input for Ritplan and determine the costs;
- Determine the ratio between Ritplan and the matching model, where Ritplan is 100%;
- Analyse the deviation of the matching model;

Note that all output costs of Ritplan are 100%. Therefore, there is no use for a t-test, Z-test or \( \chi^2 \)-test. These tests determine whether there is a significant difference between two or more groups. The matching model can only be accepted when there is no significant difference between the Ritplan and matching model outcomes. Unfortunately, since all Ritplan outcomes are 100%, these tests will result in a significant difference under all circumstances; the standard deviation of Ritplan is 0 for all tests. One way to deal with this issue is plotting a histogram with a normal distribution. This normal distribution determines the standard deviation of the Matching model/Ritplan ratio. Even though the distributions shown are not completely normal, they do approximate a normal distribution. This normal distribution gives a clear indication of the deviation and average of the Matching-model Ritplan ratio.

Furthermore, there are several important differences between Ritplan and the matching model: the level of detail for geocoding, the distance for driving between the shipments and the duration for driving between the shipments. These differences are shown in Table 18. These differences have an impact on the results that cannot be fully controlled. The consequence of these differences is that the results only reflect a “rules of thumb”. Hence, this validation can only be used as an indication. The last instance of the table is the algorithm. The difference in algorithms is the result this validation tests. This difference should fall within an acceptable margin. Acceptable is when the results approach a ratio of 1 (0.90 ≤ \( \mu \) ≤ 1.10) and the confidence level falls within -15% and 15% of the distributions mean is 80% (\( \sigma \leq 0.117 \)). This confidence level is sufficient to conclude that the matching model, by indication, is able to reflect reality.

<table>
<thead>
<tr>
<th>Instance</th>
<th>Matching model</th>
<th>Ritplan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detail road network</td>
<td>PC3 &amp; NUTS3</td>
<td>Complete Zip + house number</td>
</tr>
<tr>
<td>Distance roads</td>
<td>Euclidean * 1.3</td>
<td>Real road network</td>
</tr>
<tr>
<td>Duration roads</td>
<td>Distance determines speed (Bard &amp; Ahmad, 2009)</td>
<td>Real speed per road segment</td>
</tr>
<tr>
<td>Algorithm</td>
<td>High-speed estimation</td>
<td>Complete VRP</td>
</tr>
</tbody>
</table>

An example of the road network differences is given in Figure 50. This figure illustrates two differences: the Euclidean distances compared to real distances and the detail of the road network. The first, the distances, also come with differences in duration. The distances are corrected by multiplying the Euclidean distance by 1.3, but that correction is an approximation and will never be the exact same as driving on real roads. In addition, a deviation in distance also results in a deviation in duration. Hence, the duration and distance costs for driving between the same locations differs between Ritplan and the matching model. Furthermore, Ritplan determines real vehicle speed per segments of a road, but the matching model uses a rough approximation of Bard & Ahmad, (2009). The second observation, the level of detail, shows two locations for the matching model while Ritplan shows three. This is caused by the PC3 level of the matching model: the two shipments in Apeldoorn are geocoded to the same location in the road network. Ritplan has a higher level of detail and therefore is able to
geocode all three shipments to the exact locations. These differences again result in a deviation in distance and duration between Ritplan and the Matching model.

The Matching model in Matlab. The blue lines are the Euclidean distances for three shipments. There are two shipments geocoded to the same road network node. The same shipments planned in Ritplan. In contrast to the matching model, the two shipments in Apeldoorn are geocoded to different nodes.

Figure 50, Differences between Euclidean and real distances and a difference in the level of detail for the same three shipments.

### 7.1.3 Tests Performed

All performed tests are shown in Table 19. It is only useful to perform additional tests when clusters are accepted to be reasonable. Therefore, is chosen to perform a face validity test on clusters first. Clusters are not reasonable when shipments that are geographically far away from each other are clustered, while there are shipments in close proximity available. Thereafter all shipment types (delivery, pickup and P&D delivery) and the shipment capacity and backhaul are tested. These tests are performed with a face validity and comparison to Ritplan by means of parameter-sweeps. The last test is the matching test. This test determines whether the model finds the right collaboration partner. All tests use generated data to ensure that the data can be fully controlled during the validation process.

<table>
<thead>
<tr>
<th>Test</th>
<th>Technique</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clustering</td>
<td>Face validity</td>
<td>Geographically reasonable clusters</td>
</tr>
<tr>
<td>Delivery shipments</td>
<td>Face validity,</td>
<td>Shipment density and distance service area for delivery shipments</td>
</tr>
<tr>
<td></td>
<td>Comparison to Ritplan</td>
<td></td>
</tr>
<tr>
<td>Pickup shipments</td>
<td>Face validity,</td>
<td>Shipment density and distance service area for pickup shipments</td>
</tr>
<tr>
<td></td>
<td>Comparison to Ritplan</td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td>Face validity,</td>
<td>Capacity constraints</td>
</tr>
<tr>
<td></td>
<td>Comparison to Ritplan</td>
<td></td>
</tr>
<tr>
<td>Backhaul</td>
<td>Face validity,</td>
<td>Bundling delivery and pickup shipments</td>
</tr>
<tr>
<td></td>
<td>Comparison to Ritplan</td>
<td></td>
</tr>
<tr>
<td>P&amp;D</td>
<td>Face validity,</td>
<td>Shipment density and distance service area for P&amp;D shipments</td>
</tr>
<tr>
<td></td>
<td>Comparison to Ritplan</td>
<td></td>
</tr>
<tr>
<td>Matching</td>
<td>Face validity</td>
<td>Reasonable company matching</td>
</tr>
</tbody>
</table>
7.2 CLUSTERING

The goal of the clustering tests is to determine whether the shipments allocated to a cluster is geographically reasonable. These clusters fall in two categories: the shipments for delivery and pickup shipments (1) and the P&D shipments (2). Delivery and pickup shipments can be easily clustered as either the origin or destination is at depot. This, however, is not the case for P&D shipments and therefore are harder to cluster and to validate. Therefore, there is chosen to perform several tests with delivery and pickup shipments prior to the P&D shipment tests. For the delivery and pickup tests are 300 shipments generated in a service area with a radius of max. 60 km from depot. The depot is located in Doorn. All shipments utilize 10% of the vehicle capacity, thus one cluster consists of maximum 10 shipments. The tests for P&D shipments are performed by importing CBS data from a random company that delivers NSTR0 or NSTR7 goods. The tests are performed by first plotting all shipments and depots. Then a shipment from the schedule is selected and the cluster for this selected shipment is build. Finally, the highlighted cluster is optically validated.

7.2.1 FACE VALIDITY (ACCEPTED)

The delivery or pickup shipments

- Expectation: since either the origin or destination is at depot and the capacity utilization is equal, it is expected that maximum ten closest shipments are allocated to the selected shipment. It is not beneficial when shipments located in Almere are clustered with shipments in Maastricht, assuming that there are sufficient shipments in Almere. Therefore, two hypotheses tests are formulated:
  - Test 1:
    - \( H_0 \): more than 10 shipments are clustered;
    - \( H_1 \): maximum 10 closest shipments are clustered;
  - Test 2:
    - \( H_0 \): not only the closest shipments are clustered;
    - \( H_1 \): only the closest shipments are clustered;

- Outcome:
  - Test 1:
    - Each of the 300 clusters consists of exactly 1 cluster. \( H_0 \) rejected, \( H_1 \) accepted;
  - Test 2:
    - Each cluster contains the closest shipments to the selected shipment. An example of a cluster for one shipment is given in the left image of Figure 51. \( H_0 \) rejected, \( H_1 \) accepted;

The P&D shipments

- Expectation: the clusters should be built at the origin and destination of the selected shipment. Only the P&D shipments that involve the smallest detour should be allocated to the cluster.
  - Test:
    - \( H_0 \): shipments that involve larger detours than other shipments are clustered;
    - \( H_1 \): only shipments that involve the shortest detours are clustered;

- Outcome: only the shipments that involve the shortest detour costs are allocated to the clusters. An example is given in the right image of Figure 51. The selected shipment, identified by the black circles, is clustered with one other P&D shipment. This cluster contains only two shipments due to the time constraints. Also, other shipments north of Liege are not clustered because their deliveries are in Groningen and Friesland while the selected shipment has its delivery in Utrecht. This shows the effect of the different origins and destinations of P&D shipments.
• Test:
  - Only the shipments that involve the shortest detour costs are clustered.
  
  $H_0$ rejected, $H_1$ accepted;

![Figure 51, Cluster examples. The left image consists of delivery shipments and the right image consists of P&D shipments. Red square: depot, Green diamonds: clustered shipments, Blue diamonds: remaining shipments, Black circle: selected shipment, Blue lines: P&D commodity flow.](image)

Recommendation: weighted clustering:

Even though the face validity is accepted, there is a feature that could be incorporated that takes the difference in distance between depot $\rightarrow$ origin and depot $\rightarrow$ destination into account. This is called weighted clustering. An example is given in appendix Q. It can be more beneficial to accept larger detours for the customer that is located farther away. Especially, when the shipment density decreases with an increase of the STEM distance. For example, when the depot and origin of the selected shipment are located in the Utrecht and the destination is in Leipzig, longer detours may be accepted for the cluster in Leipzig. Without weighted clustering, a vehicle tends to serve more shipments close to depot in Utrecht and cluster less shipments in Leipzig.

7.3 DELIVERY SHIPMENTS TEST

For the delivery shipment test are then schedules randomly generated from one to maximum ten delivery shipments in a circle with a radius of 35 km. This is repeated then times where the centroid of the circle is placed 14 km farther away from depot. There are no capacity constraints in this test. The test design is given in Figure 52. The test analyses the behaviour of the stem, shipment density and the costs of the schedules for the delivery shipments.
7.3.1 FACE VALIDITY (ACCEPTED)

The fixed costs (Accepted)

- **Expectation:** All schedules can be served by one vehicle, even the ten shipments that are located farthest away from depot. Driving time or distance has no influence on the fixed costs. Therefore, it is expected that the fixed costs for all schedules are €181.
  - **H₀:** Fixed costs ≠ €181;
  - **H₁:** Fixed costs = €181;
- **Outcome:** (Appendix I 1)
  - The model output for all 100 schedules this fixed costs are €181.
    - **H₀ rejected, H₁ accepted;**

The STEM costs (Accepted)

- **Expectation:** The STEM costs are the costs for reaching the service area. Therefore, these costs should increase when the service area is located farther away from depot, but the number of shipments around that centroid has no influence.
  - **H₀:** the STEM costs do not increase when the shipments are farther away from depot, but the number of shipments has effect;
  - **H₁:** the STEM costs increase when the shipments are farther away from depot, but the number of shipments has no effect;
- **Outcome:** (Appendix I 2)
  - The costs increase when the distance between the centroid and depot increases (from €40 to €200) and the number of shipments has no effect.
    - **H₀ rejected, H₁ accepted;**

Inter-order costs (Accepted)

- **Expectation:** The distance between the centroid of the schedule and depot has no impact on the inter-order costs. The number of shipments do, since combining more shipments results in higher detour distance for driving between the shipments.
  - **H₀:** the IO costs change with the distance between depot and the shipment, but the IO costs remain unchanged with the number of shipments;
  - **H₁:** the IO costs do not change with the distance between depot and the shipment, but the IO costs increase with the number of shipments;
- **Outcome:** (Appendix I 3)
  - The inter-order costs do not change when the distance between the centroid and depot increases, but the inter-order costs do increase with the number of shipments (from €0 to €380).
    - **H₀ rejected, H₁ accepted;**

Total costs (Accepted)

- **Expectation:** The total costs should be the highest for the shipments that are the farthest away from depot and with the most shipments. This schedule should result in the highest STEM costs and highest IO costs. The lowest costs should be observed closest to depot with only one shipment. In that case the STEM costs are minimal and the IO costs are 0.
  - **H₀:** total costs do not increase with the number of shipments and the distance between depot and the service area;
  - **H₁:** total costs increase with the number of shipments and the distance between depot and the service area;
• Outcome: (Appendix I 4)
  o The highest costs are observed for the maximum number of shipments that are located farthest away from depot (€750). The costs decline with lowering the number of shipments and decreasing the distance between depot and the service area (from €750 to €250).
    \( H_0 \) rejected, \( H_1 \) accepted;

Average costs per shipment (Accepted)

• Expectation: In contrast to the total costs, the average costs per shipment should decrease with the number of shipments as the STEM and fixed costs are divided over the number of shipments. The inter-order costs increase with an increase in shipments, but this will not outweigh the benefit realized for the decrease in STEM and fixed costs. In addition, the closer the service area to depot, the lower the average costs per shipment as the STEM costs decrease and the IO and fixed costs remain unchanged.
  o \( H_0 \): the average costs do not decrease with an increase in shipments and the average costs do not increase with an increase in distance between depot and the service area;
  o \( H_1 \): the average costs decrease with an increase in shipments and the average costs increase with an increase in distance between depot and the service area;

• Outcome: (Appendix I 5)
  o The lowest average costs are observed for the schedule with the maximum number of shipments and the closest service area (€70). The costs increase when either the distance between the service area and depot increases or the number of shipments decreases (from €70 to €380).
    \( H_0 \) rejected, \( H_1 \) accepted;

7.3.2 COMPARISON TO OTHER MODELS (ACCEPTED)

• Hypotheses:
  o \( H_0 \): 0.90 > \( \mu \) > 1.10 and \( \sigma \) > 0.117
  o \( H_1 \): 0.90 \leq \( \mu \) \leq 1.10 and \( \sigma \) \leq 0.117

• Outcome: (Figure 53):
  o The mean falls well within the limits: \( \mu = 1.01 \). The observed \( \sigma = 0.087 \) implies that 80% of all samples drawn from this distribution fall within the range from -11% to 11%.
    \( H_0 \) rejected, \( H_1 \) accepted;
7.4 PICKUP SHIPMENTS TEST

The pickup shipment test is designed similarly to the delivery shipment test (Figure 52). The only two differences are that this test concerns pickup shipments instead of delivery shipments (1) and that the shipments are randomly generated for this test again (2). The goal for this test is to determine whether the fixed, STEM, IO, total and average costs behave as expected.

7.4.1 FACE VALIDITY (ACCEPTED)

Since the tests for the pickup shipment test is performed in the same way as the delivery shipment test, there is no need to further address the hypotheses and argumentations for the face validity. For example, the fixed costs for the delivery shipments is equal to the fixed costs of the pickup shipments. Only small differences may occur since the pickup shipments are randomly generated. The test results are presented in appendix J. These results are similar to the delivery shipment test.

- The fixed costs (H₀ rejected, H₁ accepted) (Appendix J, 1)
  - H₀: Fixed costs ≠ €181;
  - H₁: Fixed costs = €181;
  - The fixed costs are €181 for each schedule; every schedule can be served by one vehicle.
  - H₀ rejected, H₁ accepted;

- The Stem costs (H₀ rejected, H₁ accepted) (Appendix J, 2)
  - H₀: the STEM costs do not increase when the shipments are farther away from depot, but the number of shipments has effect;
  - H₁: the STEM costs increase when the shipments are farther away from depot, but the number of shipments has no effect;
  - The STEM costs increase from €40 to €200 when the service area is farther away from depot. The number of shipments has no effect.
  - H₀ rejected, H₁ accepted;

- Inter-order costs (H₀ rejected, H₁ accepted) (Appendix J, 3)
  - H₀: the IO costs change with the distance between depot and the shipment, but the IO costs remain unchanged with the number of shipments;
- $H_0$: the IO costs do not change with the distance between depot and the shipment, but the IO costs increase with the number of shipments;
- The IO costs only increase with the number of shipments, from €0 to €350.  
  $H_0$ rejected, $H_1$ accepted;

- **Total costs ($H_0$ rejected, $H_1$ accepted) (Appendix J, 4)**
  - $H_0$: total costs do not increase with the number of shipments and the distance between depot and the service area;
  - $H_1$: total costs increase with the number of shipments and the distance between depot and the service area;
  - The total costs are the highest for the largest distance and highest number of shipments (€720). These costs decline to €250 for one shipment, closest to depot.  
    $H_0$ rejected, $H_1$ accepted;

- **Average costs ($H_0$ rejected, $H_1$ accepted) (Appendix J, 5)**
  - $H_0$: the average costs do not decrease with an increase in shipments and the average costs do not increase with an increase in distance between depot and the service area;
  - $H_1$: the average costs decrease with an increase in shipments and the average costs increase with an increase in distance between depot and the service area;
  - The average shipment costs are the highest for 1 shipment farthest away from depot (€370) and decreases to €70 for the 10 shipments closest to depot.  
    $H_0$ rejected, $H_1$ accepted;

### 7.4.2 COMPARISON TO OTHER MODELS (ACCEPTED)

The pickup shipment test results for the comparison to Ritplan are shown in Figure 54.

- **Hypotheses:**
  - $H_0$: $0.90 > \mu > 1.10$ and $\sigma > 0.128$
  - $H_1$: $0.90 \leq \mu \leq 1.10$ and $\sigma \leq 0.128$

- **Outcome (Figure 56):**
  - The cost index is a little over 1 on average ($\mu = 1.02$). The observed deviation is $\sigma = 0.059$. The 80% confidence level is the area from -7.5% to 7.5%.  
    $H_0$ rejected, $H_1$ accepted; (OK)
7.5 CAPACITY SHIPMENTS TEST

For the capacity test is a circular service area chosen which is located east from depot. In this service area are 1 to 10 shipments generated. For each shipment quantity are 10 schedules generated with a capacity utilization of 10% to 100% per shipment. The capacity intervals are 10%. All schedules together add up to 100 schedules, 10 (number of shipments) * 10 (capacity utilization per shipment). The test design is shown in Figure 55. The capacity shipment test focuses on how the matching model solves the capacity constraints.

7.5.1 FACE VALIDITY (ACCEPTED)

The fixed costs (Accepted)

- Expectation: Not all schedules can be served by one vehicle due to the capacity constraints. Therefore, the fixed costs increase with the number of shipments if the capacity increases. A capacity utilization per shipment over 50% cannot be bundled, therefore the increase should stop at >50% capacity utilization per shipment.
  - $H_0$: the fixed costs do not increase when the number of shipments increases if the capacity utilization per shipment increases;
  - $H_1$: the fixed costs increase when the number of shipment increases if the capacity utilization per shipment increases;
- Outcome: Appendix K 1
  - The fixed costs increase when both the capacity utilization per shipment increases and the number of shipments increase from €181 to €1810. No increase is observed for the shipments that utilize more than 50% of the vehicle capacity.
    $H_0$ rejected, $H_1$ accepted;

The Stem costs (Accepted)

- Expectation: The STEM costs should increase when the capacity utilization per shipment increases as the service area has to be served by more vehicles.
  - $H_0$: the STEM costs do not increase when the number of shipments increases if the capacity utilization per shipment increases;
  - $H_1$: the STEM costs increase when the number of shipment increases if the capacity utilization per shipment increases;
- Outcome: Appendix K 2
  - The STEM costs increase with the capacity utilization and the number of shipments from €100 to €780. The STEM costs do not increase for the shipments that utilize only 10% as these can all be served by one vehicle.
    $H_0$ rejected, $H_1$ accepted;

Inter-order costs (Accepted)
• Expectation: The inter-order costs should be €0 for the capacity utilization per shipment >50% as these are served individually. For the others, the IO costs should increase with the shipment count and decrease with the increase of capacity utilization per shipment. Put differently: the IO costs increase with the number of shipments that can be served by one vehicle.
  o $H_0$: the IO costs do not increase with an increase of the number of shipments and do not decrease when the capacity utilization per shipment increases;
  o $H_1$: the IO costs increase with an increase of the number of shipments, but decrease when the capacity utilization per shipment increases;
• Outcome: Appendix K 3
  o The inter-order costs are €0 for the shipments that utilize over 50% of the vehicle’s capacity. The IO costs decrease from €170 for 10 shipments and 10% capacity utilization per shipment to €50 for 2 shipments and €50 utilization.

Total costs (Accepted)
• Expectation: The fixed costs should dominate the total costs as many tours are planned due to the capacity utilization per shipment. These costs account for the largest share (70%). In addition, since the STEM costs increase with the number of vehicles as well, these costs increase similarly to the fixed costs. This leaves only the IO costs, which are insignificant in the total costs. Therefore, the total costs will behave similarly to the fixed and STEM costs.
  o $H_0$: the total costs do not increase with an increase of the number of shipments and do not decrease when the capacity utilization per shipment increases;
  o $H_1$: the total costs increase with an increase of the number of shipments, but decrease when the capacity utilization per shipment increases;
• Outcome: Appendix K 4
  o The fixed costs dominate the total costs. This implies that the highest costs (€2500) are observed for the highest number of shipments with a capacity utilization of more than 50% per shipment. These costs decrease to €300 for 1 shipment and an arbitrary capacity utilization per shipment.

Average costs (Accepted)
• Expectation: The average costs per shipment should be more or less the same for the capacity utilization per shipment above 50%. The costs decline when the capacity utilization per shipment declines and the number of shipments increases as this allows bundling shipments in one vehicle.
  o $H_0$: the total costs do not increase with an increase of the number of shipments and do not decrease when the capacity utilization per shipment increases;
  o $H_1$: the total costs increase with an increase of the number of shipments, but decrease when the capacity utilization per shipment increases;
• Outcome: Appendix K 5
  o The shipments that utilize over 50% of a vehicle result in similar costs. When the number of shipments increase and the utilization per shipment decreases below 50%, the average shipment costs decline.

7.5.2 COMPARISON TO OTHER MODELS (ACCEPTED)
The differences between the matching model and Ritplan are quite significant (Appendix K 5). The reason for this is that Ritplan plans more tours for one vehicle, while the matching model assumes only one tour per vehicle. Thus, Ritplan plans five returns to depot for five full truck loads, while the
matching model plans five individual vehicles. One vehicle for each shipment. Figure 56 shows the cost index for the corrected values. This figure assumes that Ritplan would have used the same number of vehicles as the matching model. This figure shows that the matching model undershoots a little: 8%. The original figure is shown in appendix K 6.

- Hypotheses:
  - $H_0$: $0.90 > \mu > 1.10$ and $\sigma > 0.117$
  - $H_1$: $0.90 \leq \mu \leq 1.10$ and $\sigma \leq 0.117$

- Outcome: (Figure 56):
  - The mean falls just within the limits: $\mu = 0.91$. The confidence level is higher than the minimum ($\sigma=0.073$). The 80% area for $\sigma=0.073$ is from -9.3% to 9.3%. $H_0$ rejected, $H_1$ accepted;

![Cost Index Corrected Capacity Sweep (Ritplan=100%)](image)

Figure 56, Corrected cost index for the capacity shipments test, where the cost index = Matching model costs / Ritplan costs. Blue bars = histogram, red line = normal distribution fit

7.6 BACKHAUL SHIPMENTS TEST

The backhaul shipments test is used to check if the backhaul utilization works. This is done by generating shipments in a circle east of depot. First are 1 to 10 delivery shipments generated, then 1 to 10 pickup shipments, resulting in 20 individual schedules. The backhaul scenario combines the schedules that have the same number of shipments. Thus the schedule with 5 pickup shipments is combined with the schedule of 5 deliveries resulting in a combined schedule of 10 shipments. The test design is shown below:

![Backhaul shipment test design](image)

Figure 57, Backhaul shipment test design. ($n_D = \#$ shipments delivery schedules, $n_P = \#$ shipments pickup schedules and $n_{D,P} = \#$ shipments combined schedules)
7.6.1 FACE VALIDITY (ACCEPTED)

The face validity for the backhaul shipments test is done by first determining the costs for the individual pickup schedule and individual delivery schedule. These are the first two scenarios. Thereafter the costs for the combined schedules, \( n_D, P \), are determined. Only the total costs and average costs are validated as these are sufficient for validating the backhaul.

Total costs (Accepted)

- **Expectation:** The total costs for the schedules combined should be significantly lower than the summation of the delivery and pickup schedules individually. This because the backhaul can be utilized when there are delivery and pickup shipments available in the service area. The total costs will increase when the number of shipments increase as the share of the inter-order costs increases.
  - \( H_0: \) the total costs do not decrease when a delivery schedule is combined with a pickup schedule, compared to serving the schedules individually;
  - \( H_1: \) the total costs decrease when a delivery schedule is combined with a pickup schedule, compared to serving the schedules individually;
- **Outcome:** Appendix L 1
  - Utilizing the backhaul realizes a maximum cost reduction for schedules that consists of less than 5 shipments (50%). The cost reduction declines to 30% cost reduction for the schedules with 10 shipments. This reduction can be explained by an increase in vehicle use or inter-order costs.
    \( H_0 \) rejected, \( H_1 \) accepted;

Average costs per shipment (Accepted)

- **Expectation:** The average costs per shipment should decrease when utilizing the backhaul as more shipments can be served by a single vehicle. Also the costs should decrease when the number of shipments increase.
  - \( H_0: \) the average costs do not decrease when a delivery schedule is combined with a pickup schedule, compared to serving the schedules individually;
  - \( H_1: \) the average costs decrease when a delivery schedule is combined with a pickup schedule, compared to serving the schedules individually;
- **Outcome:** Appendix L 2
  - The average costs per shipment decreases from €260 to €145 for a schedule with one shipment. The results for the largest schedules are lower: from €60 to €40 per shipment. That these schedules are less profitable is a result of time constraints, not all shipments can be served by one vehicle when the delivery and pickup schedules are combined.
    \( H_0 \) rejected, \( H_1 \) accepted;

7.6.2 COMPARISON TO OTHER MODELS (ACCEPTED)

- Hypotheses:
  - \( H_0: \) 0.90 > \( \mu > 1.10 \) and \( \sigma > 0.128 \)
  - \( H_1: \) 0.90 ≤ \( \mu \) ≤ 1.10 and \( \sigma \leq 0.128 \)
- **Outcome (Figure 58):**
  - There are more outliers on the left side of the graph. This results in a mean of \( \mu = 0.98 \). The standard deviation is \( \sigma=0.066 \). This implies that the 80% range is from -8.4% to 8.4% of the mean.
    \( H_0 \) rejected, \( H_1 \) accepted;(K)
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

7.7 P&D SHIPMENTS TEST

The P&D shipment tests if the proposed clustering method used for the matching model works. The test design is given in Figure 59. The pickup locations are generated together and the delivery locations are generated together. The pickup centroid is located north east of depot and the delivery locations south east. A P&D shipment has its pickup point in the pickup circle and the delivery shipment in the delivery circle. For each centroid are 1 to 10 shipments generated. This generation process is repeated 10 times for where the pickup location is located farther to North West and the delivery location farther to the South East.

Figure 58, Cost index for the backhaul shipments test, where the cost index = Matching model costs / Ritplan costs. Blue bars = histogram, red line = normal distribution fit
7.7.1 FACE VALIDITY (ACCEPTED)

The P&D shipment test for the face validity is performed in the same way as the delivery shipment test and the pickup shipment test. In analogy with the pickup shipment test, there is no need to explain the expectations for each aspect as these are already explained at the delivery shipment test. Only the fixed costs are further explained since not all schedules can be served by one vehicle. The costs will be different, as both the origin and destination are not at depot. All results are plotted in appendix M.

- **The fixed costs**
  - Expectation: not all schedules can be served by one vehicle, therefore some schedules result in higher costs than €181.
    - $H_0$: The fixed costs for all schedules that can be served by one vehicle are not **€181, the remaining schedules do not cost more than €181**;
    - $H_1$: The fixed costs for all schedules that can be served by one vehicle are **€181, other schedules are more expensive**;
  - Outcome: Appendix M, 1
    - The fixed costs are €181 for each schedule that can be served by one vehicle. Others result in maximum €205 for the 10 shipments that have the highest STEM distance.
      - $H_0$ rejected, $H_1$ accepted;

- **The Stem costs ($H_0$ rejected, $H_1$ accepted) (Appendix M, 2)**
  - $H_0$: the STEM costs do not increase when the shipments are farther away from depot, but the number of shipments has effect;
  - $H_1$: the STEM costs increase when the shipments are farther away from depot, but the number of shipments has no effect;
The STEM costs increase from €40 to €380 when the service area is farther away from depot. The number of shipments has no effect.

**Ho rejected, H1 accepted;**

- **Inter-order costs (Ho rejected, H1 accepted) (Appendix M, 3)**
  - Ho: the IO costs change with the distance between depot and the shipment, but the IO costs remain unchanged with the number of shipments;
  - H1: the IO costs do not change with the distance between depot and the shipment, but the IO costs increase with the number of shipments;
  - The IO costs only increase with the number of shipments, from €0 to €280.
  
  **Ho rejected, H1 accepted;**

- **Total costs (Ho rejected, H1 accepted) (Appendix M, 4)**
  - Ho: total costs do not increase with the number of shipments and the distance between depot and the service area;
  - H1: total costs increase with the number of shipments and the distance between depot and the service area;
  - The total costs are the highest for the largest distance and highest number of shipments (€900). These costs decline to €300 for one shipment, closest to depot.
  
  **Ho rejected, H1 accepted;**

- **Average costs (Ho rejected, H1 accepted) (Appendix M, 5)**
  - Ho: the average costs do not decrease with an increase in shipments and the average costs do not increase with an increase in distance between depot and the service area;
  - H1: the average costs decrease with an increase in shipments and the average costs increase with an increase in distance between depot and the service area;
  - The average shipment costs are the highest for 1 shipment farthest away from depot (€550) and decreases to €60 for the 10 shipments closest to depot.
  
  **Ho rejected, H1 accepted;**

Recommendation on fixed costs:

There might be scenarios when the total fixed costs do not have to be a multiple of the fixed costs for a single vehicle. This can happen when vehicles are shared between companies, or when these are rented for only a part of a day. Thus, when company A is using the vehicles during the day and company B during the night, the fixed costs can be split. On the other hand, if the fixed costs cannot be shared, then the total costs should be a multiple of the costs for a single vehicle. The design of the matching model does not ensure this. An example: there are 10 shipments of which 9 can be served in total by one vehicle. The matching model estimates (€181/9*10=€201), but in reality there are two vehicles needed (2*€181=€362). Further research should be done on the fixed costs and solution like rounding up to a multiple of the fixed costs or the effect of the schedule size on the fixed costs issue.

**7.7.2 COMPARISON TO OTHER MODELS (ACCEPTED)**

As observed by the face validity of the P&D shipment test, the matching model undershoots the fixed costs when a schedule contains one shipment too much for being served by one vehicle (Appendix M, 6). Therefore, the costs are corrected by making it possible for Ritplan to serve all shipments by one vehicle.

- Hypotheses:
  - Ho: 0.90 > μ > 1.10 and σ > 0.128
  - H1: 0.90 ≤ μ ≤ 1.10 and σ ≤ 0.128

- Outcome: (Figure 60)
  - The mean undershoots a little (μ = 0.98), which can be caused by the correction for the fixed costs. The standard deviation of σ=0.076 results in an area of -9.7% to 9.7% for a confidence of 80%.
$H_0$ rejected, $H_1$ accepted;

**Figure 60,** Corrected Cost Index for the P&D shipments test, where the cost index = Matching model costs / Ritplan costs. Blue bars = histogram, red line = normal distribution fit

### 7.8 PERFORMANCE MATCHING TEST

The final tests for the validation of the matching model is a test for 10 generated companies. The performance matching test determines whether the model is able to find the expected matches. All companies have their depot in the Utrecht. Each company has 10 generated shipments in a circular service area. Each circle is located in the Benelux. See Figure 61 for the schedules, each company is indicated by different colour.
7.8.1 FACE VALIDITY (ACCEPTED)

The different companies are located in such way that easily can be observed which companies should be matched. All shipments are equal, only the geographically locations influence a match. Therefore, the companies that are closest together should be matched.

- **Expectation:**
  - $H_0$: One of the companies proposed in $H_1$ is matched to a different company;
  - $H_1$: The following companies are matched:
    - Company 1 $\rightarrow$ Company 2
    - Company 2 $\rightarrow$ Company 1
    - Company 3 $\rightarrow$ Company 10
    - Company 4 $\rightarrow$ Company 7
    - Company 5 $\rightarrow$ Company 6
    - Company 6 $\rightarrow$ Company 6 or 7
    - Company 7 $\rightarrow$ Company 5
    - Company 8 $\rightarrow$ Company 9
    - Company 9 $\rightarrow$ Company 8
    - Company 10 $\rightarrow$ Company 3;

- **Outcome:** (Table 20)
  - Company 1 $\rightarrow$ Company 2 (+40%)
  - Company 2 $\rightarrow$ Company 1 (+40%)
  - Company 3 $\rightarrow$ Company 10 (+30%)
  - Company 4 $\rightarrow$ Company 7 (+19%)
  - Company 5 $\rightarrow$ Company 6 (+31%)
  - Company 6 $\rightarrow$ Company 5 (+31%)

![Figure 61. Generated companies for the performance matching tests](image-url)
Company 7 → Company 5 (+21%)
Company 8 → Company 9 (+26%)
Company 9 → Company 8 (+26%)
Company 10 → Company 3 (+30%)

$H_0$ rejected, $H_1$ accepted;

### Table 20, Matching indices for 10 generated companies

<table>
<thead>
<tr>
<th>Ni,j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.60</td>
<td>0.89</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.89</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<td>0.85</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>0.85</td>
<td>1.00</td>
<td>0.95</td>
<td>0.98</td>
<td>1.00</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
<td>0.91</td>
<td>0.81</td>
<td>0.94</td>
<td>0.99</td>
<td>0.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.69</td>
<td>0.79</td>
<td>0.91</td>
<td>0.91</td>
<td>1.00</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>0.80</td>
<td>0.95</td>
<td>0.95</td>
<td>0.98</td>
<td></td>
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<td></td>
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<tr>
<td>7</td>
<td>0.94</td>
<td>0.96</td>
<td>1.00</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>8</td>
<td>0.74</td>
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</tr>
<tr>
<td>9</td>
<td>1.00</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### 7.9 RUN TIME COMPLEXITY

The run time complexity can be expressed in the Big-O notations. These notations determine how the run time is influenced by the problem size. Fastest algorithms, identified by $O(1)$, are not influenced by the problem size and therefore are maximum scalable. Algorithms that are less scalable increase the run time dramatically when the problem size increases, for example $O(n!)$ or $O(n^2)$. Big-O notations ensure that external factors like the processor speed or implementation of the algorithm do not play a role. Since the number of shipments can increase to over a thousand, it is necessary to determine what Big-O notation applies to the model. Instead of determining the execution speed in a mathematical way to prove a certain Big-O notation, an empirical approach is chosen: generating schedules for $N = 1$ to 1000. These schedules run sequentially as input for the matching model. The tests are performed on a desktop PC with an i7-4790 processor and implementation in Matlab. The execution time is saved for each schedule and the average time per shipment is plotted in Figure 62. The average execution time per shipment is approximately 6 Ms and increases a little with an increase in problem size. Therefore, the current implementation approximates an $O(n)$ algorithm, which makes the algorithm very scalable. Especially, since no company in the CBS commodity database has schedules with more than a few thousand shipments per day. In addition, there are several methods that increase run time performance, such as calculating the detour costs for the closest shipment only, or implement the matching model in a fast IDE like Microsoft Visual Studio.
7.10 CONCLUSION

The validation process has shown that the face validity is accepted for all tests. The same holds for the comparison between Ritplan and the matching model. Even though Ritplan uses a real road network with real time and distances. The mean for all results does not deviate more than 10%, thus the ratio falls within 0.9 to 1.1. Every test meets the mean requirement. Much better results than the 10% deviation is found for most tests. The confidence level is analysed as well. This level determines the chance that a sample falls within a certain range. There is chosen that at least 80% of the observations may not deviate more than 15% from the mean of the distribution. Every test has passed this requirement. Most tests even fall within the -10% and +10% confidence range. In conclusion: all tests are passed and therefore the model is determined to be valid. The test results are shown in Table 21.

<table>
<thead>
<tr>
<th>Test</th>
<th>Face validity</th>
<th>Comparison to other models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clusters</td>
<td>Accepted</td>
<td>Does not apply</td>
</tr>
<tr>
<td>Delivery shipments</td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td>Pickup shipments</td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td>Capacity shipments</td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td>Backhaul shipments</td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td>P&amp;D shipments</td>
<td>Accepted</td>
<td>Accepted</td>
</tr>
<tr>
<td>Matching</td>
<td>Accepted</td>
<td>Does not apply</td>
</tr>
</tbody>
</table>

In addition, the run time complexity is determined by an empirical approach. The experiments have shown that the run time complexity is O(n) for 1 to 1000 shipments. This makes the matching model quite scalable and usable for other matching more than two companies.
8  APPLICATION OF THE MATCHING MODEL

What results can be expected for merging road transport activities of two companies proposed by the matching model?

The aim of this chapter is to gather results of potential matches proposed by the matching model. The results are analysed and discussed. The matching potential for real companies in the Dutch trucking sector is determined, since this chapter applies the actual CBS data.

First, the steps taken to import the data in the matching model are explained. Next the matching results are given for the companies that transport agricultural products, living animals or fertilizers. These companies fall in the NSTR 0 and 7 categories. Finally, the conclusions based on this results are given.

8.1 STEPS FOR IMPORTING THE DATA

The companies from the CBS commodity flow database are prepared during the database analysis. These companies are grouped by their transported goods. The results for the companies that transport NSTR 0 and NSTR 7 goods are selected and analysed. All seven companies report the sample data only and therefore the data of the last three years are combined. The model runs for Monday to Thursday, since these are the days that all companies have reported sufficient data. The companies transport different shipment sizes and quantities. The differences in schedule costs, average weight per shipment and average volume per shipment is given in the table below:

<table>
<thead>
<tr>
<th>Company</th>
<th>Daily costs, 1 depot</th>
<th>Weight Avg</th>
<th>Volume Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>€ 3,929</td>
<td>560</td>
<td>1.14</td>
</tr>
<tr>
<td>2</td>
<td>€ 7,937</td>
<td>5404</td>
<td>12.35</td>
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<tr>
<td>3</td>
<td>€ 13,169</td>
<td>4854</td>
<td>14.08</td>
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<tr>
<td>4</td>
<td>€ 2,077</td>
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<td>11.42</td>
</tr>
<tr>
<td>5</td>
<td>€ 2,281</td>
<td>10585</td>
<td>21.68</td>
</tr>
<tr>
<td>6</td>
<td>€ 8,674</td>
<td>12342</td>
<td>25.28</td>
</tr>
</tbody>
</table>
The depots for all companies are manually determined. These depots can be situated close to each other. Since the shipment allocation algorithm is implemented instead of the clustering algorithm, depots can decrease the possible shipment combinations. Especially when the depots are close together. Shipments that could have been clustered can be allocated to different depots which excludes beneficial combinations. Therefore, is chosen to use two depots, one in Groningen and one central in Arnhem. The depot locations that are manually determined per company are changed to these locations. The shipment origins and destinations remain unchanged. The depots are shown in Figure 64.

![Figure 64, Depot locations](image)

### 8.2 RESULTS

A complete merge for the NSTR 0 and NSTR 7 group is first calculated using the depots in Groningen and Arnhem. Next, the matching model is used with a single depot in Arnhem. The latter is further analysed on the benefits per company and the deviation per day. Finally, an overview is given for companies that fall in the NSTR 9 group. These companies transport vehicles, machinery and other goods. These other goods can be anything, like washing machines, pencils or paper.

The matching results for the NSTR 0 and NSTR 7 group are given Table 23. The results show the performance increase in percentage when these companies merge their road transport. The percentages are the average for Monday to Thursday. This scenario uses two depots, one in Arnhem and the other in Groningen. According to the mean performance increase, the best partner for company 1 is company 5 and scores 8.32%. Other matches can be found in Table 23. The realized performance increase per company is from 2.60% to 8.32%. The match for company 1 and 7 results in a decrease in performance. This is an effect of the shipment allocation process. This decrease is quite significant (-20%), but is not surprisingly. Company 7 is 20 times larger than company 1 and has only 1 depot. Company 1 has two depots, which causes that the shipments of company 7 are allocated to both depots when collaborating. This decreases the cluster opportunities.

| Table 23, Average performance increase for the alliance per match. The results are calculated with 2 depots, one in Arnhem and the other in Groningen. |
|---|---|---|---|---|---|---|---|
| \( N_{ij} \) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | -1.74% | 1.40% | 4.27% | 8.32% | 3.83% | -20.57% |
The NSTR 0 and NSTR 7 data is also calculated for one central depot in Arnhem. All vehicles start and end their tour on that depot. Hence, all shipments are served from that depot. The results are shown in Table 24. All matches are positive, thus there is no negative effect of the shipment allocation process. The realized performance increase varies from 2.3% to 22.0%. Thus there is potential for combining schedules. The results show a clear difference per match as well. Company 7 realizes less performance increase than the other companies, but that is due to its schedule size. When larger companies collaborate with smaller companies, the total benefits are relatively low. Furthermore, this results show that there is no clear relation between matches for equal sized companies and companies of different sizes. Company 1 and 4 may be the best match with approximate individual €2,000 daily costs, but combining similar sized companies 6 and 2 is not the best match for both companies.

<table>
<thead>
<tr>
<th>N&lt;sub&gt;i,j&lt;/sub&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.98%</td>
<td>9.04%</td>
<td>22.02%</td>
<td>13.58%</td>
<td>8.65%</td>
<td>2.31%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2.97%</td>
<td>4.11%</td>
<td>5.10%</td>
<td>3.81%</td>
<td>1.13%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.59%</td>
<td>5.03%</td>
<td>1.84%</td>
<td>2.02%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>8.56%</td>
<td>2.17%</td>
<td>0.57%</td>
<td></td>
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<td></td>
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<tr>
<td>5</td>
<td>6.35%</td>
<td>1.43%</td>
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<tr>
<td>6</td>
<td>0.92%</td>
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</tr>
</tbody>
</table>

The average performance increase for the alliance has shown that company 7 is not able to find high potential matches due to its large schedule size. Therefore, it is interesting to determine the performance increase for the companies individually per match. This individual performance increase shows whether there is a misbalance in realized potential. A large misbalance may also harm an alliance. The performance increase per company are shown in Table 25. Company 1 has by far the highest performance increase for each match. This can be explained by relatively low average weight per shipment of 500kg. All other companies transport 2500 to 12000kg on average. Many shipments of company 1 can be bundled with the shipments of the other companies since this will less likely violate the capacity constraints. Also, the matching model allocates costs with a capacity utilization factor which makes smaller shipments cost less. All companies, except for company 7, decrease in performance when collaborating with company 1.
Table 25, Average performance increase per company for one central depot in Arnhem. The rows is the company.

<table>
<thead>
<tr>
<th>N_{ij}</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>26.14%</td>
<td>48.13%</td>
<td>33.45%</td>
<td>25.86%</td>
<td>39.00%</td>
<td>47.35%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-4.77%</td>
<td>6.84%</td>
<td>6.17%</td>
<td>4.93%</td>
<td>7.51%</td>
<td>10.77%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-0.81%</td>
<td>3.15%</td>
<td>3.58%</td>
<td>6.42%</td>
<td>6.83%</td>
<td>6.29%</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-11.29%</td>
<td>0.00%</td>
<td>10.21%</td>
<td>5.44%</td>
<td>6.85%</td>
<td>3.24%</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-10.70%</td>
<td>9.90%</td>
<td>11.51%</td>
<td>12.54%</td>
<td>23.96%</td>
<td>12.89%</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-6.47%</td>
<td>0.81%</td>
<td>-1.83%</td>
<td>1.50%</td>
<td>2.76%</td>
<td>-2.90%</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1.82%</td>
<td>2.16%</td>
<td>3.69%</td>
<td>2.50%</td>
<td>3.19%</td>
<td>3.36%</td>
<td></td>
</tr>
</tbody>
</table>

The average performance index determines whether merges have potential. This average can be strengthened by determining whether and how much the deviation is between the days. It could be that Monday is very beneficial, but Tuesday not. Companies may prefer matches that result in a stable performance increase, only collaborate for specific weekdays or even for specific seasons. Therefore, the standard deviation is determined for the NSTR 0 and NSTR 7 group. A histogram for the standard deviation per match is shown in Figure 65. The difference per match is quite significant, there are matches with a standard deviation of more than 0.05. That implies that only 68% of the days fall within a margin of +/-5% performance increase. Companies might find that difference too high and therefore prefer an inferior, but stable match.

Figure 65, standard deviation for the performance indices for complete matches

4 companies from the NSTR 9 group are randomly drawn. These companies all have one central depot in Arnhem. All data for the last three years are imported in the matching model. The first three companies have an average weight per shipment of approximately 3,000kg, the fourth company ships smaller goods. That company has nearly 1,600kg weight per shipment. The daily schedule sizes are respectively 600, 600, 850 and 1,800. The performance increases per match are quite similar: 2.50% to 3.34%. This implies that all merges have merely the same effect. Of course, the increase for merges
with company 4 will gain more advantage in terms of overall costs as company four is larger than the others. The performance gain for the individual company within an alliance is given in Table 27. Even though that company 4 is larger than the other companies, it still realizes the same or higher individual performance increase than its collaboration partner. The match of company 4 and company 3 gains 2.83% combined, but the individual gains are 4.45% for company 4 and 1.29% for company 3. This difference is, just as company 1 of the NSTR 0 and 7 group, caused by relatively light goods of company 4 compared to the other companies.

8.3 REFLECTION ON RESULTS

This paragraph explains that the results presented in the previous chapter are bound to many factors that influence whether a match is feasible. Earlier in this thesis is stated that only the operational fit productivity KPI’s (paragraph 2.5) will be discussed, but there a side note on the results is needed. Therefore, how the company size, competition and profit sharing relate to trust are discussed. Trust comes with three important aspects: it involves uncertainty about the future (1), it implies vulnerability (2) and the behaviour is not under one’s control (3) (Ngowi & Pienaar, 2005).

- **Company sizes**
  
The companies in the CBS database vary in size. According to the matching model, different company sizes do have potential. One of the collaboration advantages is the increased bargaining power of the alliance (Adenso-Díaz, et al., 2014), but this bargaining power is experienced within the alliance as well. The smaller company will have less influence in the alliance and therefore the larger company should be more trustworthy (Hardy, et al., 1998). This results in higher vulnerability and unequal control and therefore increases the required trust (Ngowi & Pienaar, 2005).

- **Competition**
  
  Collaboration requires, among others, to share resources, information and knowledge. Alliances with partners that are highly competitive accept high risks and therefore require high trust. For example, when company A gives insight in their customers and company B could serve the same customers as well, then there is a risk that customers switch from supplier.
Furthermore, company B can learn from company A when it has complete insight in how the process are managed. Hence, giving company B a stronger competitive position in the market. If the alliance fails, the company B will use this knowledge to gain more market power. Therefore, competition needs very high trust on all three trust aspects.

- **Individual performance gain balance**
  
  There are matches that gain over 22% performance. This increase is in most cases not equally divided among the collaboration partners. This difference can be as high as 48% between the two collaborating partners. This unequal potential in the alliance for both companies results in unbalanced control and thereby increases the required trust. The company that is able to gain more performance is dependent on the effort of its partner to make it a success, which makes that company more vulnerable. On the other hand, the company that gains highest performance should be open in their savings. Therefore, companies with high differences in individual performance gain do have to have high trust in each other. Many alliances have failed on mistrust on the applied profit allocation scheme (Huijink, 2016).

### 8.4 CONCLUSION

How can a shipment matching model for companies engaging in road transportation be designed?

The matching model has shown that there is potential over 22% when companies merge their road transport activities. This potential is in most cases not equally divided among the collaboration partners. In some cases, one collaboration partner is able to decrease 50% of its transportation costs while the collaboration partner experiences an increase in costs. These unbalanced matches are caused by the company size and the good size transported. Larger companies will tend to have a relatively lower performance increase, but the costs are about to be higher. The companies that transport relatively small goods are able to combine those easier with the larger goods of the other company. Moreover, the cost allocation uses a capacity utilization factor that ensures that the smaller goods get a smaller share of the transportation costs.

The results of the matching model are only based on the provided shipments. This is not enough to determine whether a match is valid. Trust is an important factor for alliances (Huijink, 2016) (Ngowi & Pienaar, 2005). Three factors that influence the trust level are discussed:

- Company size: higher difference in size → higher trust level required;
- Competition: higher level of competition → higher trust level required;
- Individual performance gain balance: higher unbalance in individual performance gain → higher trust level required;
9 CONCLUSIONS & RECOMMENDATIONS

[Main research question]

How can a matching model for finding potential collaboration partners engaging in road transport be designed based upon their shipment data and what is the effect of matching shipment data on road transport performance?

This final chapter discusses based on the foregoing chapter the conclusions and recommendations for the matching model.

The first paragraph describes the conclusions of the first two research questions and main research question and finally states the capabilities of the matching model. The second paragraph gives the recommendations on the matching model and the CBS commodity flow database. The final section, 9.3, elaborates on the execution of this research.

9.1 CONCLUSION

The main goal of this research is developing a model that is capable of finding collaboration partners in road transport. The model focuses on the performance increase when the schedules of two collaboration partners are merged. First the findings from the first two research questions are given, thereafter the modelling and results.

RQ1: Before matching partners, it is needed to determine to what indicators should be optimized. Therefore, a wide range of KPI's that are relevant to road transport are given. These factors are categorized in productivity, utilization and effectiveness. From these categories is found that the matching model should optimize costs. This costs are fixed-, distance- and time-related. To measure the costs per shipment enables to determine the performance increase per company individually while collaborating. The methods for measuring utilization are merely interesting for policy makers. The category effectiveness measures the satisfaction level from the point of view of the customer, society, strategy and employee. The KPI's that fall in this category differ per company and are hard, if not impossible, to determine by the shipment data.

RQ2: When collaborating increases performance is researched after determining the KPI's. This increase lies in the slack of a schedule. There are three factors defined: utilizing the backhaul, increase shipment density and increase period utilization (PU). These factors can be exploited by matching complementary companies. For instance, solving the trade imbalances by matching a company that transports goods from A to B with another company that transports goods from B to A. Another
important factor is the nature of the goods. Heavy and voluminous load combined can utilize both the
volume as well as the weight capacity of a vehicle. Thereby hauling more goods. An example of this is
also given in the P&G-Tupperware case. Higher shipment density increases the possibility to combine
favourable shipments which results in a decrease of time and distance travelled per shipment. Better
combinations also utilize the fronthaul utilization and when the match consists of deliveries and
pickups it will also increase the backhaul utilization. Finally, the type of good limits the collaboration
opportunities. All companies are categorized in different NSTR groups. For this NSTR groups is
determined what goods go well and what goods are excluded for matching.

The main research question is formulated as follows:

*How can a matching model for finding potential collaboration partners engaging in road transport be designed based upon their shipment data and what is the effect of matching shipment data on road transport performance?*

The model consists of two phases: “The initial selection” and “Performance gain estimation”. The first
phase is grouping the companies by their NSTR classification. This is done manually. The second phase
consists of two scenarios: the performance for the companies individually (1) and the performance for
the companies while collaborating (Figure 67). Each scenario is determined in the same way, but the
collaboration scenario can make build combinations for shipments of both companies.

The shipment allocation is described as a variation on the transportation problem. Since this research
assumes that every depot has no limitation on the number of vehicles available, every shipment can
be allocated to the most favorable depot. Most favorable is determined by the inter-depot transportation and the Euclidean costs from depot to the shipment. Only delivery and pickup shipment are transported via a hub-and-spoke design, therefore there are no inter-depot costs charged for P&D shipments.

The performance is an extension on the estimation model proposed by Huijink (2016). This model
estimates the costs for each shipment individually. The stages are as follows: cluster the shipments such that they can be reliably served by one vehicle (1) then determine the costs for the individual shipment for that cluster (2).

The model has been accepted on the basis of several specific tests. These tests focus on delivery,
pickup and P&D shipments. Also, the vehicle capacity and backhaul utilization are tested. These tests are compared to a valid model and proven to be sufficiently accurate. Furthermore, a test to evaluate whether the matching model is able to find the correct collaboration partner is successfully performed.

The matching model approaches a linear run time complexity and needs 6 Ms per shipment. Hence,
a schedule of 1000 shipments takes 6 seconds to complete.

Seven companies from the NSTR 0 + 7 group and four from the NSTR 9 group are matched in two
runs. The maximum potential found is 20% performance gain. Some matches are unbalanced, which
implies that one company benefits more than the other. This is caused by the company size and
average shipment sizes. Smaller shipments can be bundled more easily than larger shipments
because of the capacity constraints. In addition, the shipment size determines the share of the STEM and fixed costs that are allocated to the shipment.

Trust is an important factor that determines whether a match will work in practice. Important factors that influence trust are company size, competition and performance gain balance. High levels of trust are required if the companies are very different in size or one company is gaining more performance than its partner. For example, the smaller company has less control and is more vulnerable than the larger company. Companies that compete with each other requires high trust as well as they, for example, have to give insight in sensitive data and their logistic processes.

The model proposed is validated using several tests and is able to run for all types of shipments: delivery, pickup and P&D. The model takes maximum duration, capacity and inter-depot transportation into account. Also, since the use of an estimation model, this model is scalable to very large schedules. The matching model allows companies that engage in road transport to find potential matches. These matches gain performance, reduce costs and reduce pollution as vehicles are better utilized and more efficiently used. Hence, the matching model contributes to the competitive advantage of these companies. The next steps are explained in the recommendation paragraph.

9.2 RECOMMENDATIONS

The recommendations are in twofold: first the recommendations on the matching model are given, thereafter the recommendation on the CBS commodity flow database.

The matching model:

- The matching model is ready to be implemented as a SAAS solution on a shipment database, preferably the CBS commodity flow database. Companies that report data should get access to the tool. The tool generates the opportunities for both companies and verifies whether the companies agree to exchange contact information. With this information, the companies can start building an alliance.
- Another tool is to use the matching model for shipment outsourcing. It is a high-speed solution and therefore is able to determine which shipments should be served by which company or depot. This implementation enables companies to select specific shipments and find the best collaboration partner for that shipments.
- The shipment allocation algorithm is implemented instead of the cluster allocation algorithm. This excludes beneficial clustering when depots are close together, hence the observed performance decrease for some matches. Therefore, it is recommended that the shipment allocation algorithm will be substituted with the cluster allocation algorithm.
- Also, further research on estimating the fixed costs will enhance the results. The model cannot combine multiple tours in one vehicle and therefore overshoots when full truck loads are transported, if a vehicle is able to serve more full truck loads in one day. On the other hand, when a cluster contains one shipment too much for being served by a single vehicle, the fixed cost estimation undershoots.
- The model uses an estimation approach that allows high speed outsourcing of shipments. Specific shipments can be tested on several schedules to find out which partner should serve the shipments in order to gain highest profits.
- If, for example, the pickup cluster is closer to depot than the delivery cluster, it should be more beneficial to cluster at the delivery cluster. An example of this issue is given in appendix Q.
- The capacity constraint is designed so that one cluster can utilize 100% of the capacity for the deliveries and 100% for the pickups. This implies that the deliveries have to be served first, which the model does not take into account.
• The matching model is implemented in Matlab. It would be better to implement the model in an Integrated Development Environment (IDE) like Microsoft Visual Studio or Delphi. This will allow high speed execution of the model. Also, these environments have tools for developing servers for easy access by third party software.

• The current implementation uses Euclidean distances. It would be better to use a road network with real distances and durations. In addition, a pre-calculated matrix for all distances and durations between the nodes will increase execution time.

• Even though the model can handle many planning types, there is need for the following functionality:
  o Time-windows
  o Multi-day tours
  o Different vehicle types
  o NSTR on the delivery level instead of company level

• Policy makers are often interested in capacity utilization per vehicle. An interesting add-on would be to output this capacity utilization.

• The initial selection could be improved. Atomized recognition of companies that cannot be matched on the bases of transported goods or companies that have overlap in their commodity flows can be filtered up front.

• Delivery and pickup shipments are transported via a hub-and-spoke network, which is not always the most favourable design. These shipments can also be dealt with as P&D shipments, which makes the inter-depot transportation no longer needed. In addition, P&D shipments can also be handled via a hub-and-spoke design. In that case, the P&D shipments will be split in two shipments: a delivery shipment and a pickup shipment.

**The CBS commodity flow database**

• CBS could consider to evaluate their data model. Issues found during the data analysis are:
  o Adding a table for tours with the action and time-stamp
  o Adding a table for time-windows
  o Adding a table for products
  o Adding data fields for the processed data, so that the original data remains untouched during the data processing phase

• CBS could consider changing the data processing steps:
  o Consistency in survey status, choose either to copy or change the processed record.
  o All data can be processed during the import, for example geocoding the data

9.3 REFLECTION

**Reflection on the matching model**

During the development of the matching model, there are several decisions taken that influence the outcome and working of the model.

• The matching model uses an estimation approach. This approach is quite fast and scalable, but he drawback is that the results are an approximation of real schedule costs;

• The delivery and pickup shipments are chosen to be served via a hub-and-spoke network when these are served by the collaboration partner. This is not always the best and optimal design;

• The matching model uses a road network with Euclidean distances and nodes at PC3 level. Shipments that are geographically close to each other can be geocoded to the same road network node, which results in 0 detour costs;
Reflection on the input costs

The costs for a vehicle are determined by Kostprijscalculatie. The output of the tariffs is per hour, per km or day individually. These costs are recalculated to the three cost factors (fixed, duration and distance) that are required as input for the matching model. Chosen is to give each cost factor equal weight. Hence, every cost factor accounts for one third of the total vehicle costs. Without any doubt, there are better calculations methods to determine this cost allocation. The performance indices are completely based upon costs. Therefore, a rough calculation method has major impact on the final results.

The model only implements a small share of the inter-depot transportation costs as is assumed that these vehicles are completely utilized for these trips. In assumption can be a little too optimistic.

Reflection on the results

The matching for 10 companies that transport NSTR 0, NSTR 7 and NSTR 9 are presented in this thesis. The data for this 10 companies is first sampled by CBS and then processed by the researcher before it is imported in the matching model. The steps that introduce a bias are the following:

- The ZIP location data of these shipments are converted with a random factor between +50 and -50. ZIP code 2746 is converted to 2785, for example. This is required as the data could not be exported from CBS. The actual results are partly based upon randomized data and therefore deviate from results that would be calculated on using the real data;
- Most companies report only sample data. The data is 1:3 of a complete schedule for one week, therefore the data for at least three years are selected. These data do not completely reflect complete schedules of the companies. Hence, the results will deviate from the real matching indices;
- The companies that report data are the larger companies in the Netherlands. Therefore, the results only apply to large companies;
- The companies are grouped by their type of goods transported. Companies are allocated to a group according to the goods they transport most. In reality, these companies may transport different good types and therefore only a part of the shipments can be clustered.
- The results are based on an average performance index for a week. There are more reliable tests available like the “One-way ANOVA on ranks-test” or when the indices are normal distributed a “One-way ANOVA-test”. Such test determines whether there is a significant difference between the matches. Another useful output is that this test determines the deviation of the indices. After a ANOVA test, a “Post Hoc-test” should run to determine which of the matches is superior;
- Trust is stated as important factor that is required for a successful match. Only three factors are explained that influence the level of trust needed, but there are many more factors. In addition, there can be other concepts besides trust that influence a match as well. All these concepts and factors are not determined by the matching model;
## APPENDIX

### A. PERFORMANCE INDICATORS SCORING

The following table categorizes the KPI's proposed by Krauth, et al. (2005) for LSP in productivity, utilization and effectiveness. Furthermore, the argumentation is given in the coloured fields.

<table>
<thead>
<tr>
<th>Internal perspective - Management point of view</th>
<th>Effectiveness</th>
<th>Efficiency</th>
<th>Satisfaction</th>
<th>IT and innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Internal perspective - Management point of view</strong></td>
<td><strong>Effectiveness</strong></td>
<td><strong>Efficiency</strong></td>
<td><strong>Satisfaction</strong></td>
<td><strong>IT and innovation</strong></td>
</tr>
<tr>
<td><strong>Revenue</strong></td>
<td><strong>Total number of orders</strong></td>
<td><strong>Km per day</strong></td>
<td><strong>Number of deliveries</strong></td>
<td><strong>Information system costs</strong></td>
</tr>
<tr>
<td><strong>Profit margins</strong></td>
<td><strong>Number of customers</strong></td>
<td><strong>Capacity utilization</strong></td>
<td><strong>Profit margins</strong></td>
<td><strong>Number of new products in the range</strong></td>
</tr>
<tr>
<td><strong>Capacity utilization</strong></td>
<td><strong>Number of new customers</strong></td>
<td><strong>Km per day</strong></td>
<td><strong>Benefit per delivery</strong></td>
<td><strong>% of information exchange through IT</strong></td>
</tr>
<tr>
<td><strong>Km per day</strong></td>
<td><strong>Number of regular customers</strong></td>
<td><strong>Labour productivity</strong></td>
<td><strong>Trips per period</strong></td>
<td><strong>% of information management assets used / production assets</strong></td>
</tr>
<tr>
<td><strong>Labour productivity</strong></td>
<td><strong>Number of profitable customers</strong></td>
<td><strong>Price</strong></td>
<td><strong>Perfect order fulfilment</strong></td>
<td><strong>% of invoice receipts and payments generated via EDI</strong></td>
</tr>
<tr>
<td><strong>Price</strong></td>
<td><strong>Continuous improvement, rate</strong></td>
<td><strong>Turnover per km</strong></td>
<td><strong>Total delivery costs</strong></td>
<td><strong>Up-to-date performance</strong></td>
</tr>
<tr>
<td><strong>Turnover per km</strong></td>
<td><strong>Product range</strong></td>
<td><strong>Number of deliveries</strong></td>
<td><strong>Customer service costs</strong></td>
<td><strong>% of information exchange through IT</strong></td>
</tr>
<tr>
<td><strong>Number of deliveries</strong></td>
<td><strong>Plan fulfilment</strong></td>
<td><strong>Labour utilization</strong></td>
<td><strong>Order management costs</strong></td>
<td><strong>Number of new products in the range</strong></td>
</tr>
<tr>
<td><strong>Benefit per delivery</strong></td>
<td><strong>Total loading capacity (for trucks)</strong></td>
<td><strong>Overhead percentage</strong></td>
<td><strong>Number of trucks in use</strong></td>
<td><strong>% of information exchange through IT</strong></td>
</tr>
<tr>
<td><strong>Trips per period</strong></td>
<td><strong>On-time delivery performance</strong></td>
<td><strong>% of Absent employees</strong></td>
<td><strong>Total delivery costs</strong></td>
<td><strong>% of information exchange through IT</strong></td>
</tr>
<tr>
<td><strong>Perfect order fulfilment</strong></td>
<td><strong>Long term plans availability / development</strong></td>
<td><strong>Salaries and benefits</strong></td>
<td><strong>Information system costs</strong></td>
<td><strong>% of information exchange through IT</strong></td>
</tr>
</tbody>
</table>

**Note:** The table above categorizes the KPI's proposed by Krauth, et al. (2005) for LSP in productivity, utilization and effectiveness. The argumentation is given in the coloured fields.
Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

B. NSTR DEFINITIONS

NSTR good definitions

<table>
<thead>
<tr>
<th>Code</th>
<th>Good definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Agricultural products and living animals</td>
</tr>
<tr>
<td>1</td>
<td>Other food and fodder</td>
</tr>
<tr>
<td>2</td>
<td>Solid mineral fuels</td>
</tr>
<tr>
<td>3</td>
<td>Oil and petroleum products</td>
</tr>
<tr>
<td>4</td>
<td>Ores, metal waste, iron pyrite</td>
</tr>
<tr>
<td>5</td>
<td>Iron, steel, non-ferrous metals (including semi-finished products)</td>
</tr>
<tr>
<td>6</td>
<td>Raw minerals and products, Building materials</td>
</tr>
<tr>
<td>7</td>
<td>Fertilizers</td>
</tr>
<tr>
<td>8</td>
<td>Chemical products</td>
</tr>
</tbody>
</table>

C=Costs, P=Pollution, R=Revenue, D=Distance, π=Profit, CU=Capacity Utilization, PU=Period Utilization, ER=Empty Running, LR=Loaded Running, Q=Quantity, LU=Labor Utilization

(Krauth, et al., 2005)
C. CBS DATA COLLECTION PROCESS

Large companies (fleet larger than 30) have to report each quarter, the remaining companies once per year at most. The chance for drawing a vehicle is based upon 74 strata which are based upon company size, vehicle age, branch, capacity and vehicle type. The chance for drawing a vehicle is almost 1:3 per year.

Companies are regularly contacted when they forget to report or report incorrect data. Also companies do contact CBS with questions about the surveys.

Data processing:

- The maximum capacity is divided over the stops when weight is missing
- ZIP is determined on the centroid of a city when missing. If this fails, then the locations are determined manually
- International tours that are within a range of 250km from their base at the end of a day are assumed to return to their base. These tours are split manually.
- Adding empties like pallets as transported goods when companies fail to report these.
- Change tour order when wrongly reported. For example: (Shipment1(A, B)  Shipment2(B, C)  Shipment3(C, D) becomes (Shipment1 (A, B)  Shipment2(A, C)  Shipment3(A, D))

D. CBS DATA ANALYSIS ON DUPLICATE “OPGAVE” RECORDS

The duplicates for the internet surveys are quite significant in 2013 (50%) compared to the years 2010, 2011 and 2014. An explanation is that the data processing is executed differently for the van surveys. The exact reason for this year is not relevant for this research. The XML surveys show that the duplicate records account for only a few percent. Hence, the bias will be low. Certainly when a further break down is given on the duplicate records in Figure 69. That figure shows that 4% of the surveys falls in the duplicate group. From these duplicates around half of them is copied, therefore the share of duplicates is no more than 2% and thus not significant enough to influence the research.

![Figure 68, Duplicate surveys (I=Internet, X=XML)](image-url)
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E. INTER-DEPOT TRANSPORTATION & CLUSTERING

Like P&D shipments, the delivery and pickup shipments do have an origin and destination. Where one is depot. This depot is not necessarily the same for all shipments within a cluster. This difference causes inter-depot transportation and is a characteristic of multi-depot problems. The cost reduction achieved by clustering should outweigh this inter-depot transportation costs. An example of inter-depot costs \( t_{id} \) is shown in Figure 70. All colored shipments are pickups.

![Figure 70, an example clustering shipments with two depots](image)

The formulation from Bard & Ahmad (2009) is modified for the clustering problem. The objective function \((E.1)\) minimizes the sum of the total distance from the centroid of the cluster to the shipment node plus a relative share \(a\) of the inter transportation distance. This relative share may vary from 0 to 1 and can be adjusted with parameter \(a\). Where 1 means that a vehicle used for inter depot transportation are filled to its potential. A shipment utilizing 10% capacity will therefore get 10% of the costs assigned. The decision variable \(x_k\) determines whether a datapoint is assigned to a cluster. Constraint \((E.2)\) ensures that a datapoint is assigned to exactly one cluster, \((E.3)\) defines the capacity constraint and \((E.4)\) the time constraints. \((E.5)\) and \((E.6)\) ensure that the decision variable is logical. There is no fuzzy area allowed, a shipment cannot be allocated partially to a depot.

\[
\text{Minimize } \sum_{i=1}^{N} \sum_{k=1}^{P} x_{ik} \left( d_{i,k} + d_{i}^{it} \left( a \frac{q_i}{Q} + (1 - a) \right) \right) \quad (E.1)
\]
subject to \[ \sum_{k=1}^{P} x_{ik} = 1, \quad i = 1, ..., N \quad (E.2) \]
\[ \sum_{i=1}^{N} D_i x_{ik} \leq Q, \quad \sum_{i=1}^{N} P_i x_{ik} \leq Q, \quad k = 1, ..., P \quad (E.3) \]
\[ \sum_{k=1}^{P} x_{ik}(\tau_i) \leq TOT - STEM_k, \quad k = 1, ..., P \quad (E.4) \]
\[ x_{ik} \in \{0,1\}, \quad i = 1, ..., n; k = 1, ..., P \quad (E.5) \]
\[ a \in [0,1] \quad (E.6) \]

Indices
- \(i\) Index for datapoints (origin and destination points)
- \(k\) Index for clusters

Parameters
- \(P\) Total number of clusters
- \(N\) Total number of shipments requests. Can either be a pickup or delivery action.
- \(d_i\) Distance from centroid of cluster \(k\) to shipment location
- \(q_i\) Transportation quantity of datapoint \(i\)
- \(d_i^{it}\) Inter-transportation distance for datapoint \(i\)
- \(a\) Share inter-depot distance based on capacity utilization
- \(Q\) Cluster capacity
- \(TOT\) Total time available in a day
- \(STEM_k\) Estimated time to drive to and from depot to cluster \(k\)
- \(BREAK\) Time allocated for breaks
- \(\tau_i\) Estimated drive time from \(i\) to the next customer

Decision variables
- \(\zeta_k\) Centroid of cluster \(k\)
- \(x_{ik}\) 1 if customer \(i\) is assigned to cluster \(k\); otherwise 0
F. CLUSTER DIFFERENCES FOR STEM COSTS

Charging the detour costs including the stem costs for adding an additional shipment to a cluster results in the left figure. The querying shipment is marked by a black circle. Observed is that the shipments close to depot tend to be added to the cluster. It is not favorable to first deliver goods close to depot and next drive far away to deliver only one shipment. The figure on the right shows the cluster when the change in stem costs for adding a shipment is left out.

G. ROAD NETWORK FACTORS

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<th>Duration (min.)</th>
<th>Euclidean distance</th>
<th>Duration</th>
<th>Distance Factor</th>
<th>Model speed (km/h)</th>
<th>Ritplan Speed</th>
<th>Speed factor</th>
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H. EXPORT KOSTPRIJSCALULATIE FOR DETERMINING VEHICLE COSTS

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J. VALIDATION: PICKUP SWEEP

Fixed costs

![Graph showing fixed costs vs distance and shipments](image)
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K. VALIDATION: CAPACITY SWEEP

Fixed costs

Costs (£)

Capacity utilization per shipment (%)

STEM costs

Costs (£)

Capacity utilization per shipment (%)

(1)

(2)
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L. VALIDATION: BACKHAUL SWEEP

Pickup = schedule that consists of pickup shipments only
Delivery = schedule that consists of deliveries shipments only
Combination = schedule for the combined pickup and delivery, thus utilizing the backhaul

Pickup = sum of the individual delivery and pickup schedule

![Total costs](image1)

![Avg costs](image2)
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M. VALIDATION: P&D SHIPMENTS TEST

1. Fixed costs

2. STEM costs
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Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach

N. PI INDICES MONDAY TO THURSDAY FOR NSTR 0 AND 7

Monday:

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**0. PI INDICES MONDAY TO THURSDAY FOR NSTR 0 AND 7**

**P. BIG-O EXECUTION TIME EXAMPLE**

Large-scale operational company matching for horizontal collaboration in road transport: a commodity driven approach
Q. WEIGHTED CLUSTERING

The model currently does not use weighted clusters, where clusters farther away from depot are more beneficial to cluster than the cluster close to depot. It might be more beneficial to cluster shipments farther away from depot. See example (1). The cluster close to depot is clustered with at least four other shipments, denoted by a green diamond. The querying shipment could also be combined with the shipment farther away, marked as “Optional for weighted clustering”. When the cluster is built from the second shipment in Vlaanderen (2), the first shipment is put into the cluster. Which is logical, as the pickup and delivery requests are both in Vlaanderen.
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