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Automating cost estimations for intermodal bulk transport

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Automating cost estimations for intermodal bulk transport

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Abstract

Cost estimations within intermodal transport are time consuming, complex and hard to be done accurately. The complexity arises from the effect of the quote order on the empty container repositioning and empty trucking, that depend heavily on the the execution of other orders. The current cost estimation requires creating scenarios, subsequently calculating the cost of those scenarios and multiplying with estimated likelihoods that the scenarios occur. Creating the scenario's and likelihoods is challenging because of the size of the network, cleaning requirements, and container and previous load requirements. An integer programming model was developed that calculates the cost of serving a certain order set, while ending with the same container balances as at the start of the period. Subsequently, the model was run for the order set and for the order set plus the quote order. The cost estimation was obtained by subtracting the former from the latter. The model encompasses truck routing with time windows, cleaning insertions, and empty container repositionings. The difference in using the closest cleaning to the loading location and a more sophisticated cleaning station selection was investigated. Also, the impact of adding empty container repositionings within trucking paths was researched. Moreover, cost estimations for multiple scenarios were compared to the results of cost estimations carried out by experts. The results show that the cost estimation of this study outperforms the current cost estimation process in unbalanced regions.

Keywords: Intermodal transportation, cost estimation, empty container repositioning, truck routing, bulk transport, integer programming

Executive summary

Problem definition and goal

Van den Bosch processes more than a hundred quotes per week, the prices are determined after estimating the costs of that quote order. Cost estimations are relevant because of the high competition and thus relatively low margins within the transport industry. Currently a scenario planning is required for cost estimations. Making the cost estimation process time consuming and possibly inaccurate. Which in turn leads to valuable business opportunities not being exploited. Possible inaccuracy may result from the inability to estimate changes in empty trucking and empty container repositioning moves caused by the quote order, that also depend on the routing of other orders. Additional complications are cleaning station selection, container sizes, and prior load and container requirements. Conclusively, data-driven methods should be researched. This study proposes a method for automatically calculating the costs of quote orders at the tactical planning level. In addition, the difference in cost estimations using the closest cleaning to the loading location or a more sophisticated cleaning selection without considering cleaning requirements was investigated. Also, the effect of empty container repositioning within trucking paths that serve the customer locations is researched. The goal is to further automate cost estimations for quote orders that will occur several weeks to multiple months into the future. Lastly, the goal is to lay the groundwork for further cost estimation models that focus at the operational planning level of intermodal transport. For those purposes, the following main research question was defined:

How can accurate cost estimations for quote orders be processed automatically?

A literature review was conducted to identify state-of-the-art approaches for cost estimations in the transport industry. The particular focus was on their applicability to large intermodal networks. Cost estimation models for intermodal truck transport that included empty container repositioning and empty trucks was scarce. However, integer programming applied to route optimization showed the ability to handle large instances within a deterministic system. Also modern integer programming solvers like Gurobi, provide information about the solution's gap to optimality. Integer programming was therefore selected as the solution method.

The network of Van den Bosch was decomposed into regions: the region where the quote loading would take place, the region where the quote unloading would take place, and the region of the remaining locations called the non-trucking region. For the quote loading and quote unloading region, truck routing was modeled as well as empty container repositionings to achieve the same number of containers at each terminal at the start and end of the period. Where the period corresponds to a one-week duration of orders. In the non-trucking region, only the empty container repositioning between terminals was modeled. An integer programming model with path-based decision variables was used where the trucking paths visited one or more customer locations. Where only trucking paths were included that started and ended their path at the same terminal, thereby considering empty trucking cost. For the corresponding decision variables, the optimal starting terminal, cleaning insertion, minimized penalty cost for arriving outside the time windows and the effect on terminal balances, were predetermined. This results in a linear programming model with a limited number of decision variables and constraints. For the quote order, multiple train/boat options were provided with their corresponding prices of which one must be chosen. Trucking legs corresponding to the chosen train/boat connection were included in the model. The model was able to generate solutions with a proven negligible gap to optimality, extremely fast.

Results

A case study was conducted with real-life data of bulk logistics provider Van den Bosch. Three cost estimation scenarios were investigated in depth by comparing the empty container repositioning and empty trucking distance of this study with both the post-calculation and the current cost estimation process. The analysis showed that the model performed well in export and import regions. Additionally, using a data-driven method to consider a large order set appeared to especially outperform the cost estimation for the empty trucking component. The cost estimation of this study performed poorly when the quote loading location or quote unloading location occurred in a balanced region.

Recommendations and further research

This study shows promising results for an operational division with low previous load and container requirements, and where the quote loading and quote unloading occurs in either clear import or export regions. However, quantifying the exact accuracy of the outcomes is hard. The analysis also indicates that the current cost estimation practice should discontinue the use of a round trip scenario for journeys between heavy export and heavy import regions. Also, the current cost estimation seems to overestimate the increase in empty trucking distance for unloadings in import regions and loadings in export regions. Therefore, it is advisable to conduct further analysis regarding the accuracy of the outcomes from this study and the current cost estimation method, potentially exploring more advanced post-calculation methods. Additionally, it is highly recommended to explore solutions aimed at mitigating extreme outcomes of this study in regions that are close to being balanced.

Given the critical importance of accurate cost estimations in attracting valuable business opportunities, it is recommended to conduct further investigation into data-driven methods. Areas for further research include: previous load and container requirements, the reliability and capacity of outbound trips, and a model targeting short-term operational planning that incorporates workforce and equipment capacities.

It is recommended to first start using the results of the model in a decision making tool for operational divisions with low previous load and container requirements, aimed at supporting sales and the PMC team leader. In the future it may be considered to implement a tool that provides fully automated cost estimations.

Conclusion

In conclusion, this study shows that it is possible to automate the cost estimation process at Van den Bosch. Nevertheless, accurately quantifying the exact level of accuracy or enhanced accuracy remains challenging. In import and export regions, the model appears to outperform both the post-calculation method and the current cost estimation process. In balanced regions the models seems to provide extreme solutions. Where cost estimations of this study underestimate the costs of quote orders from a slight import regions to a slight export regions. The reverse appears to be true for quote orders from slight export regions to slight import regions. Implementing those solutions would likely increase demand significantly from regions with slight import tendencies to regions with slight export tendencies, potentially transforming a slight import region into an export region, and vice versa. Consequently, this could result in financial losses, lost business or necessitate informing customers of necessary price increases, potentially leading to damage of the company's reputation.

The results indicate that benefit could be obtained by using data driven methods as a decision making tool, improving the solutions of the current cost estimation process. Thereby, increasing revenue, reducing imbalances and a more reliable customer image of Van den Bosch. Besides, large labour cost savings can be obtained of 2000 euros per week.

Preface

Want to thank all employees of Van den Bosch for creating an open atmosphere where asking questions as an intern was welcomed 100% of the time. I would highly recommend other students to consider Van den Bosch both for work and academic endeavors.

In particular, I want to thank Teun Franssen for your contagious enthusiasm for modeling transport problems. Also, I want to thank you for recognizing and openly addressing the weaknesses in a constructive manner.

Next, I want to thank both Alp Akcay and Albert Schrotenboer for the essential feedback and creative insights offered.

I also want to thank my family for always being there for me with all the support. Want to thank my friends immensely. Love how I can discuss absolutely everything with you guys.

Lastly, I want to thank God for everything you have done for me.

Ivan Lievense,

Erp, May 2024

Contents

1 Introduction

Van den Bosch is a large bulk transport provider operating primarily in Europe and Africa. Bulk transport concerns transporting large quantities of unpacked goods. Van den Bosch is increasingly using intermodal transport for carrying out the orders. Intermodal transport is a form of transport that makes use of multiple types of transport while keeping the same loading unit. Intermodal transport at Van den Bosch usually means a combination of truck and train or truck and boat (Van Den Bosch, n.d.). Long-distance transportation in an intermodal way, is usually cheaper and environmentally friendlier than transportation solely by truck (Sahin et al., 2014) (Braekers et al., 2009).

Van den Bosch has around 300 truck drivers in different European countries, such as Netherlands, Italy and Spain. Besides trucks, Van den Bosch also owns around 6000 container load units, several cleaning stations, storage places, designated rest areas and a truck maintenance facility.

Van den Bosch believes that the focus should be on continuously optimising their own and their customers supply chain. Partnerships with shipping companies, rail operators, carriers, cleaning partners and agencies, should offer a competitive solution for the transport of bulk. In order to optimize customers their supply chain and Van den Bosch their own processes, Van den Bosch has to make use of data, create insights and know-how. Van den Bosch calls themselves the supply changer in bulk (Van Den Bosch, n.d.). One of the processes that could potentially be further automated is the quotation process, by generating automatic cost estimations.

1.1 Operational divisions

Van den Bosch splits their operational activities into several divisions. Regulations concerning cross-contamination are strict, especially for food products Food products cannot be transported in containers that carried non-food products. Therefore food products are assigned to a different division than chemical products. Liquid products are loaded and unloaded in a completely different way, requiring different equipment. Therefore, container load units and in general, trucks, are split between between liquid and dry products. Consequently, the oeprational divsions are: Liquid food, Dry food, Liquid chemical and Dry chemical. Only a few products can be categorized into multiple divisions.

Figure 1 shows the wide assortment of containers that are in operation at Van den Bosch. The size of the containers differ substantially. Low density products are generally shipped in smaller containers than high density products. National regulations specify a maximum total weight for the truck and container combination. This makes lighter, smaller containers more suitable for transporting high-density products. The liquid division typically has containers with a volume of 20 or 25 ft. The dry division primarily uses containers with volumes of 30 or 40 feet.

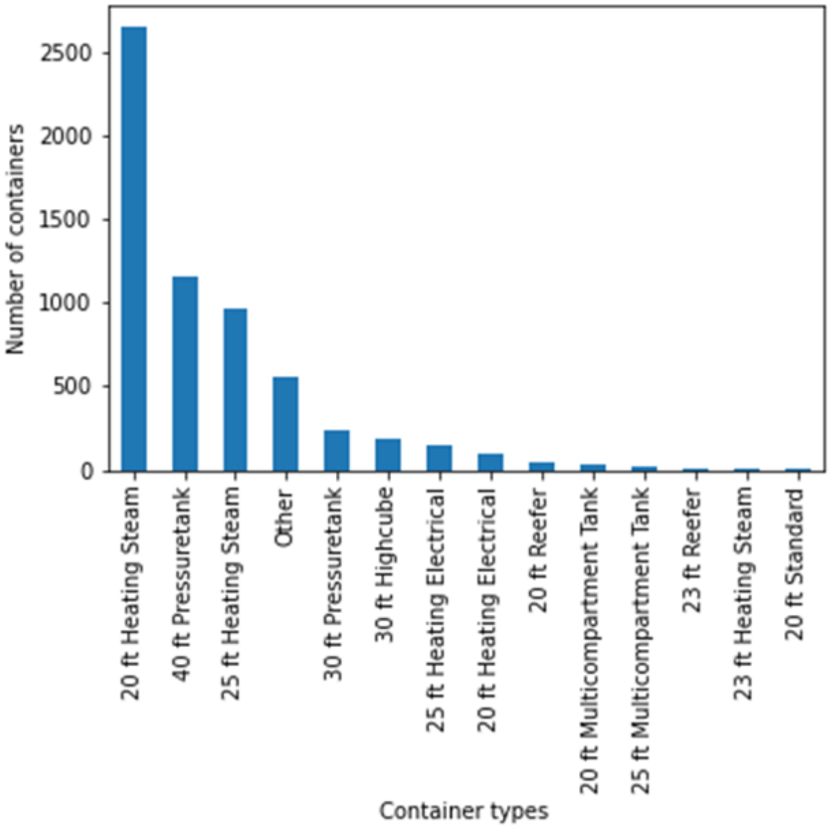

Figure 1: Different containers in use at Van den Bosch

Liquid food

The liquid food division has the largest number of orders. Generally, loading and unloading liquid products is substantially easier as the product can flow in and out of the container. Since this division handles food, cooled or heated transport is occasionally necessary, requiring containers equipped with these functionalities. Also, customers regularly provide the bulk logistic provider with a list of acceptable previous loads. The most occurring previous load requirements are the halal, kosher and allergen requirements. Those requirements must be met up to the last three previous loads. Complicating the container selection and planning.

Dry food

The dry food division is much smaller at van den Bosch. Unloading dry products often requires a combination of tilting and compression. Since dry food is also a food division, the halal, kosher and allergen requirements occur here regularly as well.

Liquid chemical

Chemical is defined as all products excluding food products. Halal, kosher and allergen requirements are rare in the liquid chemical division.

Dry chemical

Dry chemical is the second largest division at Van den Bosch. Even though unloading dry products is more complicated and requires compression and lifting, the operational requirements are lower. Practically all containers are suitable for compression and tilting.

1.2 Transportation network

There are six type of locations in the transportation network: cleaning stations, terminals, loadings, unloadings, storage locations and designated rest areas. Below follows a concise description of the various types of locations in the network.

Cleaning stations

Containers must be cleaned to meet cross-contamination requirements. The cleaning station and the type of cleaning operations depends on both the previous load and requirements specified by the customer of the next order. For instance, a customer may request container sealing or specify approved cleaning stations. Therefore, a container undergoes cleaning when the next load is determined. Otherwise, it may need to visit a cleaning station again.

Exceptions occur, for instance, a container that carried diary is cleaned within 24 hours due to bacteria growth. In addition to the availible cleaning operations, factors such as expected waiting time, quality, and cost are key considerations when selecting a cleaning station.The cost of the same cleaning operation at various cleaning stations was briefly analyzed. Figure 2 displays the costs of an acid cleaning operation at different cleaning stations.

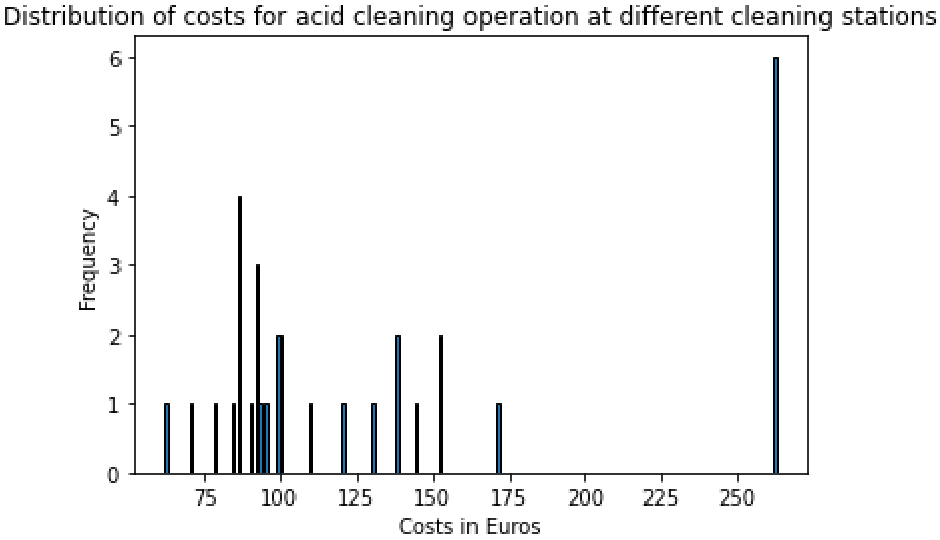

Figure 2: Costs for an acid cleaning operation at different cleaning stations

The same cleaning operation shows substantial cost discrepancies across various cleaning stations. The difference between the most expensive and cheapest cleaning station for an acid cleaning operation is 275 - 50 = €225.

Terminals

Terminals are the locations where the containers are put on and off the boat or train. A terminal operator provides a time window when a container can be picked up for free. Outside that time window, storage costs apply, typically at higher rates compared to the nearby depot locations. In this report, depot locations are referred to as storage locations.

Loading locations

Loading a container at a customer's address requires close communication with the customer. The customer at the loading address typically provides Van den Bosch with a time frame for an order, with a loading date that must occur approximately three days later. Subsequently, Van den Bosch must choose a smaller time frame of approximately 1-3 hours, roughly two days upfront. The final time windows can vary significantly, ranging from less than an hour to several days. Loading containers is time-consuming due to their large volume. Loading times below two hours occur seldom. Occasionally, drivers must wait at the loading location before the loading process can start. If the waiting is caused by the customer, the customer must bear the associated operational costs extensively.

Unloading locations

Unloading a container also takes about two hours. The facilities at the loading or unloading location are crucial for selecting the container or chassis. For instance, if compression facilities are available at the unloading location, chassis without compression equipment are also suitable.

Storage locations

In addition to costly storage options at terminals, there are dedicated storage locations that charge lower rates. The cost rates for storage are usually set in an increasing step-wise manner. For example, the first two days may cost two euros per day, and subsequent days for fifteen euros per day. Van den Bosch also has several own storage locations.

Rest areas

Drivers are required to take breaks and do so at designated rest areas for their sleep breaks. The designated rest areas charge a small fee per night. Van den Bosch owns rest areas in the Netherlands.

1.3 Current cost estimation process

This section details the current pricing process and the tasks of various people involved. The cost estimation is the first step of the pricing process. At the end of this section, a swimming line diagram provides an overview of the pricing process. First, a set of contractual elements that influence the scope of the cost estimation is examined. The cost estimation resulting from this process is also known as the pre-calculation.

Contract

Van den Bosch has a standard contract that applies when a quote is processed and subsequently awarded. The contract specifies what is included in the price. Regarding the cost estimation, the following contractual elements are the most relevant:

- Loading and unloading costs are included in the price for the first two hours. If it takes longer, an additional cost of around 60 euros per hour applies.
- Cleaning costs are included in the price.

The rise in fuel prices must be partially or fully covered by the customer. Depending heavily on the industry and the specific preferences of the customer. The contract may also include a penalty and bonus structure base on on-time reliability.

For instance, arriving more than 95% on time results in 1% bonus of the price. Conversely, arriving less than 90% on time results in a penalty equal to 2% of the price. Lastly, the customer has no preference for how the empty container arrives at the loading location. However, a small subset of customers prefer to have multiple empty containers available at the loading location at all times. In such cases, Van den Bosch charges a fee per container per day.

Sales

The cost estimation process begins when a customer contacts sales for a price quotation of an order. Typically, a request for a quotation is received via email. Sales must receive information about the loading location, unloading location, and product in order to perform a quotation.

The exact size and timing of the order are often not provided. Sales utilizes a software program called Quintiq for the cost estimations. Quintiq automatically generates a ”preferred path” based on the loading and unloading locations provided. The path typically includes the following arcs: from the loading location to a terminal, a train or boat connection between two terminals, from the terminal to the unload location, and from the unload location to a cleaning station. The first arc is referred to as the trucking leg loading. The second arc starts from the departure terminal and ends at the arrival terminal. The third arc is referred to as the trucking leg unloading. Besides the trucking and train/boat cost, the cleaning costs for the corresponding product group are also included. Storage costs are excluded as well as the cost of driving to a storage location. Evidently, additional costs must be added for transportation with special requirements, such as cooled transport. Finally, the cost of the container is also added proportionally to the time used, with more advanced containers incurring higher rates. For instance, an insulated container has a slightly higher rate than a non-insulated container. The preferred container size is determined based on the product density and the container sizes used in the loading and unloading region. Also, the calculation considers whether company owned trucks can be used or charters must be used. Driver salaries are set per region and are included in the cost of arcs.

Also, the calculation takes into account whether own trucking can be used or whether charters are used. Driver salaries are set per region and included in the cost of arcs. Figure 3 displays the output of Quintiq for a hypothetical scenario.

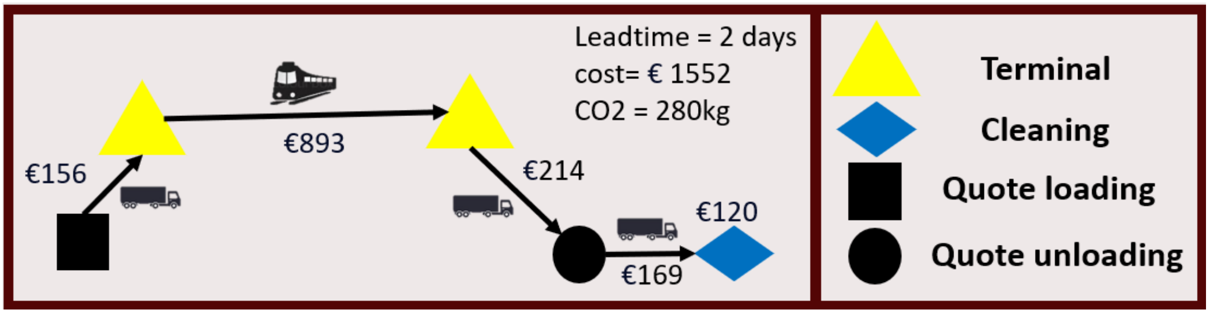

Figure 3: An example of a preferred path in Quintiq

The path given by Quintiq is often changed based on experience of the sales employee. For example, a cleaning station might be avoided based on experienced low quality by the load unit planners. Adjusting the ’preferred path’ also occurs when Quintiq provides clearly false or missing information.

Unfortunately, the preferred path does not include information about expected empty mileage costs. Empty trucking and empty container repositioning costs depend on how and with which orders the quote order will be combined. Quintiq has the capability to combine customer locations that can be transported with the same container type and searches for the optimal cleaning stations in between. Regions are frequently imbalanced, meaning that the number of loadings and unloadings differ significantly. Empty container relocation is necessary from surplus to shortage areas. A substantial portion of overall costs is attributed to the relocation of empty containers and empty trucking mileage.

After sales has received the quotation, it typically sends an email to the product-market combination (PMC) team leader. Asking for likely return scenarios and corresponding likelihoods of those scenarios. Sales then estimates the costs for the different scenarios that the team leader provided. Next, the role of the PMC team leader will be discussed and how he/she creates the scenario planning for a quote order.

PMC team leader

The PMC team leader provides sales with the scenario planning. The scenario planning includes a boat/train connection based on the lead time, frequency and reliability requested by the customer. For the connections that meet these requirements, the one with the lowest combined cost boat/train and trucking is generally chosen. In addition to estimation the costs of intermodal transport, occasionally transport solely by truck is investigated by placing the ride on Bulkio. Bulkio is a transport matching service platform of Van den Bosch, where charter companies can bid on rides.

The PMC team leader must estimate how the return trip will occur. The PMC team leader does this based on past data, already booked orders, volume predictions provided by customers and their experience with the market in the quote loading and quote unloading region. The time between processing the quote and actually executing the order is often more than two months. Two months from now, there are almost no orders scheduled. As transport dates and times are typically finalized approximately five days before the actual transport takes place. Therefore, the future order set is uncertain at the time the quote must be processed. Moreover, the week and regularly the month when the quote order must be executed is not provided by the customer.

Container and previous load requirements further complicate the creation of a scenario planning. The PMC team leader forecasts a future order set that can be combined with the quote order. Subsequently, scenarios are drawn from this set.

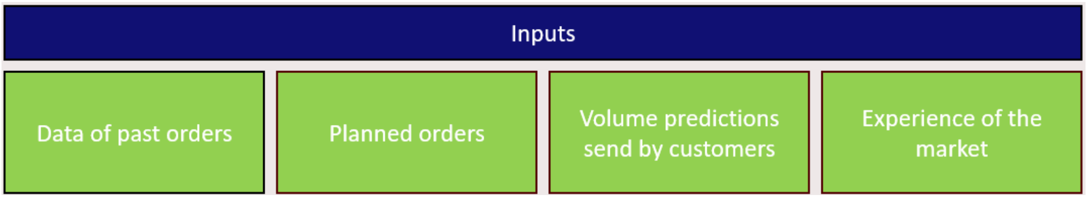

Figure 4: Inputs for the scenario planning

Aside of making the scenario planning, the PMC team leader advises sales which orders to pursue in order to minimize the repositioning of empty containers. The PMC team leader also informs the pricing managers what major connections of the network have changed. The pricing manager uses this information to strategically search for new customers and adjust prices.

Cost estimation example

First follows a hypothetical example of a scenario planning and related cost estimation. Subsequently, the role of the pricing manager is discussed.

A hypothetical example of a scenario planning is visualized in Figure 5. A customer asks for a price from the port of Rotterdam to a company in Hungary, Budapest. After creating the foretasted compatible order set, the PMC team leader draws a scenario planning where 20% of the rides return empty (green), 50% of the outbound trips have a pickup close to Budapest (purple), and 30% of the rides have a pickup in Zagreb (blue). The train ride that is used for the outbound trip goes from Duisburg to Budapest. Where all orders that were consolidated with the quote order had an unloading location close to Rotterdam.

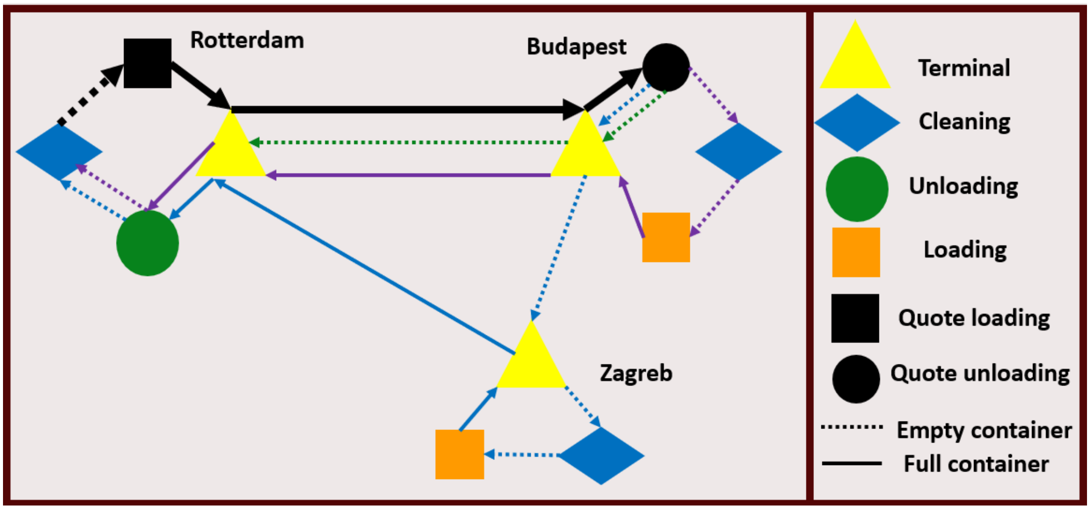

Figure 5: Example of a scenario planning

Sales receives the scenario planning via email from the PMC team leader and begins calculating the costs for the different scenarios. For example in the dedicated scenario (purple), first a truck is needed from the loading location in Rotterdam to the terminal in Duisburg. Then, the container is transported by train from Duisburg to Budapest. The costs of the train ticket is estimated based on past prices or set equal to price agreements established by the procurement department. From the terminal in Budapest, the container load unit is transported to the unloading location. In the (green) scenario the now empty container is transported from the unloading location to the terminal in Hungary and then back to the terminal in Duisburg. In the (purple) scenario, the container is cleaned after unloading and then loaded at a loading location nearby, shipped to Rotterdam, unloaded and cleaned. In the last scenario (blue), a combination is made with a loading in a different region .

For certain products, additional services are such as heating or compression are required, which obviously incur extra costs. After calculating the operational costs, a contribution margin is added to cover overhead costs and potential profit for Van den Bosch.

A overview of the costs for the dedicated scenario (green) is provided by Table 1. The cost of the container is already included in the trucking and train arcs. Sales always uses trucking paths that have the same starting and ending points. The cost assigned to the quote order is either done as a percentage of the empty mileage plus the loaded outbound trip of the quote order. Or the revenue (minus the minimally required contribution margin) of the consolidated order is subtracted from the total cost of the rounded trip. Finally, the cost of the different scenarios are put in Excel and multiplied with the likelihood corresponding to that specific scenario.

Expenses	Amount in euros
Trucking Rotterdam	350
Trucking Budapest	300
Train ticket empty	540
Train ticket loaded	620
Cleaning	80
Heating	150
Contribution margin	510
Total	2550

Table 1: A hypothetical example of a cost estimation

Pricing manager

The pricing manager is responsible for determining the final price. The cost estimation serves as crucial input for determining the final price. Next to that, the price is based on strategic objectives and market predictions. For example, pricing managers might opt for a lower contribution margin to attract a new customer. Alternatively, they might increase the profit margin if they know their network is stronger than that of competitors. Next to experience, pricing managers also utilize a model that predicts an appropriate sales price. Among the model parameters, parameters such as the oil price or an industry performance indicator, are included in the model. Where the price change because of the model input is not allowed to be more than 2%. An overview of the pricing process by means of a swimming lane diagram is shown in Figure 12.

In the following sections, a brief description will follow regarding how the actual order is planned and transported.

Operational load unit planner

The operational load unit planner assigns containers to orders, that meet the order requirements and lead to relatively low operational costs. The load unit planner determines the actual routing of the container, including selection of the train/boat connection and cleaning station. The load unit planner relies heavily on experience to assess the reliability of train/boat connections, the quality and busyness of cleaning stations, and their impact on truck routing. As this information is typically not available in Quintiq. Due to the required experience, each operational load unit planner specializes in a specific region and operational division.

Operational fleet planner

The operational fleet planner assigns trucks and truck drivers to the container routing determined by the operational load unit planner.

Truck driver

Truck drivers are required to deliver the containers according to the planning established by the operational fleet planner. A truck driver must adhere to several rest regulations set largely at the national level. For example, in the Netherlands a truck driver has a maximum total driving time per day of ten hours.

Post-calculation

Van den Bosch calculates the operational cost of orders after completion of the order. However, a proper method for this lacks. The challenge lies in accurately allocating the costs of empty trucking and empty container repositioning to the orders that caused them. One method used assigns the costs of empty trucking and empty container repositioning from the unloading location of an order until the container is reused for another loading or placed into storage.

Trend intermodal bulk transport

Bulk carriers are embracing digitization and increasingly make data-driven decisions (Nitonye et al., 2024). Bulk carriers are innovating by offering customers a choice between various transport modes in real-time through digital platforms. In the future, bulk logistic providers will guide customers in their mode choice based on how well it integrates into their operational network. For instance, customers can choose a time window where time windows that lead to estimated efficient truck routing, will be priced cheaper. Automatic cost estimations will be the backbone of these digital platforms.

2 Problem description and research questions

2.1 Business problem

Accurate cost estimations are important in the transport industry, with relatively low margins. Setting a price to low leads to a loss. While Setting it too high results in lost business, as competitors may offer lower prices.

Creating scenario plannings that accurately reflect the costs of a quote order is a challenging task. Firstly, not all orders can be combined due to previous load and container requirements. Secondly, it is difficult to predict changes in empty trucking and empty container repositioning due to the extensive size of the network. The current scenario plannings focus on the container balances near the quote loading and quote unloading, while the container balances in the other regions are largely neglected. Also, obtaining an overview of the trucking paths and determining how an additional order fits in is challenging. Moreover, there is a tendency to calculate the cost of the average return trip. While actually the focus should be on the average return trips caused by the additional quote orders. For example, a quote order from Netherlands (heavy export region) to Great-Britain (heavy import region) is calculated with a 80% empty return trip. However, every additional order will clearly result in an additional empty container repositioning move. Besides the potential for more accurate cost estimations, the current cost estimation process is also time consuming.

Van den Bosch processes approximately 250 quotes per week across all offices combined. Where the quotation process takes, on average, between 15 and 20 minutes. This results in a labour cost of approximately 2000 euros per week, assuming labor cost of 25 euros per hour. Only a small proportion of the quotations lead to actual business, as customers ask multiple bulk logistic providers for a quote price. Since the PMC team leader is occupied with plenty of other tasks, it occasionally takes more than 24 hours for the scenario planning to be delivered to the sales team. Subsequently, customers might already agree to a price from another bulk logistics provider. Conclusively, there is potential for faster processing times, improved accuracy and reduced labor costs.

2.2 Research questions

The goal is to automatically calculate cost estimations for quotes. From this goal, the main research question can be derived.

> *How can accurate cost estimations for quote orders be processed automatically?*

The main research question is divided into several sub-questions:

> *1. How are the cost estimations for quote orders currently processed at Van den Bosch?*

Thoroughly investigating the current cost estimation process is useful for beneficial reasons. Firstly, since the process is partly automated, it must be investigated where additional value can be added. Secondly, investigating the current cost estimation process will show which factors are relevant for accurate cost estimations.

> *2. What models can be found in the literature that accurately estimate the costs of bulk transport?*

2A: What cost estimation models are studied for the transportation industry?

2B: What mathematical models accurately reflect empty container repositioning and empty trucking costs?

Models will be reviewed that accurately reflect empty container and empty trucking cost. The literature study will also explore methods to effectively manage the complexity of the problem.

3. How can the cost estimation process be modeled and solved?

3A. How can the empty repositioning costs of trucks and containers be modeled?

3B. How can the model be extended with optimal cleaning selection?

3C. How can the model be extended to include the selection of the outbound trip for the quote order?

An integer programming model will be developed that solves trucking operations within the quote regions and the imbalances of containers of the whole network. Subsequently, the model is extended with a more sophisticated cleaning station selection. The difference between using the the more sophisticated cleaning station selection and the closest cleaning station is researched. Subsequently, the outbound trip selection for the quote order will be added. Thereafter, the options of empty container repositionings within the trucking paths is researched.

4. How accurately does the model estimate the costs of empty trucking and empty container repositioning?

Several scenarios will be compared to the pre-calculation and the post-calculation. The outcomes will be thoroughly analyzed.

The remainder of this thesis is structured as follows. In chapter 3, a literature review is presented. Subsequently, a network flow model is designed in chapter 4. In chapter 5, a proposed solution method is proposed. In chapter 6, analysis and motivations for model input values are described. Chapter 7 contains the computational experiments conducted. Lastly, answers to the research questions will be provided, the limitations of the research are discussed, recommendations are made for Van den Bosch and future research opportunities are opted in chapter 8.

3 Literature review

In this section, current literature related to cost estimations for intermodal transport is presented. First, the customer key attributes are briefly reviewed. Next, current pricing models with a focus on cost estimations are reviewed. Subsequently, empty container repositioning (ECR) models are reviewed. Lastly, vehicle routing problems (VRP) and corresponding solution methods capable of handling large instances are discussed.

Intermodal transportation is a type of multimodal transportation where goods are transported from origin to destination in the same intermodal transportation unit (SteadieSeifi et al., 2014). Intermodal transportation compared to full-truck transportation, is agreed to have lower emissions and lower costs for long distances. The overhead costs are typically higher for intermodal transportation than for uni-modal transportation (Zgonc et al., 2019). The Vehicle Routing Problem with Pickup and Delivery (VRPPD) is a fundamental model and underpins many intermodal transportation problems (Imai et al., 2007). Freight transportation research is often classified into full truckload transport (FTL), less-than truckload transport (LTL) and express deliveries (Wieberneit, 2008). Bulk transport almost solely concerns the pickup and delivery of full truck loads (Berbeglia, Cordeau, Gribkovskaia, & Laporte, 2007). The category that combines time windows with pickup and delivery tasks is known as the Vehicle Routing Problem with Pickup and Delivery and Time Windows, which resembles closely with bulk transport (VRPPDTW) (Toth & Vigo, 2002).

Literature in the field of logistics and operations research often categorize processes into operational, tactical and strategic levels. The pricing process clearly belongs to the tactical level. Since decisions involved are choosing services and associated transportation mode, while real-time operational requirements are excluded (Macharis & Bontekoning, 2004).

3.1 Customers key attributes for service selection

There exists a comprehensive yet conflicting body of research regarding the significance of various customer key attributes in service selection. There is no consensus on cost as the most important factor for selecting transportation services. Evers et al. state that customers can roughly be characterized in three groups. The first group is almost exclusively driven by price. The second group places the most emphasis on lead time and availability. The third group has specific and complex transport requirements, focusing their primary search on transportation services capable of meeting those specialized needs. (Tsamboulas & Kapros, 2000). Bayazit and Karpak found that for some customers being on-time and the responsiveness in the face of disruptions, are the most critical factors (Bayazit & Karpak, 2013). The impact on the environment was not found to be a significant customer key attribute, although it is likely gaining in significance. Numerous research highlights the hesitancy of logistics companies in embracing sustainability (Wolf and Seuring, 2010) (Lin and Ho, 2008). From a modeling perspective, incorporating CO_2 is often intuitive and does not significantly increase the complexity of the transport problem. Regularly, the impact of CO_2 is modeled as a penalty in the objective function (Demir et al., 2019b) (Zhao et al., 2018). Alternatively, a maximum amount of CO_2 is modeled by a constraint in an integer programming model.

3.2 Pricing methods

Pricing strategies for the logistics industry are extensively discussed in the literature. Whether it is cost-plus pricing or network pricing (Kienzler and Kowalkowski, 2017). Network pricing involves setting prices for the movement of goods over arcs in a networks such that the network is not over-utilized and maximum profit is achieved.

Most network pricing models assume knowledge of the price elasticity of demand, which quantifies the percentage change in demand corresponding to a percentage change in price. One network pricing model integrates the pricing decisions with repositioning empty containers, aiming to maximize profitability (Najafi & Zolfagharinia, 2021). Assuming to know the price elasticity of demand is a significant assumption, and research support for the assumption in third-party logistics (3PL) was not found.

There is a substantial body of literature discussing pricing integrated with operations planning in intermodal transportation, but only a small subset addresses the impact of empty container repositioning moves. One example that considers this is that of Li and Tayur, where the model aims to maximize profit derived from revenue and costs. The cost components include train ticket costs and equipment expenses. The decision variables in the model involve setting prices between terminals for specific service classes. The model also incorporates capacity constraints for the terminals. The model is solved by means of an integer programming model (Li & Tayur, 2005). A study at a bulk logistics provider examines the impact of pricing on empty container repositioning while considering capacity restrictions for the arcs (Holle, 2019). However, the study aggregated empty container repositioning to the regional level and dedicated trucking was assumed. Another study presented a model that maximized profit by incorporating both empty repositioning decisions and pricing strategies. Their perspective was that of a rail transport provider offering trailer-on-flatcar operations (Yan et al., 1995). Which differs significantly from the perspective of a bulk transport provider.

Cost-estimation and cost-plus pricing methods do not rely on the price elasticity of demand assumption. Cost-plus pricing involves first calculating the cost of the service and then adding a profit margin to obtain the final price. One drawback of cost-plus pricing is that cost estimations are based on forecasted volumes. Which can result in different costs and potentially losses. While many people assume that cost-plus pricing guarantees profits. The second drawback of cost-plus pricing is that it ignores customers' willingness to pay and competitors' prices. However when carefully implemented, the benefits can be multifold: powerful differentiation, customer trust, reduced risk of price wars and steady predictable profits for the company. Besides, cost-plus pricing is easily communicated to the workforce (Dholakia, 2018). The literature about cost-plus pricing methods that include a quantitative model for intermodal transportation is limited. A significant portion of the literature is dedicated to frameworks or suitable decision support systems (DSS). A recent paper proposes a cost-plus pricing method for intermodal transportation with at the basis a planning model that minimizes transport costs. An integer programming model is formulated where the transportation cost for serving the demand is minimized. The costs include storage, transfer, transportation and potential subcontracting costs. Capacity of the own fleet is considered and when it is exceeded a more expensive subcontracting option must be used. The model also includes lead time constraints (Li, 2015). The case study, however, considers an extremely small network and no information regarding computation times is provided.

Several studies dissect the entire cost structure of transporting loads by truck, train or boat. Considering numerous parameters related to the cargo and the chosen mode of transportation. Boardman, Malstrom, and Trusty provide a comprehensive overview of cost calculations for several modes of transportation. Among model parameters included are: distance, average speed and weight of transported good (Boardman, 1999). While most papers assume that the costs of arcs are known, this paper focuses on accurately modeling the costs of these arcs.

The change in costs due to empty container repositioning (ECR) and empty trucking resulting from an additional order is seldom included in cost estimation and pricing models. Which is surprising, given the extensive body of non-conflicting research emphasizing the relevance of repositioning empty containers.

3.3 Empty container repositioning

Multiple papers conclude that the cost of ECR is significant. Shintani et al. report that in hinterland around 40 % of the shipments are empty repositionings, resulting in substantial costs (Shintani et al., 2010). In maritime shipping the percentage of empty repositioning costs is around 20%, which constitutes 8% of the total cost (Sanders et al., z.d.). No specific cost percentage for the hinterland was found but presumably the percentage is significantly higher than for maritime shipping. The main cause of ECR is imbalanced trade. Even when overall demand is balanced, container type imbalances can occur due to the shipment of different products that require different container types (Başarici & Satır, 2019). Due to its significance, the body of research on empty container repositioning (ECR) is extensive and dates back to more than 30 years.

Already in 1993, researchers expressed the desirability of jointly optimizing the allocation of loaded and empty containers within a single mathematical model (Crainic et al., 1993a). This finding is quantitatively confirmed by Erera et al., who developed a model for global intermodal tank container transport. The model incorporates constraints to ensure equal inflow and outflow at terminals, thereby accounting for empty container repositioning, as flows of empty containers are possible between all terminals. Along with trucking costs incurred from loading locations to terminals and from terminals to unloading locations. All variables incorporate the time dimension. A rolling horizon approach was used where the horizon was set to one week. The customer set consisted of 100 customers. By simulating with both an integrated model and a two-phase model, it was found that the integrated model outperformed the two-phase model by 2%. The paper states that the actual savings must be larger, considering the potential reduction in fleet size. Interestingly, the paper extends the model with cleaning requirements, where cleanings are conducted at terminals (Erera et al., 2005). However, the number of ports was extremely small, equal to six. The possibility of street turns was not included. A street turn concerns combining an unloading leg with a loading leg in a single trucking path to reduce the empty trucking kilometers. The effectiveness of street turns in the intermodal transportation context is thoroughly researched, the next paragraph provides a brief summary. Kolar et al. reviewed the literature on ECR, with a particular focus on landlocked countries. They concluded that current strategies for ECR are predominantly focused at the global level, and that there is a lack of strategies tailored to the local level (Kolář et al., 2018).

One common strategy to reduce the cost of empty trucking in hinterland is the use of street turns. Several papers state that a street turn requires the matching of the time windows, locations, and container types. The requirements limit the use of street turns (Braekers et al., 2011) (Smilowitz, 2006). The paper by Reinhard et al. was the only one found that, in an extension, demonstrates how to incorporate the impact of trucking paths on terminal container balances. A constraint is set for every terminal where the increase or decrease of containers caused by the trucking paths needs to be smaller or larger than a certain quantity. An additional parameter was introduced to track the increase or decrease of containers at terminals by trucking paths. Where trucking paths can be dedicated, and street turns are possible. The paper also recognizes that combining orders becomes an NP-hard problem. However, smaller time windows result in fewer feasible combinations, which in turn reduces the number of decision variables. Customer locations, loading, and unloading locations are pre-assigned to terminals where containers need to be picked up or delivered, respectively. For any feasible combination of an unloading and a loading, one trucking path is generated. The authors recognize that imposing a minimum or maximum number of containers at a terminal can be feasible. However, the range must be sufficiently large, or the model may become infeasible. The model was able to find optimal solutions within one minute for real life instances (Reinhardt et al., 2012). If arcs between terminals were included in the model, constraints ensuring balanced terminals would still be feasible. The model solely captures the regional level. The model excludes cleaning operations, which might significantly affect the routing of containers. The incorporation of cleaning stations within trucking routes has received limited attention. Most research in this area focuses on the cleaning of multi-compartment in combination with multi-vehicle routing (Lahyani et al., 2015).

Within the literature on ECR, a large part attempts to incorporate stochasticity of one or multiple factors. Stochastic programming has been applied to manage empty containers, addressing uncertainties in demand and transportation capacities (Crainic et al., 1993). Specific papers on maritime networks also model stochastic demand(Chao & Chen, 2015) (J. Li et al., 2007) (Di Francesco et al., 2009). Recently, there is substantial growth in research focusing on obtaining robust solutions for empty container management (Chang et al., 2008). Stochasticity significantly increases the complexity. Therefore, researchers often develop heuristics or decomposition methods. One commonly practiced decomposition method is the rolling horizon approach. Where the horizon is divided into several periods. The first period is solved to optimality, and then subsequent periods are solved using the variables obtained from the previous period, and so on. Choong et al. studied the effect of the length of the rolling horizon for empty container management, including a case study on intermodal container transport (Choong, 2002). Deterministic models combined with a rolling horizon approach are able to handle large networks. Integer programming models are the most commonly used models for ECR (Huang et al., 2015) (Akyüz & Lee, 2016). Where both branch and bound, and column generation methods are frequently used as a solution method.

Researchers turn towards heuristics when the nature of the problem is stochastic or multi-objective in combination with a large-scale network. For large-scale deterministic networks with a single objective, integer programming performs well (Kuźmicz & Pesch, 2019). Otherwise heuristics such as genetic algorithms or ant colony optimization(ACO) are often used and provide fast and close to optimal solutions (Bernat et al., 2016). For example genetic algorithms are used for network construction in combination with ECR (Shintani et al., 2005b). One disadvantage of heuristics is that the optimality gap can be unknown or larger than 0,1%.

Wang et al. recognize the importance of empty container repositioning within the hinterland. An integer programming model was made that serves the loadings and unloadings in a region with multiple depots. After completing unloading, the model can decide to which depot the empty container should be brought. Similarly, before loading, the model can decide from which depot the empty container should be taken (Wang & Wang, 2007). Street turns are possible, but closed-loop truck routing is not required. Meaning that a truck does not need to return to the port where it started. Jula et al. research the reuse of empty containers at the regional level. After containers are unloaded the container can be moved directly to a loading location. Combining the unloading and the loading is feasible if the truck can arrive within the specified time window. The paper start with an integer programming model that includes time window constraints. Later, the time window constraints are relaxed but extremely high costs are assigned to infeasible combinations. A real life scenario was solved with and without the possibility of street turns. Large savings were reported. The authors note that actual savings are even larger, because street turns lead to lower waiting time for the drivers at storage locations (Jula et al., 2006). There still is a need for models studying multi-asset resources, the use of multiple types of containers (SteadieSeifi et al., 2014b). Conclusively, The body of literature that focuses on ECR for intermodal transportation with the inclusion of street turns or other regional strategies is limited.

3.4 Vehicle routing problems

An extremely large body of literature is written with regards to vehicle routing problems (VRP). Next to a single depot case, the multiple depot case is extensively studied as well. Flow constraints make sure that vehicles return to the depot from where they started (Montoya-Torres et al., 2015). Another classification is the inclusion of time windows or without time windows. For time windows the distinction is further made between soft time windows and hard time windows. Hard time windows do not have the possibility of arriving early or late, where with soft time windows early or late arrivals are possible under the incurrence of penalty costs. Modelling hard time windows is typically done by setting constraints (Sousa et al., 2011). Problems for soft time windows are often modeled by including them as a penalty cost in the objective function. Hokey Min developed a model for soft time windows that analyzes the trade off between route cost and penalty cost incurred for arriving to late or to early (Min, 1991).

Since VRP's are NP-hard, a tremendous body of research focuses on handling and mitigating the complexity of the problem. One research approach eliminates the outgoing arcs from customer nodes to other customer nodes, where this would likely lead to suboptimal solutions, considering both distance and time windows. Meaning that a customer cannot be visited from another customer if the arrival time would be outside of the time window (Bent & Van Hentenryck, 2010). A nearest neighbour algorithm was proposed decades ago and also recently is shown to effectively improve solutions in a second stage (Mohammed et al., 2017). Insertion heuristics have been demonstrated to be effective when a large number of complicating constraints must be incorporated. Insertion heuristics ensure feasible solutions by verifying the feasibility of the constraints before inserting the location. Insertion heuristics can be extremely efficient because regularly only a small subproblem needs to be checked to verify feasibility. (Campbell & Savelsbergh, 2004).

Other strategies focus on decomposition, for example reducing the complexity by first clustering the customers, called cluster first route second. This involves assigning a vehicle to the cluster and subsequently optimizing routes within each cluster (Miranda-Bront et al., 2016). Recent research combines this approach with evolutionary algorithms such as particle swarm optimization (PSO) (Sultana et al., 2017). Another evolutionary algorithm used for VRP's is a genetic algorithm. First unloading and loadings are combined when the saved travel time is significantly large. A local search heuristic combines sequences of unloading and loading. Subsequently, the solutions are improved by an insert and cross operator (Caris & Janssens, 2009). Besides spatial decomposition, a common strategy is to use temporal decomposition such as the rolling horizon approach.

Study	Cost estimation	Willingness to pay	Intermodal transport	ECR	Truck routing	Cleaning operations	Previous load requirements	Large network	Stochas-ticity	Capacity	Method	Subject
(Li & Tayur, 2005)	✓	✓	✓							✓	IP	Pricing and planning for intermodal transport
(Holle, 2019)	✓		✓	✓				✓	✓	✓	Simulation	Pricing strategies in transportation networks
(Yan etal., 2005)	✓		✓	✓				✓		✓	IP(simplex)	Opportunity cost of conveyor TOFC
(Erera et al., 2005)			✓	✓		✓		✓		✓	IP	Intermodal tank container management
(Reinhardt et al., 2012)			✓	✓	✓		✓	✓		✓	IP	Optimization of the drayage problem
To be found					✓	✓	✓	✓		✓		
This study	✓		✓	✓	✓	✓	✓	✓			IP	Cost estimations for intermodal transport

3.5 Research gaps

Several limitations and research gaps were identified through the literature review:

- There is a lack of cost estimation or pricing models that include empty container repositionings and empty trucking.
- Most works that consider empty container repositioning focus either on the global or the regional level. Models that integrate empty container repositioning at the global and regional level are scarce.
- Truck routing that integrates cleaning station selection cleaning operation requirement and cleaning cost remains rare.

In order to address the gaps identified, this research focuses on cost estimations for intermodal bulk transport by integrating truck routing with optimal cleaning selection at the local level, empty container repositionings at the global level and outbound trip selection for the quote order.

4 Model

The goal is to calculate the operational costs of a potential new order, the so called quote order. This section presents an integer programming formulation that computes the minimal costs of serving an order set plus the quote order. Orders are fulfilled using intermodal container transport. The journey from the loading to the unloading location of an order is defined as the loaded outbound trip. The loaded outbound trip consists of a trucking leg from the loading location to the departure terminal (trucking leg loading), a train/boat connection between the departure and arrival terminal, and a trucking leg from the departure terminal to the unloading location (trucking leg unloading). The complete outbound trip is assumed to be known for all orders except for the quote order. The trucking legs must be traversed by trucks, where trucking paths start and end their routes at the same terminal. A truck must visit a cleaning station directly preceding the loading location, where the container is required to be cleaned. Additionally, the inflow of containers must equal the outflow at all terminals. Using an integer programming model, the cost of serving the order set plus the quote order is computed. Subsequently, relaxing the constraints for the quote order, the cost for the order set without the quote order is computed. The subtraction of the latter from the former leads to the cost estimation of the quote order.

The transportation network is denoted by $TN = (C, L, U, T, OQ)$. Where C is the set of cleaning stations, L is the set of loading locations, U is the set of unloading locations and T is the set of terminals. The set OQ contains the set of potential train and boat connections available for the quote order. The corresponding set of truck loading legs and truck unloading legs for the quote order are the set QL and QU, respectively.

Sets	
L	Loadings
U	Unloadings
T	Terminals
C	Cleanings
OQ	Set of outbound trips for the quote order
V_l	Vector of paths visiting loading l
V_u	Vector of paths visiting unloading u
P_t^-	Vector of paths reducing the number of containers at terminal t
P_t^+	Vector of paths increasing the number of containers at terminal t
P_{ql}	Vector of paths serving customer location ql
P_{qu}	Vector of paths serving customer location qu
Model parameters	
c_p	Cost of path p
po_{oq}	Cost of outbound trip oq
$pn_{p,t}^-$	Decrease in number of containers by path p at terminal t
$pn_{p,t}^+$	Increase in number of containers by path p at terminal t
ql	Quote loading
qu	Quote unloading
Decision variables	
p_p	Selecting path p
x_{oq}	Selecting outbound trip oq

4.1 Integer programming formulation

The objective function (1) jointly minimizes the cost of empty container repositioning, trucking, cleaning operations and outbound trip for the quote order, all of which are encompassed in the cost of paths c_p. The loading and unloading locations must be visited by trucking paths, where p_p contains the set of trucking paths that visit one or more loading and unloading locations. Also, the set p_p contains empty container repositioning moves between all terminals. The decision variable x_{oq} represents which train/boat connection is chosen for the quote order. The cost of the associated train/boat connections are represented by po_{oq}.

$$min \sum_{p \in P} p_p \; c_p + \sum_{oq \in OQ} x_{oq} \; po_{oq} \tag{1}$$

The network flow model is subject to the following constraints:

Traversing trucking leg customer locations constraints

$$\sum_{p \in V_l} p_p = 1 \qquad \forall \, \mathrm{l} \in \mathrm{L} \tag{2a}$$

$$\sum_{p \in V_u} p_p = 1 \qquad \forall \, \mathrm{u} \in \mathrm{U} \tag{2b}$$

Constraint (2a) ensures that all loading trucking legs are traversed by one of the trucking paths that visits the loading location. Constraint (2b) ensures all unloading trucking legs are traversed by one of the trucking paths that visits the unloading location.

Terminal balance constraints

$$\sum_{p \in P_t^-} p_p \; pn_{p,t}^- - \sum_{p \in P_t^+} p_p \; pn_{p,t}^+ = 0 \qquad \forall \; \mathrm{t} \in \mathrm{T} \tag{3}$$

Constraint (3) ensures that each terminal maintains an equal inflow and outflow of containers. It is assumed that there are always enough containers available at terminals, as the constraint is not defined per time unit and no starting inventory is used.

Selection train/boat connection quote order constraint

$$\sum_{oq \in OQ} x_{oq} = 1 \qquad \forall \; \mathrm{oq} \in \mathrm{OQ} \tag{4}$$

Constraint (4) ensures that exactly one train/boat connection is selected for serving the quote order.

Traversing trucking leg loading and unloading quote order constraints

$$\sum_{p \in P_{oq,ql}} p_p \; x_{oq} = x_{oq} \qquad \forall \; \mathrm{oq} \in \mathrm{OQ}, \; \mathrm{ql{=}ql} \tag{5a}$$

$$\sum_{p \in P_{oq,qu}} p_p \; x_{oq} = x_{oq} \qquad \forall \; oq \in OQ, \; \mathrm{qu{=}qu} \tag{5b}$$

Constraint (5a) ensures that the trucking leg of the quote loading is served when that specific trucking leg corresponds to the chosen train/boat ticket for the quote order. Similarly, constraint (5b) ensures that the appropriate trucking leg of the quote unloading is served.

4.2 Creating paths

There are two type of paths: trucking paths and train/boat connections between terminals. In this subsection, the construction of trucking paths and empty container repositioning paths is described. Firstly, it is demonstrated how the cleaning stations can be inserted into the trucking paths. Secondly, customer sequences are created that are feasible time window wise. Thirdly, the cost of the paths are calculated. Lastly, the empty container repositioning paths are added. Below, the meta-parameters are shown that form necessary inputs for generating the paths.

Secondary sets	
Q	Set of customer locations $U \cup L$
N	All locations $U \cup L \cup C \cup T$
A	Set of arcs between all locations *(i,j)* for all $i, j \in N$
PG	Set of product groups
Secondary model parameters	
pg_q	Product group belonging to customer location q
$[st_q, et_q]$	Time window for serving customer location q
tl_q	Terminal connected to customer location q
clo_{pg}	Vector of cleaning stations offering the cleaning of product group pg
$cc_{c,pg}$	Cost of cleaning product group pg at cleaning station c
ct	Cleaning time in hours
lt	Loading time in hours
ut	Unloading time in hours
t_{ij}	Time it takes to traverse arc *(i,j)*
vct	Vehicle cost per kilometer travelled by truck
vcc	Vehicle cost per kilometer travelled by a boat or train connection
w	Wage of the truck driver in euros
vs	Vehicle speed in kilometers per hour
c_{ij}	Cost in euros for traversing arc *(i,j)*
te	Time in hours allowed to arrive earlier than st_q under penalty costs
tl	Time in hours allowed to arrive later than et_q under penalty costs
pe	Penalty cost in euros per hour for arriving earlier than st_q
pl	Penalty cost in euros per hour for arriving later than et_q
co_q	A vector of locations after which customer location q can be inserted in a trucking path
mnc	Maximum number of customer locations in a trucking path p

4.2.1 Creating trucking paths

Optimal cleaning insertion between customer locations

It is assumed that a cleaning operation must correspond to the previous load when the container is immediately combined with a loading in a trucking path, after visiting an unloading location. Alternatively, a cleaning operation must match the next load when the container originates from a terminal. Thereby, not requiring to update information about the previous load of a container in the decision variables. Moreover, it is assumed that a loading location is always directly preceded by a cleaning station visit. The last assumption closely resembles practice, as the previous load is not the only factor that needs to be considered when choosing the appropriate cleaning operations. Customers regularly ask for specific cleaning operations such as a halal/kosher cleaning or sealing of the container. Occasionally customers provide a list of acceptable cleaning stations. Thus, cleaning a container without knowing its assigned upcoming order is generally inefficient. Another assumption is that all customer locations already have the loaded trucking leg to a terminal determined. Given that each customer location q is already assigned to a terminal tl_q, and the set of quote loadings QL specifies the trucking legs for the different outbound trips OQ, the optimal cleaning station can be inserted between two customer locations.

From an unloading location a truck can drive to a cleaning station and then to a loading location. For all cleaning stations in the region that offers the cleaning operation for the product group clo_{pg} of the unloading, those arcs between the unloading and loading location are totalled and the cleaning station is selected that minimizes the trucking cost plus cleaning cost $cc_{c,pg}$ of the product group pg at cleaning station c.

From a loading location, a truck must first drive to the terminal where that loading is destined to be delivered. As a result, the arcs between that terminal and a cleaning station and then to the second loading location must be evaluated. This evaluation considers the cleaning stations in the region that provide cleaning services suitable for the product group of the second loading. Again, the cleaning station that minimizes the trucking cost plus cleaning cost was chosen.

Optimal starting terminal and first cleaning of a trucking path

To model the empty trucking costs, trucks must begin and end a trucking path from the same terminal after visiting one or more customer locations, thereby, capturing the empty trucking cost.

The optimal start and end terminal depends on the first and last customer location of a trucking path. For every combination of customer locations as the first and last location in the trucking path, the optimal terminal is determined to start and end the trucking path. The type of customer locations, being loading or unloading locations, determine which arcs need to be minimized. If the last location is a loading, the truck must travel to the terminal assigned to the loading anyways. Thus that terminal is the optimal terminal to start and end the trucking path. Similarly, if the first customer location in a trucking path is an unloading, the truck must first pick up the container from the corresponding terminal. That terminal is then the optimal terminal to start and end the trucking path. When the last customer location in the trucking path is an unloading and the first customer location is a loading, determining the starting terminal is not straightforward. In that case, the distance from the last customer location via the starting terminal to the cleaning of the first customer location (loading) must be calculated. Observe that in the latter case, the minimization involves a path consisting of three arcs. To reduce the running time, Dijkstra's algorithm could be used in this case (Dijkstra, 1959).

Feasible customer location extensions

Here, the customer locations that can be inserted after other customer locations within the same trucking path are determined. Soft time windows are assumed, a customer location can be inserted after another customer location if the time window of the next location minus the travel time to that location, is not more than te earlier or tl later than the time window of the previous location. Since, the optimal (under the presented assumptions) cleaning stations are known between customer locations, the travel time between customer locations can be extracted.

The travel time between customer locations directly effects which customer locations can be combined. The time window of the next customer location is shifted backward by the travel time between the customer locations. Also, the lower bound of that time window is decreased by the allowed earliness te under the incurrence of penalty costs and the upper bound is increased by the allowed lateness under penalty costs, tl. Subsequently, if the intersection between the two sets is not empty, the customer locations can be combined in a single trucking path. The procedure is outlined in Algorithm 1. An example when customer locations can be combined or cannot be combined is shown in Figure 6.

For explanatory purposes the travel time between the customer locations is varied. $t_{u3,l8}$ is the time to travel from the unloading location 3 to loading location 8. The time already includes the unloading time at unloading location 3 and the cleaning time at the cleaning station. The procedure for determining which customer locations can be combined in a single trucking path is shown in Algorithm 1. If the travel time between the customer locations is only 2 hours, the customer locations cannot be combined. If the travel time is 3 hours, the customer locations can be combined with penalty costs. Finally, if the time would be 5 hours the customer locations can be combined.

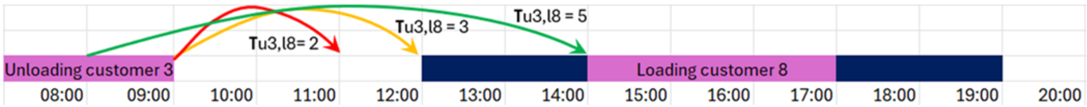

Figure 6: Example whether two customer locations can be combined

Algorithm 1 Feasible customer insertions in a trucking path after a customer location

```
for location in customer locations $q \in Q$ do
    Initiate empty list, $co_q = [\,]$
end for
Location1 = q1, location2 = q2
for location1 in customer locations, $q_1 \in Q$ do
    for location2 in customer locations, $q_2 \in Q \wedge q2 \neq q1 \wedge R_{q1} = R_{q2}$ do
        Time window location1 $[ES_{q1}, LS_{q1}]$
        Extended and shifted time window location2 = $[st_{q2} + te - t_{q1,q2}, et_{q2} + tl - t_{q1,q2}]$
        Overlapping time window = $otw_{q1,q2} = [st_{q1}, et_{q1} + tl] \cap [st_{q2} + te - t_{q1,q2}, et_{q2} + tl - t_{q1,q2}]$
        if overlapping time window is not empty, $otw_{q1,q2} \neq \emptyset$ then
            Append location1 to combinations location2, $co_{q2} + [q1]$
        end if
    end for
end for
```

The model parameter co_q then includes all customer locations after which location q can be inserted in a trucking path. In the next subsection this model parameter is used to generate sequences of customer locations that can be visited by single trucking paths.

Sequences of customer locations

Sequences with a length ranging from one up to and including the maximum number of customer locations in a single trucking path, mnc, are generated. Where mnc represents the maximum number of customer locations in one trucking path. First, sequences of length 1 are generated, consisting simply of the customer locations within the quote regions. How the quote regions are determined is shown in Chapter 5: Solution method. Generating the sequences is done in a sequential manner. After obtaining the sequences of length 1, these sequences are then used to generate sequences of length 2, and so forth. To generate sequences of length2, an iteration through all customer locations in the quote regions is performed. the parameter co_q contains all the locations where location q can be inserted afterwards. Subsequently, given a path with its last location q, new paths are generated with the extensions contained in co_q. Performing that operation for all paths leads to sequences of size 2. Iterating through all the sequences to find the sequences ending with a specific customer location takes a tremendous amount of time. Therefore, dictionaries were created with the last customer location in the sequence as keys and all the sequences ending with that customer location as the values. By doing so the lookup time was immensely reduced. The procedure is shown in Algorithm 2.

Algorithm 2 Sequences of customer locations

```
Initiate empty set of sequences, $sequences$
Initiate sequences of length 1, sequences[length1] = [ ]
for location in customer locations, $q \in Q$ do
    Append customer location to sequences of length 1, $sequences[length1] + q$
end for
for length in [2,max-length], $length \in [2, mnc]$ do
    Initate empty list, $sequences[length] = [\,]$
    for location in customer locations, $q \in Q$ do
        for location in locations that can extend that location, $q1 \in co_q$ do
            for sequence in sequences[length-1], $s \in route[length - 1]$ do
                Last-location = s[-1]
                if last-location is the same as the location that can be extend, $s[-1] = q1$ then
                    Extended-sequence equals the route plus extension, $ns = s + q$
                    Append extended-sequence , $sequences[length] + ns$
                end if
            end for
        end for
        for sequence in sequences[length] do
            if customer locations occur twice then
                Remove that sequence, $sequences[length].remove(sequence)$
            end if
        end for
    end for
end for
```

Table 2 provides a small example illustrating how customer sequences are created. The number of customer locations is equal to five and *mnc* is equal to three in this example, meaning that a trucking path can have a maximum of three customer locations. co_1 is a list of customer locations after which customer location 1 can be inserted.

Feasible insertions	Sequences[length1]	Sequences[length2]	Sequences[length3]
CO_1 = [2,3,4]	[1]	[2,1]	[3,2,1]
CO_2 = [3,4]	[2]	[3,1]	[4,2,1]
CO_3 = [4,5]	[3]	[4,1]	[5,3,1]
CO_4 = [ ]	[4]	[3,2]	[4,3,2]
CO_5 = [3]	[5]	[4,2]	[5,3,2]
		[4,3]	~~[3,5,3]~~
		[5,3]	~~[5,3,5]~~
		[3,5]	

Table 2: Example of customer sequences creation for trucking paths

An alternative approach was implemented using the itertools library, where all combinations of customer locations with a maximum length of *mnc* were generated, without considering the time windows. Subsequently, infeasible routes were eliminated. The approach led to extremely long running times and for larger values of *mnc*, a memory error was encountered. Therefore, the aformentioned approach was developed.

Cost of trucking paths

After obtaining the sequences, the cost of the trucking paths are determined. The cost calculation consists of four parts: the costs between the customer locations in the sequence, the cost of closing the sequence, the cleaning cost, and the penalty cost for arriving late or early at the customer locations. To calculate the costs between the customer locations in a truck route, iterations through the sequences were performed and the cost between customer locations were summed.

Additionally, the cost for moving from the last customer location to the starting terminal and from the starting terminal to the first customer location must be included. If the first customer location is a loading location, the truck must travel from the starting terminal to a cleaning and then to that loading location. If the first customer location is an unloading location the truck simply travels from the starting terminal to the unloading location. If the last customer location is a loading, the customer must travel from the loading location via the terminal assigned to that loading to the starting terminal. If the last customer location is an unloading location the truck must travel from that unloading location via the terminal assigned to that unloading to the starting terminal.

The third cost component of the trucking paths is the penalty for arriving to late or to early. It is assumed that a truck can arrive up to te hours earlier at the customer location, but then must wait until the start of the time window of that first customer location. The penalty costs are then equal to the waiting time multiplied by the wage of the driver. Also, a truck can arrive up to tl hours later at the customer location, and the penalty costs for arriving late are equal to pl. In order to find the minimal penalty cost of a trucking path, the optimal departure time from the starting terminal must be determined. The optimal departure time was determined by iterating over the extended time window of the first customer location in the trucking path. Observe that arriving early at the first customer location is clearly sub-optimal. As the assumption is that a truck must wait at that customer location until the start of the time window, incurring penalty costs for arriving early. By iterating through the extended time window and considering the travel time between customer locations, the hours arriving early or late can be determined. The hours for arriving early are multiplied by pe and the hours for arriving late are multiplied by pl. Adding those penalty costs results in the cost of the paths c_p.

Figure 2 shows an example of the penalty cost for the sequence [unloading location 3,loading location 8]. The total time required for unloading the container, cleaning the container, and driving between the customer locations is six hours in total. The optimal departure time is either 9:00 or 10:00 o'clock.

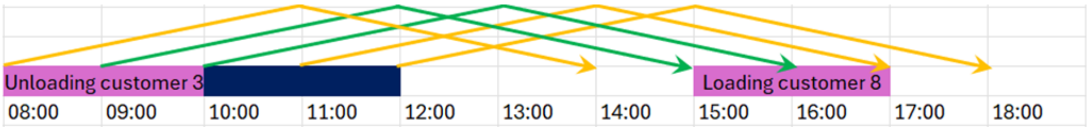

Figure 7: Example of determining the optimal departure time of a trucking path

Start time	Penalty costs
8:00	pe
9:00	0
10:00	0
11:00	pe
12:00	$2*pe + pl$

Table 3: Penalty costs for different starting times of the truck path

Achievements trucking paths

The outcomes of trucking paths are twofold: serving customer locations and adjusting container balances at terminals. To simplify the model, it is assumed that it is known from which terminals containers are picked up and dropped off.

If the first location is a loading, then an empty container is taken away from the starting terminal. If the last customer location of a trucking path is an unloading location, an empty container will be delivered to the starting terminal. If the first location is an unloading and the last location is a loading, a container will be withdrawn from the starting terminal and another container will be brought to the starting terminal. Note, for example in the latter case, that the arrival terminal can be different than the departure terminal. In practice, a container could be dropped off at the arrival terminal, resulting in an increase of one container at the arrival terminal and a decrease of one container at the departure terminal.

To update which customer locations are served in a path, first, each customer location is assigned an empty list. Afterward, an iteration is performed through all paths, and through all customer locations within each path. The set for each customer location gets the path appended, when that customer location is encountered in the path. Resulting in a set of paths that visit a certain customer location, for every customer location. Thus, obtaining the vectors of paths visiting the loading locations V_l and the quote loading locations V_{ql}. Similarly, a vector of paths visiting the unloading locations V_u and the the quote unloading locations V_{qu}.

The increase or decrease of container balances at terminals from trucking paths, $pn^+_{p,t}$ and $pn^-_{p,t}$, is determined in two steps. In the first step, iterations through the paths are conducted, and whenever an empty container is transported to or from a terminal these paths are appended to the set corresponding to the affected terminal. Each terminal has a set for paths that increase the number of containers at that terminal and a set for paths that decrease the number of containers at that terminal. When a trucking path reduces or increases the number of containers by more than one, that trucking path is appended multiple times accordingly.

Since a trucking path can be included multiple times within the lists P^+_t and P^-_t, the frequency of the paths within those list are counted. Once the occurrences are obtained the actual increase or decrease in the number of containers at terminals by trucking paths is calculated. Resulting in the model parameters $pn^+_{p,t}$ and $pn^-_{p,t}$.

4.2.2 Paths between terminals

The procedure for the paths between the terminals is simpler and the paths involve only two locations. Paths are created between all terminals to each other terminal. The cost of these paths is simply the cost of the arcs $c_{i,j}$. The increase in containers at a terminal by the path $pn^-_{p,t}$ equals one for the departure terminal. Reversely, the decrease in containers at a terminal by the path $pn^+_{p,t}$ equals one for the arrival terminal.

5 Solution method

To reduce the complexity of the model, a spatial decomposition is proposed. Also, resulting sub-optimal trucking paths are eliminated. Afterwards, the simplified integer programming model is solved using the commercial solver Gurobi. The initial optimality gap of the integer program was reduced to 0.0001%, this accuracy was required to have at most a five euro cheaper or more expensive quote price, compared to the optimal solution.

5.1 Spatial decomposition

Customer locations are categorized into either one or both the quote regions, or the non-trucking region.

Quote regions

The regions where truck routing and repositioning empty containers will be modeled are called the quote regions, specifically the quote loading and quote unloading region.

A maximum number of customer locations per region mc was specified to control the complexity of the resulting model. Dummy locations are placed between the customer locations of the quote order and assigned terminals. Around these dummy locations, as well as around the customer location and assigned terminals, all locations within a negligible small search distance are stored. The search distance is gradually increased until the number of customer locations mc is exceeded. Once the customer locations are determined for the quote regions, the terminals that are connected to these customer locations are added to the quote region. Also, all cleaning stations are added to both quote regions. The sequences of customer locations for the trucking paths were then created separately for the quote loading and the quote unloading regions. The remaining customer locations were assigned to the non-trucking region.

Non-trucking region

Customer locations in the non-trucking region are assigned to the terminal tl_q that corresponds with the selected outbound trip. The container balance b_t is determined. This balance is calculated by subtracting the number of loadings from the number of unloadings assigned to each terminal. The terminal at the bottom of Figure 15 is surrounded by numerous loadings, therefore a shortage of containers starts to exist. The shortage needs to be resolved in the long run by repositioning empty containers to that terminal.

5.2 Eliminating sub-optimal paths

Despite the aforementioned spatial decomposition, the number of paths/decision variables in the integer programming model can still become large. To mitigate this, efforts are made to eliminate sub-optimal trucking paths before feeding them to the integer programming model. A trucking path is clearly sub-optimal if the customer locations visited by that path and the resulting container terminal balances at terminals, can be achieved by a combination of other paths with lower total costs. More specifically, trucking paths that serve two unloading locations can be eliminated if the cost of serving them by two separate trucking paths is lower. The exact same approach can be deployed for trucking paths that serve two loading locations. Trucking paths that sequentially serve an unloading location followed by a loading location may possibly be identified sub-optimal as well. However, the repositioning of empty containers must be considered, as performing dedicated trucking paths might lead to different container balances compared to the street turns. When the loading and unloading locations are assigned to the same terminal, there is no need to consider the repositioning of empty containers. If the assigned terminals are different, the cost of an empty container repositioning move between the terminal assigned to the loading and the terminal assigned to the unloading must be added to ensure that decision variable is sub-optimal.

Note that this approach becomes particularly compelling when container and previous load requirements are considered. Trucking paths could then be generated where a container type (including its previous load) can be assigned to a loading location. The model would then require additional constraints for the unloadings to ensure that the same container or updated (in terms of previous load) container type is utilized after unloading. Loading locations in the non-trucking region are also given the option to select which container to withdraw from their assigned terminal. The balance constraints for the terminals should be set per container type. Requiring additional decision variables to exclusively clean a container and bring it back to the terminal and requiring the removal of a non halal, non halal or allergen previous load against high costs. Otherwise the model may become infeasible. Implementing this model would lead to an extremely large number of decision variables, particularly because of the trucking paths involving two loadings. For each loading, a container type must be selected. Therefore, for each trucking path visiting two loading locations, the number of related decision variables increases quadratically with the number of container types. Suppose there are 100 loadings in each quote region. Further, suppose that each loading can be paired with 20 other loadings being time window feasible. Supposing there are ten product groups, and only the last preceding load must be taken into account for halal, kosher, and allergen requirements. Lastly, suppose there are four critical container requirements that are absent in most containers (otherwise there is no need to consider them). This leads to $10 \times 2 \times 2 \times 2 \times 4 = 320$ container types, and resulting in $320 \times 320 = 102.400$ trucking paths for each loading, loading combination. Clearly, the container types that are not suitable for the order type can be removed. Moreover, each trucking path that involves two loadings with the same container type, is suboptimal when dedicated loadings lead to lower trucking costs. The product group of the previous load may differ in this case, as long as the halal, kosher and allergen specifications of the previous load are similar. Lastly, in other cases it can still be checked whether dedicated trucking is clearly superior, but then empty container repositioning moves must be considered.

6 Model input

The inputs of the model were derived from real-world data collected at bulk logistics provider Van den Bosch.

6.1 Data preprocessing

Three datasets were utilized: the datasets of the orders, the lanes and the cleaning stations. The order dataset, contained all unloadings of a specified week and their corresponding loadings. The loading locations were shifted forward in time, with the size of the shift equal to the average lead time, which was 72 hours. The orders dataset included the product group, coordinates of the loading and unloading locations, and the time windows for the loading and unloading locations. In some cases, certain orders had product groups that were more detailed than those used in the cleaning dataset. If that was the case, the product groups were aggregated to a higher level. For instance, plastic granules was changed to plastic. Next, an identifier key was created for the orders by combining the loading location, unloading location and product group. The lane dataset already included such an identifier key.

The lane dataset detailed the routes between an unloading and a loading location for a certain product group. A small number of orders were removed because no corresponding lane was included in the lanes dataset. Some lanes had the departure terminal and arrival terminal falsely switched, this was corrected. Another subset of orders was removed, the orders that were carried out by full truckload shipment, which was approximately 10% of the total order set.

The third dataset contained information about the cleaning stations, including their locations, available cleaning operations and corresponding prices. Cleaning operations at a cleaning station that had a cost of zero were removed. Furthermore, the order dataset was split per operational division. Where the division under investigation then contained 503 orders. Van den Bosch typically separates the planning of chemical and food orders due to the risk of cross-contamination. Which can lead to dangerous scenarios and reputation damage. Additionally, truck drivers require different certifications for transporting dry and liquid products. Finally, chassis for dry products are generally heavier due to the compression and tilting equipment. Using these chassis for transporting liquid products results in lower volumes because the maximum allowed weight limit on the road is reached with less transported goods.

Due to confidentiality reasons regarding customer names and locations, the data was anonymized. A distance matrix was generated using Euclidean distances to calculate distances between these coordinates.

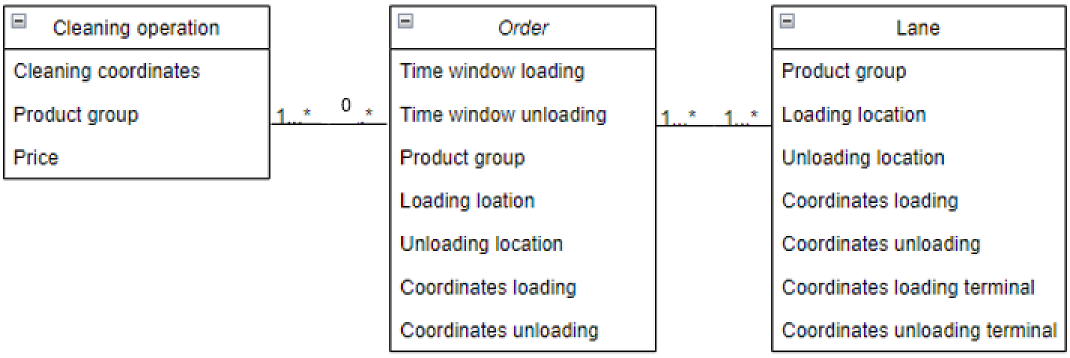

Figure 8: Entity-relationship diagram regarding transportation network data

6.2 Order data

From the dataset of the orders, the product group pq_q and the time windows $[st_q, et_q]$ were extracted. A random lane was selected from the lane dataset that corresponded to the loading location, unloading location and product group of the order. The delivery and arrival terminals tl_q of the order q were extracted from this lane.

6.3 Duration operations

The loading time lt, unloading time ut, and cleaning time ct were standardized to 3 hours, 3 hours, and 1 hour, respectively. These operation times were established through extensive contact with sales and planners. The cleaning time ct was determined based on the average cleaning duration. The loading time lt and unloading time ut seldom took less than 3 hours. If loading or unloading exceeds 3 hours, customers are required to pay high rates as stated in the contract terms.

6.4 Travel costs

The cost of traveling a kilometer by truck vct was determined by averaging the costs of 20 trucking actions in the Benelux divided by the average trucking distance. Leading to an average of 91 cents per kilometer. Subsequently, a round up was used of one euro per kilometer. To adjust for the relatively short distances by setting euclidean distance, an additional 20% was added. For the train/boat connections the cost per kilometer traveled vcc was set equal to one euro per kilometer. Obviously, those model parameters are set quite inaccurately. However, accurate values for traversing arc costs require detailed data, including toll expenses, regional driver wages, and whether company owned trucks or charters must be used. This data was not readily accessible.

6.5 Penalty costs

The values for allowed earliness under penalty cost te and allowed lateness under penalty cost tl were set to eight hours. Drivers have the flexibility to arrive earlier and pick up the container at the terminal before the customer's designated time window and obviously are allowed to arrive earlier than the loading time window.

The allowed lateness under penalty cost allows for the combination of customer locations that are typically grouped together due to scheduled sleeping breaks in between. The sleeping break was not included in this model. The penalty cost for arriving early, pe, was set equal to the wage of drivers in the Benelux region. The penalty cost for arriving late, pl, was standardized at 100 euros, the most frequent value used in contractual agreements.

6.6 Length trucking paths

Since this study did not consider information regarding previous load or container requirements, the maximum number of customer locations mnc was set equal to two.

7 Computational experiments

First, a model parameter controlling the spatial decomposition will be tuned. Second, the effect of a presolve on the running times is researched. Third, results of three cost estimation scenarios will be examined in depth. Lastly, a sensitivity analysis will be conducted.

All computations been have run on an Intel Core i7-7700HQ with a 2.80GHZ processor and 16 GB RAM.

7.1 Parameter tuning

The effect of the maximum number of customer locations per quote region, denoted as mc, is researched. Where the number of customer locations per quote region was increased until convergence. The quote regions consist of a quote loading and quote unloading region. 100 random orders were selected and different values for mc were chosen. The accuracy was compared to an extremely large number of customers per quote region equal to 500. Where the resulting cost estimation with 500 customer locations per quote region was subtracted, from the results of the lower number of customer locations per quote region. The results obtained are shown in Table 4.

Max. number of customers	MSE	ABS	MBE	Time IP (s)	Time data processing (s)
200	3240	32	18	0.1	22
300	1359	19	8	0.2	30
400	1150	15	8	0.3	42
500	-	-	-	0.5	88

Table 4: Results for different maximum number of customers in the quote regions

The results do not show convergence for the selected values, especially considering that values for mc beyond 500 are not researched. The convergence is not happening even for large number of customer locations per quote region. The non-convergence must have occurred because of the integration of the empty container repositioning and trucking paths that serve customer locations. Whereby a large number of customer locations in the quote region can change the balances at terminals. Also, it was observed that for more than 90% of the quote order the difference was already negligible between 200 and 300 customer locations per quote region. Where negligible was defined as less than 50 kilometers in empty distance. The quote orders that were the most effected by an increase in mc all had long quote loading trucking legs in the Benelux. The mean squared error (MSE) is still quite large because of large deviations of these few quote orders. Therefore, the spatial decomposition is not deployed. The mean bias error (MBE) does show that on average considering quote regions with a larger number number of customer leads to lower cost estimation values. Which is conform hypothesis. The absolute error shows that on average the effect of a larger number of customers per quote region is small. The results of the processing times, do show that considering a smaller number of customer per region, leads to lower computation times. The results do also show that the cost estimation is highly sensitive towards other customer locations and resulting container balances.

7.2 Eliminating suboptimal paths

Potentially paths leading to suboptimal solutions can be identified, as described in Section 5.2. Fifty random orders were selected from the order set, and no spatial decomposition was applied. The results comparing the models with and without presolve are shown in Table 5.

	Nr of decision variables	Running time IP (s)	Data preprocessing time (s)
Without presolve	180169	4.47	314
With presolve	116055	2.55	277

Table 5: Results with and without presolve

The solutions obtained without presolve and with presolve resulted in differences smaller than the optimality gap. The presolve reduced the computation time of the integer programming model by 42.9%. Where the presolve time was included in the data preprocessing time. The reduction in data preprocessing time was mainly caused by the penalty calculation function having to process less paths. As paths were eliminated before the penalty calculation function was applied. The largest portion of the data preprocessing time was spent identifying the optimal combination of cleaning stations and starting terminals for trucking paths that first visit a loading location and lastly visit an unloading location. Each integer programming model contained 16.002 decision variables representing the empty container repositionings moves between the 127 terminals. None of these variables were eliminated in the presolve.

7.3 Case study

Three distinct cost estimation methods are evaluated for three distinct cost estimation scenarios. The first method, the post-calculation, involves the calculation of costs after the completion of operations. The second method is the current cost estimation process as outlined in section 1.3. The third method is the model developed in this study.

The three cost estimation scenarios were derived from the order dataset of a division, which included 503 orders. Within this division, previous load requirements were generally low, and the container requirements associated with the orders can be met by almost all containers utilized in the division. The same loaded outbound trip was used by all three methods for the different scenarios. The selected scenarios included balanced, import and export regions, allowing for a comparison of performance across various environments. Moreover, the quote orders chosen were extreme scenarios, making it easier to comprehend the impact of the quote order on the empty kilometers.

The model input for this study incorporated a relatively simplified cost of traversing arcs, in contrast to the more sophisticated cost of arcs used in both the post-calculation and the current cost estimation process. More specifically, the cost of arcs in the post-calculation method included additional factors such as tolls, regional wages, actual road and speed limit data, and actual prices for train and boat connections. Consequently, the evaluation focused on comparing the empty trucking and empty container repositioning distance rather than the actual costs. In all scenarios, the empty trucking distance was calculated using the Euclidean distance multiplied by 1.2, while the empty repositioning distance was simply equal to the Euclidean distance. Thus, the cost of arcs used in the post-calculation and the current cost estimation process was adjusted to match the simplified cost of arcs employed in this study. The cost of trucking arcs mentioned below already includes the multiplication factor. Moreover, the current cost estimation process is typically conducted several months in advance of order execution. For a fair comparison, the current cost estimation also used the past order set instead of forecasted values for the orders. To maintain the overview, the cleaning stations are not shown, but the resulting detour is included in the cost of arcs.

The empty container repositioning distance caused by the quote order depends on the number of loading and unloading locations in different countries. Figure 9 shows the container balances per country. Where the balances were calculated by subtracting the number of loadings from the number of unloadings. A positive balance indicates a surplus of containers. Generally, there is a shortage of containers around the Benelux region, while other regions tend to have a surplus of containers.

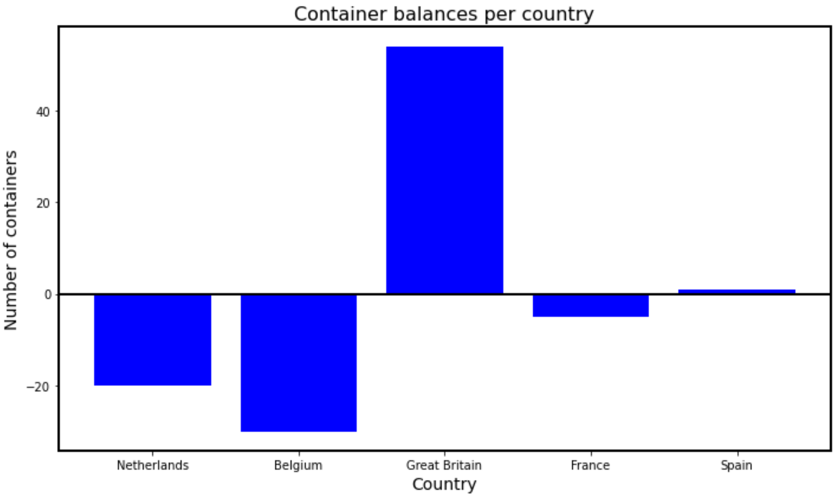

Figure 9: Balances per country

7.3.1 Scenario 1: Export region to import region

Scenario 1 involves five orders transported from a loading location in Vondelingenplaat, Netherlands, to Burnley, Great Britain. As illustrated in Figure 9, the quote loading occurs in an export region, while the quote unloading occurs in an import region. All methods utilized the same outbound trip, which involved transporting the goods by boat from Rotterdam to Hull. Vondelingenplaat is located extremely close to Rotterdam, while Burnley is approximately 160 kilometers from Hull. Additionally, Burnley is situated near one of the few loading locations in Great-Britain, Blackburn. Almost without exception, the concentration of cleaning stations in the Netherlands and Belgium is exceptionally high.

The post-calculation method does not include the empty trucking distance for the quote loading region, as it simply assigns the empty distance from the quote unloading location to the next loading location or a storage location. Consequently, the empty trucking distance in the quote loading region is always zero. In the quote unloading region the order was combined two times with one of the few loading locations in Blackburn. Resulting in a small empty trucking distance in the quote unloading region and, more importantly, an empty container repositioning distance of zero kilometers. The other three orders were shipped back to the Netherlands empty, with the corresponding empty trucking distance from Burnley to Hull and empty container repositioning distance from Hull to Rotterdam. The exact number of empty kilometers (km) are shown in Table 6.

Post-calculation: Netherlands, Vondelingenplaat → Great-Britain, Burnley (Plastic)

Empty trucking arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
Burnley → Hull → Rotterdam	0	170	381	551
Burnley → Blackburn	0	15	0	15
Burnley → Blackburn	0	15	0	15
Burnley → Hull → Rotterdam	0	170	381	551
Burnley → Hull → Rotterdam	0	170	381	551
Average	0	102	229	331

Table 6: Results post-calculation for scenario 1

The current cost estimation process used a round trip and a dedicated trip to approximate the empty distance of the quote order. The dedicated trip included an empty container repositioning move from Hull to Rotterdam. Also, it included empty trucking distance for the quote loading region from the departure to the quote loading equal to 11 kilometers. Similarly, empty trucking distance for the quote unloading region was equal to the distance from the quote unloading location to the arrival terminal equal to 170 kilometers. The considered likelihood of the dedicated trip was estimated to be 85%, based upon the large number of unloading locations and low number of loading locations in the UK. The round trip, a combination of the quote order with another order, had an estimated likelihood of 15%. The order was combined with an order from Sheffield to Hellingenplaat, with 100% of the empty distance assigned to the quote order. The orders chosen for the round trip usually occur at least several times and have a cleaning station in the neighborhood. The PMC team leader prefers those scenarios as they are considered robust. This resulted in similar values for the empty trucking and no empty container repositioning distance. The exact number of empty kilometers are shown in Table 7.

Cost estimation current process: Netherlands, Vondelingenplaat → Great-Britain, Burnley (Plastic)

Empty arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
Rotterdam → Vondelingenplaat & Burnley → Hull & Hull → Rotterdam (85%)	11	170	381	562
Hellingenplaat → Vondelingenplaat & Sheffield → Burnley (15%)	5	160	0	165
Average	10	169	324	503

Table 7: Results current cost estimation process for scenario 1

The cost estimation of this study, shows empty trucking distance slightly larger than the distance from Vondelingenplaat to Rotterdam, 11 compared to 10. Which likely resulted from the necessary detour by visiting the cleaning station. The optimality gap of one euro could have caused the difference in empty trucking distance in the quote loading region between the orders, where the distance was either 11 or 12 kilometers. The empty trucking distance upon unloading in Burnley was slightly less than the distance from Burnley to Hull. This reduction must have occurred because the order was strategically combined with other customer locations within the trucking path. The average empty container repositioning distance equaled 381 kilometers, which coincides with the distance from Hull to Rotterdam. The cost estimation methodology in this study results from changes in traversed arcs when planning for the order set versus the order set plus the quote order. This results in numerous altered traversed arcs, making the visualization more complex compared to the arcs involved in the post-calculation and current cost estimation methods. The exact number of empty kilometers are shown in Table 8.

Cost estimation this study: Netherlands, Vondelingenplaat → Great-Britain, Burnley (Platic)

Empty arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
-	12	153	381	546
-	11	160	381	552
-	11	154	381	546
-	12	160	381	553
-	11	158	381	550
Average	11	157	381	550

Table 8: Results cost estimation this study for scenario 1

The exact empty trucking distance and empty container repositioning distance resulting from the quote order were not known. Therefore, the exact accuracy of the different methods cannot be determined. However, it is evident that the quote order consistently causes an additional empty repositioning move from the UK to the Netherlands. Because of the large shortage of containers in the quote loading region and the large surplus of containers in the quote unloading region. Additionally, unloading in a heavy import region poses challenges for efficient combination with other orders in trucking routes. The reverse is true for a loading location in an export region. Since efficient truck routing generally involves combining a loading location after an unloading location.

The post-calculation method inadequately addresses empty trucking in the quote loading region since it does not account for it. In this scenario the expected empty trucking distance in the quote loading region was low, as the loading was located close to the departure terminal. The post-calculation method also underestimates the empty trucking cost in the quote unloading region. Other unloadings could have been combined with the loading location in Blackburn, resulting in only a couple of kilometers in empty trucking detour.

The current cost estimation process demonstrates better performance overall than the post-calculation. However, the accuracy of the empty container repositioning distance is questionable due to the significant container imbalances. The cost estimation of this study seems to outperform the two other cost estimation methods for this scenario.

7.3.2 Scenario 2: Import region to export region

Scenario 2 concerns two orders from a loading location in Great-Britain to an unloading location in Belgium. Figure 9 shows that the loading location occurs in an import region and the unloading location occurs in an import region. For this scenario, all methods utilized the boat connection from Hull to Zeebrugge as the outbound connection for the quote order (360 km). Burythorpe, the loading location, is located 68 kilometers from the departure terminal, while Vaux Sous Chermont, the unloading location in Belgium, is 253 kilometers from the arrival terminal. Where the network of cleaning stations Belgium is extremely dense.

The post-calculation method indicates that the empty trucking distance in the quote unloading region is significantly shorter than the loaded trucking leg from the quote loading region. Additionally, the empty container repositioning cost is equal to zero. Detailed results of the post-calculation for scenario 2 are shown in Table 9.

Post-calculation: Great-Brittain, Burythorpe → Belgium, Vaux Sous Cheremont (Minerals)

Empty trucking arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
Vaux Sous Chevremont → Antwerp	0	145	0	145
Vaux Sous Chevremont → Dusseldorf	0	110	0	110
Average	0	128	0	128

Table 9: Results post-calculation for scenario 2

The current cost estimation used a round trip to determine the empty distance. The quote order was combined with an order from Antwerp to Sheffield. Where the total empty trucking distance was assigned for 50% to the quote order. The round trip saved an empty container repositioning move from Hull and Zeebrugge, compared to a dedicated scenario. Resulting in a negative empty container repositioning distance of 360 kilometers. In the quote loading region, the empty trucking distance is slightly larger than the loaded trucking of the quote loading order. Which is surprising, as the import region contains many unloading locations after which the loading location combined. Thus also several unloading locations with a cleaning station in the neighborhood. Instead an unloading location was selected that occurred relatively far away. In the quote unloading region the empty trucking distance is significantly smaller 253 compared to 61 kilometers. Detailed results of the current cost estimation process for scenario 2 are shown in Table 9.

Cost estimation current process: Great-Britain, Burythorpe → Belgium, Vaux Sous Chermont (Minerals)

Empty arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
0.5*Sheffield → Burnley & 0.5* Vaux Sous Chermont → Antwerpen & Hull → Zeebrugge (100%)	70	61	-360	-229
Average	70	61	-360	-229

Table 10: Results current cost estimation process for scenario 2

The cost estimation of this study for Scenario 2 shows an empty trucking distance in the quote loading region of 51 kilometers on average, which is slightly shorter than the loaded trucking leg of the quote order. In the quote unloading region, there's an average of 36 kilometer reduction in empty trucking distance. Which must have occurred because an unloading in an export region can be combined with many loadings connected to the same terminal as the quote loading, resulting in an efficient trucking path. For one order, the reduction in empty container repositioning distance is slightly less than the cost of the train/boat connection used for the quote order. Which must have occurred because this study integrates truck routing and empty container repositioning. Thus slightly more expensive truck routing can occasionally be used when that leads to a lower empty container repositioning distance. The results of this study for scenario 2 are shown in Table 11.

Cost estimation this study: Great-Brittain, Burythorpe → Belgium, Vaux sous Chermont (Minerals)

Empty arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
-	57	-60	-322	-325
-	44	-12	-360	-328
Average	51	-36	-341	-326

Table 11: Results cost estimation this study for scenario 2

Clearly, in practice an additional order from a heavy import region to a heavy export region results in a negative empty container repositioning distance. The post-calculation method fails to account for the saved empty container repositioning move in this scenario. Both the current cost estimation process and the cost estimation methodology used in this study accurately capture the saved empty container repositioning move from Hull to Rotterdam. The cost estimation in this study showed slightly lower empty trucking costs in the quote loading region compared to the results obtained from the current cost estimation process. The current cost estimation includes a round trip where the unloading location is quite far way from the loading location. There are closer unloading locations, located near the quote loading location. The cost estimation in this study showed significantly lower empty trucking costs in the quote unloading region compared to the results obtained from the current cost estimation, amounting to approximately 100 kilometers less. Again, an unloading in an export region can result in a significant savings in empty trucking mileage. As particularly efficient trucking paths generally result from an unloading location followed by a loading location. Generally, more of these type of trucking paths can be created when a quote unloading occurs in an export region. The reverse is generally true for an additional loading location in an import region. in conclusion, the cost estimation of this study apppears to outperform the current cost estimation with regards to the empty trucking distance.

7.3.3 Scenario 3: Balanced region to import region

Scenario 3 involves four orders from a loading location in Spain, Lobon with corresponding unloading location in Belgium, Veurne. Figure 9 shows that the loading location occurs in a region that has a container surplus of two containers. All methods used the boat from Spain, Santander to Belgium, Zeebrugge. Lobon is located 748 kilometers away from the departure terminal. The trucking leg for the quote unloading from Zeebrugge was 60 kilometers. A cleaning station offering several cleaning operations was located only 34 kilometers away from Lobon, which is relatively close compared to the long trucking legs in Spain.

The post-calculation shows small total empty distance solely caused by empty trucking in the quote unloading region. The detailed results of the post calculation for scenario 3 are shown in Table 12.

Post-calculation: Spain, Lobon → Belgium, Veurne (Plastic)

Empty trucking arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
Veurne → Antwerp	0	135	0	135
Veurne → Antwerp	0	135	0	135
Veurne → Breda	0	203	0	203
Veurne → Oostende	0	35	0	35
Average	0	127	0	127

Table 12: Results post-calculation for scenario 3

The cost estimation of the current process shows a large empty trucking distance in the quote loading region, slightly less than the loaded trucking leg of the quote loading, 644 compared to 748 kilometers. Additionally, the cost estimation shows a low empty container repositioning distance relative to the substantial distance between the departure and arrival terminals. The detailed results of the current cost estimation process for scenario 3 are shown in Table 13.

Cost estimation current process: Spain, Lobon → Belgium, Veurne (Plastic)

Empty arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
Gijon → Lobon & Veurne → Antwerpen (80%)	630	150	0	780
Santander → Lobon & Veurne → Zeebrugge (20%)	748	60	1170	1978
Average	654	132	234	1020

Table 13: Results current cost estimation process for scenario 3

The cost estimation of this study shows a large saving in empty container repositioning distance, even when the container surplus is only two containers. Also, the empty trucking in the quote loading region is high and the empty trucking in the quote unloading region is quite low.

Cost estimation this study: Spain, Lobon → Belgium, Veurne (Plastic)

Empty arcs	Empty trucking quote loading region (km)	Empty trucking quote unloading region (km)	Empty container repositioning (km)	Total empty (km)
-	748	59	-657	150
-	714	60	-657	117
-	702	90	-700	92
-	748	90	-700	138
Average	728	75	-679	124

Table 14: Results cost estimation this study for scenario 3

Given that the quote loading region is almost balanced, a small empty container repositioning distance or a negative empty container repositioning distance seems to be appropriate. Especially since the quote unloading region is an export region. The excessively large negative empty repositioning distance of this study is considered too high. A small imbalance might be reduced in the future by lowering prices of certain orders and rejecting certain other orders. This highlights the model's weakness in effectively managing scenarios where regions are nearly balanced. The current cost estimation process seems to outperform the cost estimation of this study for scenario 3, with regards to the empty container repositioning distance.

Again, the empty trucking in the quote unloading region is slightly overestimated by the current cost estimation process. Similarly, the empty trucking in the quote loading region is underestimated by the current cost estimation process. The PMC team leader did not consider the time windows of the unloading orders in Spain. When the current cost estimation process is executed in practice, the timing (by the hour and the day) of the orders is also not considered, only by the month. Because the current cost estimation is too far way from the execution of the order. Which bares the question what the actual performance difference would be, when forecasts are used.

Comparing the empty trucking distance in the quote loading and quote unloading region, and the empty container repositioning distance individually is flawed. The current cost estimation process calculates costs by creating round trips, which involve combining the quote order with another order. Where the other order is a previously executed order. The PMC team leader is searching for an order that captures the overall empty distance. Therefore, this does not imply that the disaggregated empty distance components, such as empty trucking in the quote loading region, are accurately captured. Similarly, this study integrates both empty trucking and empty container repositioning within a single model.

In conclusion, the post-calculation method does not accurately capture the empty distance caused by a specific order. The cost estimation of this study appears to outperform the cost estimation of the current process in unbalanced regions. Also, it more accurately captures the trucking in the quote regions. The current cost estimation process seems to outperform the cost estimation of this study with regards to empty container repositionings, when the quote loading or quote unloading occurs in a nearly balanced region.

7.4 Sensitivity analysis

A sensitivity analysis is conducted with regards to the cleaning station insertion, maximum number of customer locations in a single trucking path, and empty repositioning moves within trucking paths.

Cleaning insertion

An optimal cleaning location insertion was compared to a closest cleaning insertion for 50 random orders drawn from the order set. For each order, the cost estimation was computed using the following cleaning station insertions:

1. Closest cleaning location insertion
2. Closest cleaning location insertion, except for the quote loading
3. Closest cleaning location insertion, except for both the quote loading and the loading(s) directly following the quote unloading in the same trucking path

The cost estimation using the optimal cleaning insertion was subtracted from each of the first three cost estimations. Thereby comparing the difference in the cost estimation using the closest cleaning station location with the cost estimation using the optimal cleaning location. For this analysis the prices at cleaning stations were set to zero and all cleaning stations were able to offer all cleaning operations. Optimal thus was defined here as the cleaning station location insertion that led to the lowest increase in empty trucking. The comparison is shown in Figure 10.

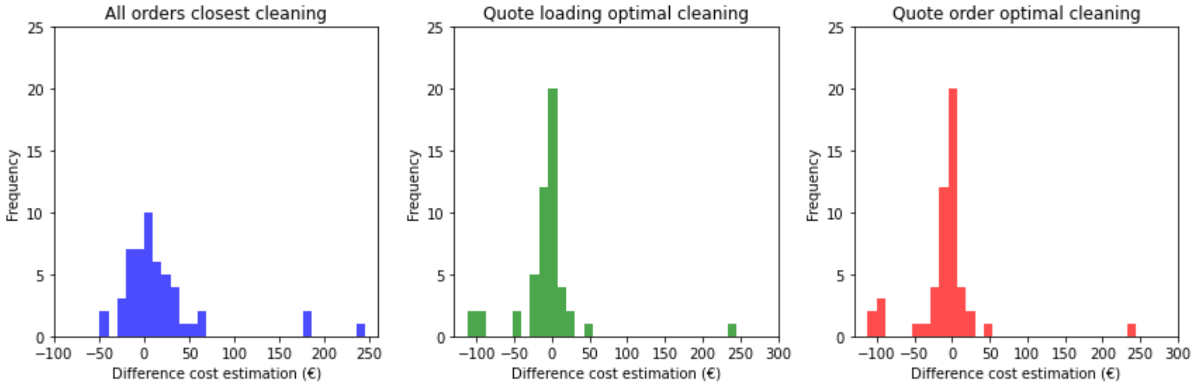

Figure 10: Closest cleaning insertion versus optimal cleaning insertion

The leftmost figure shows the additional cost for the quote order in euros when inserting the closest cleaning stations instead of the optimal ones. Utilizing the closest cleaning station insertion for all orders clearly results in a higher cost estimation for the quote order. Note that the total costs for serving the order set is strictly higher or equal when using the closest cleaning station insertion compared to the optimal cleaning station insertion. However, the cost estimation results from the difference in costs serving the order set plus quote order minus the costs of serving the order set without the quote order. Therefore, the resulting cost estimation using the closest cleaning station insertion can be higher than using the optimal cleaning station insertion and thus the leftmost figure shows several negative values. The figure in the middle depicts the same scenario, with the distinction that the quote loading gets assigned the optimal cleaning station. The cost estimations become significantly smaller when the optimal cleaning station is inserted for the quote loading compared to the closest cleaning station insertion (comparison between left figure and figure in the middle). The right figure shows the cost estimation difference when subsequently adding the optimal cleaning insertion for the loading location(s) directly succeeding the quote unloading location. The loading location in that case must be contained by the same trucking path as the quote unloading location. Obviously, all resulting cost estimations are strictly lower compared to using the optimal cleaning station insertion solely for the quote loading location. Surprisingly, one cost estimation still was around 250 euros more expensive when the optimal cleaning insertion was used for the quote order. This must have occurred because the optimal cleaning station selection led to changes in trucking paths that did not included the quote loading or quote unloading location. However, these changes led to the selection of different trucking paths, subsequently affecting the empty trucking or empty container repositioning cost caused by the quote order. The resulting cost estimations are nonetheless quite similar (comparison between figure in the middle and right figure), which must be caused by the utilized order set. Where one week of unloading locations was selected with their corresponding loading locations. Then the loading locations their time windows were shifted to the right by the average lead time. But the lead times differed substantially. The actual difference in cost estimation with all optimal cleaning insertions is expected to be much lower. Conclusively, performing an optimal cleaning insertion solely for the quote order using a cost estimation approach as in this study, can result in cost estimations that are too low. Caution is appropriate when adding more sophisticated approaches solely for the quote order.

Maximum number of customer locations in a trucking path

The effect of the maximum number of customer locations in a trucking path, denoted as *mnc*, was investigated. The number of customers per quote region, denoted as *mc*, was set equal to 150. Because larger values led to a memory error. Figure 11 presents the averaged results for 25 randomly withdrawn orders.

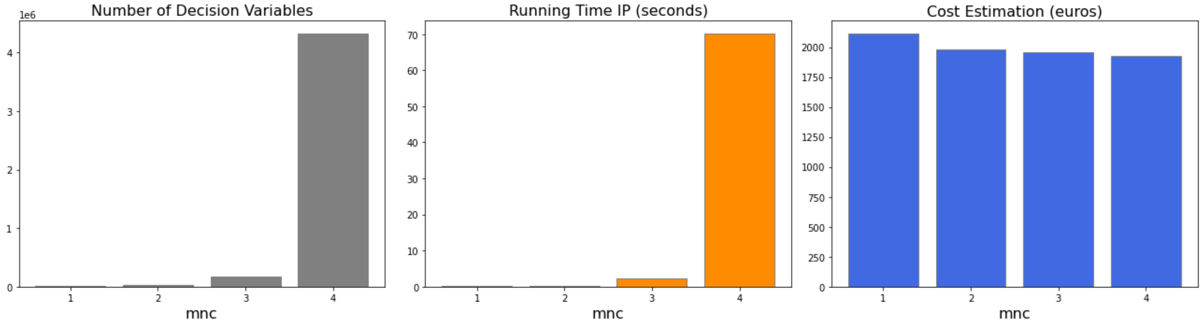

Figure 11: Effect of increasing the maximum number of customer locations per trucking path

Clearly, increasing the maximum number of customer locations per trucking path increases the complexity and reduces the cost estimation, on average. Increasing *mnc* beyond two does not seem to result in extremely lower cost estimations. It is expected that when previous load and container requirements are incorporated that the differences will become even smaller.

8 Conclusion

The purpose of this final chapter is to summarize the findings of this research project. First, the research questions will be answered. Second, the limitations of this research are discussed. Third, recommendations for Van den Bosch will be formulated. Lastly, recommendations for future research will be presented.

8.1 Evaluation of the research questions

Cost estimations for quote orders depend on numerous factors. The purpose of this research was to develop a proof of concept that considers the most relevant factors, that were not automated yet at Van den Bosch. To this end, the following research-questions were defined:

> *1. How are the cost estimations for quote orders currently processed at Van den Bosch?*

The PMC team leader searches for the appropriate train/boat connection for the quote order and makes scenario plannings with associated likelihoods. Sales employees calculate the cost of those scenario's with the software program Quintiq. Subsequently, the cost of those scenarios are multiplied by their associated likelihoods and then summed up. On average, processing a quote order takes approximately fifteen to twenty minutes. Evaluating the accuracy of cost estimations is challenging due to the simplified nature of the post-calculation process.

> *2. What models can be found in the literature that accurately estimate the costs for intermodal bulk transport?*

The literature on cost estimation models for intermodal bulk transport is extremely sparse. Also, the transport models that take into account the increase in transport cost because of truck routing and empty container repositioning changes caused by the quote order are scarce in the literature. Surprisingly, since there is consensus in the literature that empty container repositioning is a significant cost component.

A substantial body of research has demonstrated that integer programming models can effectively manage network flow models with a large number of nodes or customers. Moreover, commercial solvers like Gurobi can find the optimal solution or provide solutions close to optimality with a quantified optimality gap and lower computation times. Strict optimality gaps are necessary for cost estimation methods that utilize the difference in operational planning between an order set including the quote order and an order set excluding the quote order, for estimating the cost of a quote order. Inspiration was drawn from research showing the effectiveness of path-based models for vehicle routing problems with time windows.

> *3. How can the cost estimation process be modeled and solved?*

An integer programming model was created that minimized the cost of serving an order set. The model was solved for both the order set without the quote order and the order set including the quote order. Whereby the cost estimation was derived by subtracting the former (cost of the order set without quote order) from the latter (cost of the order set plus the quote order). The model included constraints that forced the inflow of containers at terminals to be equal to the outflow of containers. Truck routing was modeled where the truck must start and end at the same terminal, thereby capturing empty trucking distance. Feasible trucking paths considering time windows, were determined in advance. Also, a parameter was introduced that captured the effect of the truck routing on the number of containers at terminals. Cleaning stations were inserted into the trucking paths. The cost of trucking paths included traversing arcs, cleaning cost and penalty costs for arriving to late or to early. The train/boat connection for the loaded outbound trip was selected exclusively for the quote order. Constraints forced the associated trucking legs to be traversed. The approach led to a relatively small number of decision variables and constraint. The number of decision variables was further reduced by eliminating sub optimal decision variables upfront. Resulting in 40% faster computation times for the integer programming models.

> *4. How accurately does the model estimate the costs of empty trucking and empty container repositioning?*

Determining the accuracy of the model is challenging. The precise costs associated with empty trucking and empty container repositioning are not known. Three cost estimation methods were evaluated and compared within three extreme situations. In those situations, the anticipated increase in empty trucking and empty container repositioning distances was relatively straightforward. The cost estimations of this study outperforms the cost estimations of the current cost estimation process, when quote loading and unloadings occurred in heavy import or heavy export regions. The cost estimation of this study performed poorly when the quote order occurred in a balanced region. The poor performance in balanced regions can be attributed to the integer programming model generating extreme solutions that lie at the boundaries of the feasible solution space. Conclusively, the model of this study requires mechanisms to mitigate the so called extreme solutions.

Furthermore, several recommendations can be drawn from the investigation of the three scenarios. The current cost estimation appears to underestimate the the costs of quotes from a heavy export region to a heavy import region. In this scenario, cost calculations should include empty container repositioning moves 100% of the time. Additionally, the current cost estimation process underestimates the empty trucking resulting from a quote loading in an export region. Similarly, the empty trucking costs for a quote unloading in an import region appears to be overestimated. In general, extra unloading locations in import regions and extra loading locations in export regions, lead to a relatively large increase in empty trucking cost. A similar observation was found for additional loadings in a heavy export region. In unbalanced regions this study appears to perform better than the current cost estimation process for operational divisions with low previous load and container requirements.

> *How can accurate cost estimations for the quote orders be processed automatically?*

Now that the sub research questions have been answered, conclusions can be drawn regarding the main research question. The implications are divided into theoretical and practical implications.

8.1.1 Theoretical implications

This study shows that cost estimations resulting from the differences in two operational plannings are promising for estimating the costs of empty trucking and empty container repositioning. Close-to-optimal solutions appear to be necessary, as a small optimality gap for an entire order set significantly impacts the cost estimation of a single order.

The path-based model results in a relatively small number of decision variables and constraints.

A simplistic spatial decomposition was investigated, where a search was started around the trucking legs of the quote order, but did not seem to be particularly effective. Given that some trucking legs are long in regions where the network is dense and the empty container repositioning and empty trucking was integrated. However, the proposed presolve effectively reduces the computation time of the integer programming model by around 40%. Furthermore, it was demonstrated that cost estimations can be performed while considering large order sets. The integer programming models used for minimizing the costs of the plannings do however generate so called extreme solutions.

A more sophisticated cleaning insertion was compared to the closest cleaning station. The optimal cleaning location was inserted without considering cleaning operation requirements and prices. The average absolute deviation was small, however for several quote orders the more sophisticated cleaning insertion was significant. Adding the optimal cleaning station for the quote order lead to significantly lower cost estimations. In general, precaution should be applied when employing more sophisticated approaches exclusively for the quote order.

8.1.2 Practical implications

This study shows the potential and feasibility of automating the cost estimation process for intermodal bulk transport. Before the model can be implemented in practice, mechanisms must be developed to counteract the extremity of solutions. The results indicate that the cost estimation model developed in this study already outperforms the current cost estimation method in several situations. The current cost estimation process seems to underestimate cost estimations for quote orders from clear export regions to clear import regions. Resolving this underestimation leads to lower imbalances between regions and consequently less empty container repositioning moves and associated operational costs. This study paves the way for further development of a decision-making tool that can assist sales operations in accurately estimating the cost of quote orders. Potentially, leading to significant decreases in labor cost of up to 2000 euros a week.

The benefits of more accurate and further automated cost estimations are multifold. First, more accurate cost estimations result in fewer unprofitable business opportunities being accepted. Second, more accurate cost estimations lead to more profitable business opportunities being exploited. Third, more accurate cost estimations lead to less price changes shortly upfront execution of the orders. Which, in turn, lead to customers having a more reliable bulk logistics provider and a more reliable reputation of Van den Bosch. Changes in the cost estimation will have implications for the pricing manager. Currently, the pricing manager briefly reviews the cost estimation and may judge it to be too optimistic or pessimistic, and subsequently adjust the contribution margin. The cost estimation of this study cannot be as easily reviewed. Thus, substantial trust in the cost estimation of this study is necessary.

The outcomes of this study could also be utilized to enhance the post-calculation process with regards to the empty container repositioning and empty trucking costs. At present, supply chain engineers try to improve upon the post-calculation by searching what customer locations could potentially have been combined with a specific order. There are plenty of opportunities for improving the post-calculation by data-driven models. Thereby, more effectively distinguishing profitable and unprofitable orders and thus which orders must be priced differently.

Further automating the cost estimation process also has implications for data management practices. Van den Bosch recognizes the importance of data in decision making. With regards to further automating the cost estimation process there are some areas that require attention. First, the distance matrix that contains information about the trucking cost between locations could be more comprehensive. The trucking costs between locations are provided by a supplier. The provider intentionally complicates the extraction of large amounts of data at once. All orders must be planned manually in order to access trucking costs to and from new customer locations. Moreover, the default setting only shows distances to the customer locations that are less than 50 kilometers away, one terminal corresponding to the selected outbound trip, and one cleaning station. Additional cleaning stations and terminals must be added manually. For the model used in this study, it is advisable to add data from multiple terminals and cleaning stations that may be relevant for the newly added customer location. Second, the updating of information with regards to cleaning stations and train/boat connections is effected, especially where the network is sparse or when unusual product must be transported. Currently, sales and the PMC team leaders update this information when a new quotation request arrives and not all cleaning stations or train/boat connections that are potentially useful have been added in that area. This step of the process is highly affected when a decision making tool would be used and even more so when automatic cost estimations would be deployed.

8.2 Limitations

This study has several limitations. First, the extremity of generated solutions will be described, along with the resulting inaccuracies. Second, neglected cost components will be described. Third, the lack of several operational constraints will be described.

The results of the model for balanced regions, show that extreme solutions are generated. If there is an excess of one container in the quote loading region and a deficit of one container in the quote unloading region, the cost estimation of this study shows a saved empty container repositioning move from the quote loading region to the quote unloading region. Since the cost estimation is usually done months upfront, it is not certain at all that an empty container repositioning move will be saved. Put differently, the likelihood of the empty container repositioning caused by the uncertainty in the order set, is not taken into account. Resulting in a cost estimation that significantly underestimates/overestimates the actual costs when container balances are approximately equal to zero. Similarly, the model assumes to know the time windows of the quote order and of the order set. Which can lead to extreme solutions with regards to empty trucking cost. This study also assumes that train/boat connections always have capacity and have a 100% travel time reliability. Thus, the cost estimations generated underestimate the cost of the train/boat tickets.

This study does not consider storage costs and cost for special operations such as heating cost. Cleaning costs are considered and a cleaning operation is selected based upon the product group of the order. However, when a truck is brought to a terminal, this study does not update the previous load of the container that arrived at the terminal. If a loading is served from a terminal instead of an unloading, the cleaning operation is selected that corresponds to the product group of the upcoming loading location. While it should clean the product group of the previously carried order.

Besides neglected cost components, this study lacks several relevant operational constraints. This study assumes only one container type and thereby neglects the container requirements posed by a large proportion of orders. Similarly, previous load requirements effect the flow of containers significantly. Other operational constraints that were left out, were related to driver regulations. Where especially the sleeping break seems relevant. Lastly, the model does not include capacity constraints for containers, trucks and workforce. Capacity requirements are relevant as exceeding the capacity leads to large operational costs. Lastly, this study does not consider intermodal transport jointly with full truck load transport.

8.3 Recommendations

Several recommendations can be made with regards to mechanisms to counteract the extremity of solutions, model extensions and the implementation strategy.

Definitely, approaches must be developed to counteract the extreme solutions generated by the integer programming model. The extremity exists both in empty container repositioning and in trucking costs. For determining empty container repositioning moves, it is recommended to consider a larger order set slice than a week. This is necessary because of the volatility in the order data. As a result, obtaining more realistic empty container repositionings at the global level. Next, the sensitivity of the quote order demand towards the empty container repositioning cost should be investigated. One way to test the sensitivity is to investigate the changes in empty container repositioning costs when the demand for the quote order is increased. Reversely, the changes in empty container repositioning costs should be investigated when demand is added for orders with a loading at the quote unloading location and unloading at the quote loading location. It is advised to set the size of the adjusted demand by means of a scenario forecast. Similarly, truck routing costs caused by the quote order are heavily influence by the timing of the quote order and consequently the customer locations with which the quote order can be combined into trucking paths. The model should be run for different time windows of the quote order and then averaging the results.

Lead time requirements and CO2 requirements are solely related to the loaded outbound trip. Therefore, it is simply a matter of feeding outbound trip connections for the quote order that adhere to those requirements. Next, the reliability of train/boat connection corresponding the outbound trip of the quote order should be taken into account, when the reliability of the chosen outbound is low. The model should then be run without that chosen outbound trip. The result of the former should be multiplied with the reliability of the 'favourite' connection and summed with the results of the latter multiplied by one minus the reliability of the 'favourite' connection.

Overall, parameters of the model should be adjusted per operational division and customers. Different operational divisions and customers might for example require different values for the allowed earliness and lateness, penalties for arriving outside the time windows, loading times and unloading times. Obviously, cost of arcs must be used that include regional wages and toll cost.

Two type of costs are excluded in the model that are significant. The first type of cost that is excluded is the storage cost. It is not recommended to add storage costs to the model developed in this study. Since adding the storage costs likely leads to a significant increase in complexity. Furthermore, the expected storage costs are mainly dependent on the outbound trip selection, the storage rates at the corresponding terminals and the lead time of the customer. Customers can be advised to shorten the lead time so that expensive storage cost rates at terminals can be avoided. Therefore, a disintegrated storage cost calculation is advised.

Especially for the food divisions it is recommended to add container and previous load requirements. Where it should be investigated if previous load requirements can be aggregated to the product group level instead of the product level, because of its effect on the complexity. The halal, kosher and allergen requirements are also extremely relevant and is advised to furhter investigate. For the container requirements it is advised to not add the container requirements that can be fulfilled by a large proportion of containers. For example in the dry chemical division, it is unnecessary to add the container requirement compression as almost all containers in that division are suitable for compression.

Once the most significant limitations are addressed, it is advised to use the results as a decision-making tool to assist sales operations and the PMC team leader. The decision making tool should first be enrolled in divisions where the number of previous load and container requirements is low. Conclusively, it is highly recommended to further investigate data-driven methods to assist or automate the cost estimation process.

8.4 Further research

The body of research that focuses on cost estimations for intermodal transport is extremely sparse. Hence, plenty of further research directions remain.

Several interesting extensions could be researched such as container sizes, container requirements and previous load requirements. An other line of research is the addition of capacity constraints for the container load units, trucks and truck drivers. Where, more expensive container rentals and charter options must be used when the capacity is exceeded. Additionally, stochasticity with regards to the order set provides an interesting line of research. Research regarding the optimal cleaning station selection compared to the closest cleaning station selection, could be further improved upon. By keeping track of the previous load of containers when they are put to storage at terminals. Thus, considering cleaning operations requirements and the prices for cleaning operations at different cleaning stations. Alternative spatial decomposition methods can be researched. Lastly this study uses a path-based approach, a quantitative comparison in terms of running time with an arc-based approach is another direction for further research.

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10 Appendix

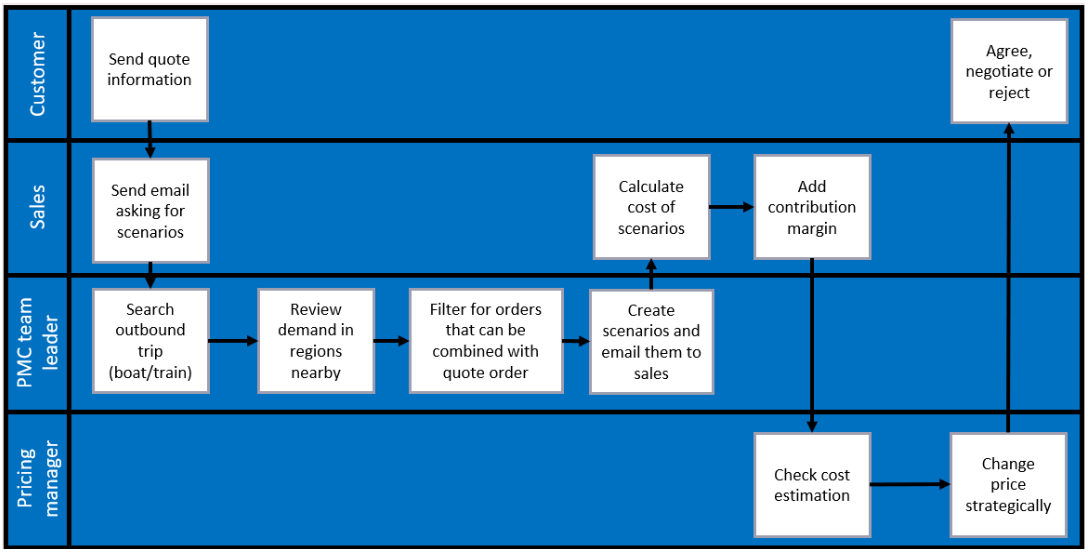

Figure 12: Swimming lane diagram of the pricing process

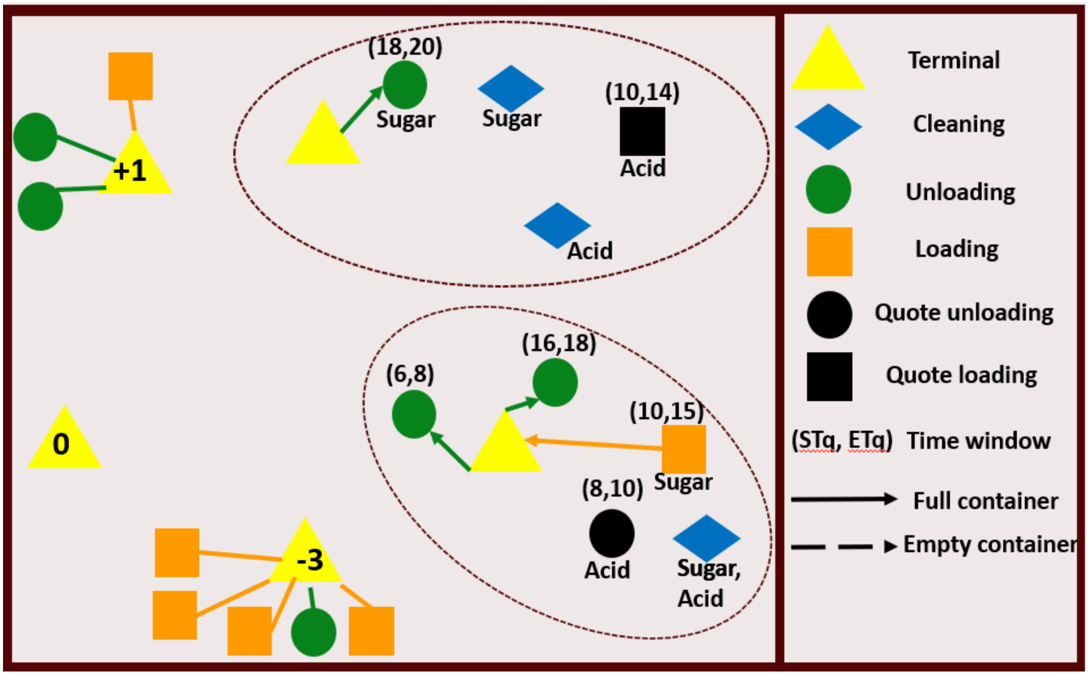

Figure 13: Schematic overview of the network with spatial decomposition and predetermined arcs

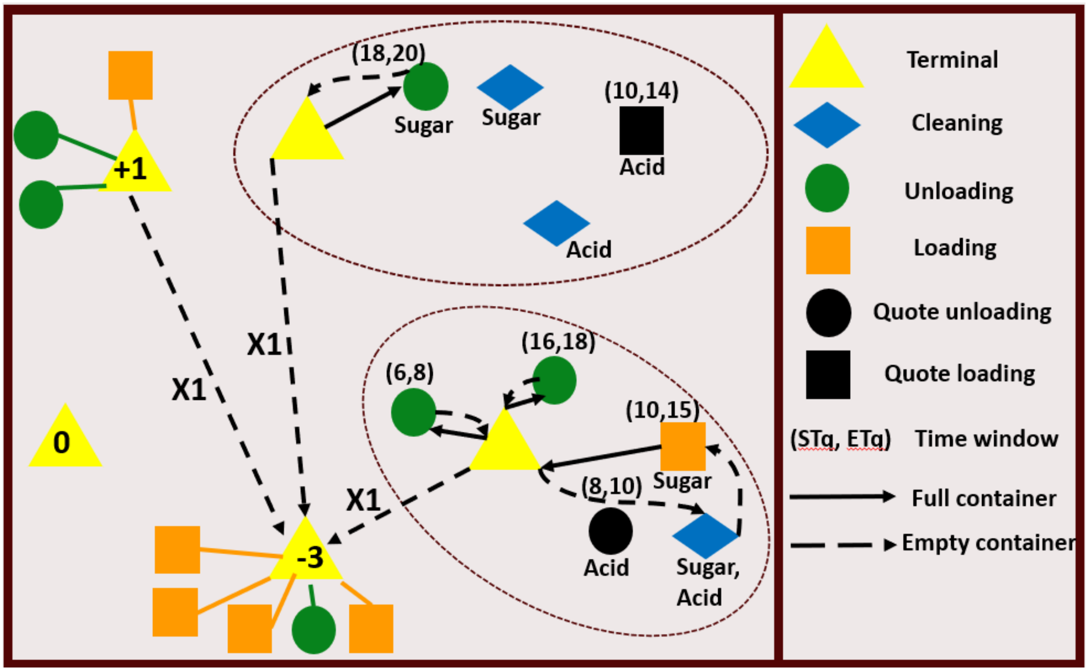

Figure 14: Schematic overview of the network and routing for the order set

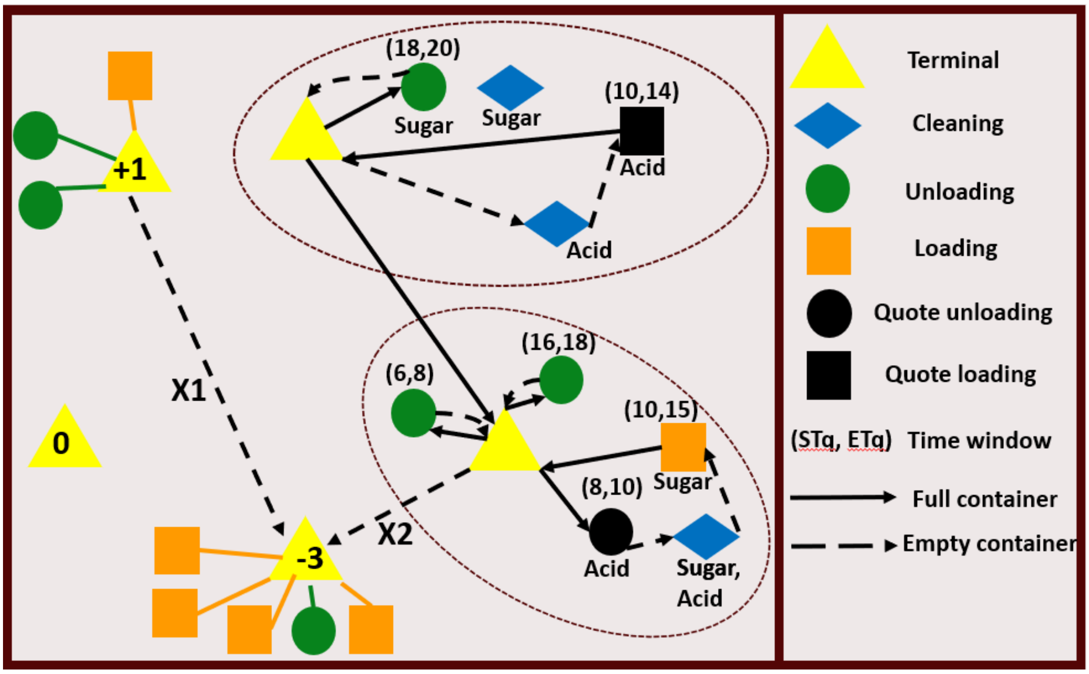

Figure 15: Schematic overview of the network and routing for the order set plus quote order

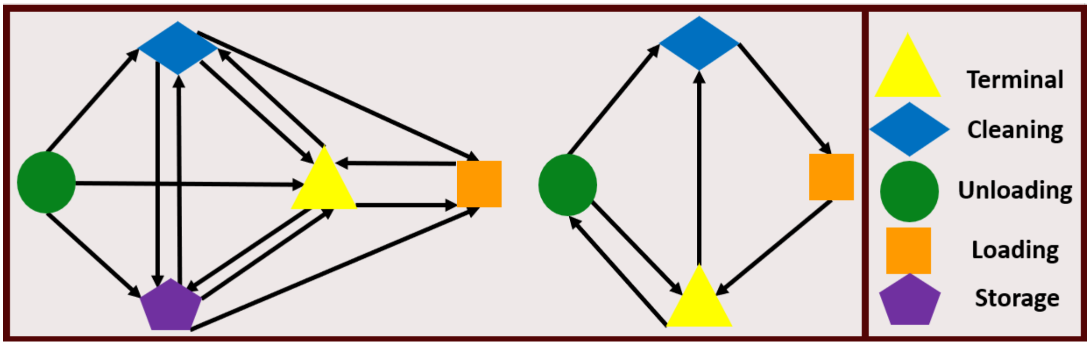

Figure 16: Arcs in practice (left) and under the assumptions of this study (right)