Network Simulation for a Logistic Service Provider in a Multimodal Setting

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Network Simulation for a Logistic Service Provider in a Multimodal Setting

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Preface

This report has been written in fulfillment of my degree in Master of Science in Operations Management & Logistics, with a specialization in Transportation, at the University of Technology in Eindhoven. During my time at Ewals Cargo Care in Tegelen, December 2022 - July 2023, I have simulated the Network Stimulation for a logistic service provider using a multimodal setting.

I would like to express my gratitude to Freek Heesen, who not only offered me various opportunities throughout my time at Ewals, but also challenged me to grow professionally. I would like to thank Lijia Tan for supervising me, and sharing her knowledge and view on academic research with me. Within Ewals Cargo Care I would like to thank in particular Rene Snijders, Sjoerd Versteeg and Stephan Verheijden for guiding this research and their valuable input. Next, I would like to thank my colleagues within the Product Intelligence department for their support and willingness to help out throughout my time here. Lastly, I would like to thank my family, friends and girlfriend for their support throughout my study time.

28^{th} of May, Roermond,

Thomas Sars

Abstract

This research was created to analyze to what extent cost reduction is possible when harbour centralization takes place in the network structure of a Logistic Service Provider considering multimodality. The chosen approach was a simulation algorithm that could quickly analyze different heuristics, in total four different heuristics have been analyzed. The first model explored what would happen in the most extreme scenario, when only one connection would be available between GB and the EU. The findings of the first model have been used as input for the second model. The heuristics that guided the model to choose a new connection was the nearest neighbour algorithm. If multiple connections were available from the nearest harbour, the cheapest was be chosen. This model was not found feasible. The third model took the greediness of model 2 into account by minimizing the road distance. This resulted in a decrease of 3,2% in cost compared to the status quo. The last model was setup together with experienced network specialists, where they gave their input in how they wanted to see the network routed between GB and EU. Despite the result showing a cost increase of 1,9%, this model has another strength. Namely, the fact that only four connections are mainly used, resulting in less procurement of cost traction according to the NEC.

Summary

Business Problem

Ewals Cargo Care (ECC) is a family-owned business led by the 4th Ewals generation The company holds over 3800 trailers, 550 own trucks, 1350 subcontractors and 31 local business units spread over 14 countries. The department that is responsible for all multimodal FTL transports is Group FTL. Group FTL, which resides across whole Europe, has as core task to oversee and offer on multimodal shipments across Europe on behalf of ECC. The modality options in ECC's network consist of short-sea ferries, rail and road, or a combination of the aforementioned options. By using multimodal transport routes on long distances, prices are lower compared to a road solution, where on the whole trip the trailer is being pulled by a truck, and therefore more competitive within the market. Because of the size and complexity of the ECC's network, there is a blind spot in assessing how efficient the current operation is performing and where possible improvement lies. ECC's perspective is that there is a missing aspect of a "helicopter" view that can help NEC engineers to see the consequences more than one step ahead resulting from modifications in the network. ECC would prefer a simulation that can compare there current way of business of their network to different scenarios and benchmark it to their status quo. Because prices are cost based, the more efficient ECC's network operates, the less costs will incur, the more competitive prices will become. This will result in more business that can be won via commercial campaigns. The main research question is as follow:

How can the harbour balances of Ewals Cargo Care's Group FTL between the European continent and Great-Britain be optimized in terms of direct cost when centralization of harbours takes place?

Simulation Model Setup

The approach to answer the main question is a simulation model. A simulation is often the only type of investigation possible in real-world systems, according to Law (2014). Another strength of a simulation is the *what would if* concept, this allows simulation developers to test the status quo to different scenarios to get the best idea of the consequences of certain adjustments to a system. ECC would prefer a simulation that can compare there current way of business of their network to different scenarios.

In the simulation models the cost are decomposed to their purchase invoice line level. In the simulation models not only the ferry tripleg are changed, but also the tripleg towards the embarking terminal and the tripleg from the disembarking terminal are changed by the model.

The tripleg cost for a short-sea ferry is a fixed tariff dependent on the season, cost for road trip-legs are variable and dependent on the distance. These variable road or traction cost are called the km-rate, expressed in €/km.

Analysis & diagnosis

After a thorough validation process of the build simulation model, four models have been analyzed. The Model 1 explored what would happen in the most extreme scenario when only one connection would be available between Great Britain (GB) and the European (EU) continent. This has been done for the top 10 connection for GB-EU. No cost reduction came from Model 1 but some insights were deduced, these insights were used in the Model 2.

In Model 2 the top 10 connections, together with two connections between Iberia and one connection between Scandinavia, were set available. Direct connections between Iberia and GB and Scandinavia and GB were introduced to reduce the lead-time and cost for these two regions. The heuristics that guided Model 2 to choose a new connection is the *nearest neighbour* algorithm. If multiple connections were available from the nearest harbour, the *cheapest insertion* algorithm was used. Model 2 had several shortcomings due to its greediness. The nearest neighbour algorithm disregarded the road distance after the crossing. By selecting the cheapest ferry the model disregarded the road kilometers it had to make after the crossing.

Model 3 took the greediness of Model 2 into account by minimizing the road distance per trip. The heuristic therefore explored all possible routings and choose the route with the minimum road kilometers. This resulted in a decrease of €1,665,683 (3.2%) in cost compared to the status quo.

Model 4 was setup together with experienced network specialists, where they gave their input in how they wanted to see the network routed between GB and EU. Model 4 yielded a cost increase of €989,999 (1.92%) in cost compared to the status quo. The strength of Model 4, while it is not cost optimal, is that only four connections are mainly used, with two harbours in GB and two on the EU side. This decreases the complexity of utilizing traction and offers a strong bargaining position with shipping companies, according to the NEC. Another strength Model 4 is reproducible with other ferry connections as input, when the NEC wishes to test other scenario's. The effective financial impact of procuring traction for Model 3 and Model 4 is up to the NEC together with the Procurement Department and ECC Colchester, the latter being responsible for the transports within GB.

Recommendations

Concluding from the results of the four scenarios analyzed in this research, the best way to optimize the network of Group FTL is to only utilize the top 10 connections together with direct connections between Iberia and Scandinavia, and use a minimum road distance approach to select the best routing for each transport.

For future research several extension possibilities are possible. Firstly, expanding the area of GB-EU step-by-step to finally cover the whole network of Group FTL in a simulation model. Secondly, including a prediction algorithm to also act on future developments.

The extension of this simulation model could go in two different directions. The first option is to extent the model as presented in this research. The second option is to use the current pricing methodology, the (Pricing Calculation Tool (PCT)). If the PCT is chosen, a large scale validation process should take place to compare the calculated cost with the actual cost that incur during transports. This should be done to ensure the simulation accuracy.

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Glossary

Multimodal Multi-modal transports are transports that use more than 1 modality for the same packaging unit of the load.

Pricing Calculation Tool Advanced calculation software with an extensive database that includes all Group FTL's routing possibilities and automated calculation outcomes.

Product With "Product", Ewals means a zone-zone relationship with equipment type, modality and execution possibility.

Tender A tender is the same as a Request For Quotation and will be used interchangeably.

Tripleg A tripleg represents a part of a trip transported via a certain modality, each transfer starts a new tripleg.

Acronyms

ECC Ewals Cargo Care.

FTL Full Truck Load.

LSP Logistics Service Provider.

NEC Network Excellence Center.

Contents

1 Introduction

1.1 Ewals Cargo Care

Alfons Ewals founded Ewals Transport in 1906 with a single horse and wagon (ECC (2023)). At the end of the last century, Ewals focused on the automotive industry and the corresponding transport links for the countries such as Great Britain (GB), Sweden and Germany, which are main players in the automotive industry. This required short-sea connections between the European mainland, Scandinavia and GB, which was managed by a new branch called Cargo Care, that took care of unaccompanied shipments on these multi-modal links. In cooperation with the automotive industry Cargo Care developed and invented the Mega Trailer, which is a trailer type that could hold approximately 25% more capacity in terms of volume. In 1994 Ewals Transport and Cargo Care merged into Ewals Cargo Care (ECC). The current company is still a family-owned business led by the 4^{th} Ewals generation, which holds over 3800 trailers, 550 own trucks, 1350 subcontractors and 31 local business units spread over 14 countries. Appendix A presents a more detailed overview of ECC.

As a company ECC wants to grow and develop themselves to be ready for the future with a renewed strategy. The established strategy - defined as a diversification strategy - is called ECC's "Next Generation Logistics Strategy" (Appendix B). This strategy consists of four strategic pillars where ECC keeps challenging themselves to be future proof, to ensure business continuity and to embrace new developments and opportunities. The main goal is to create "One Ewals", where all entities work together as one. The four programmes, that will help to create "One Ewals", are defined as the following:

1. **Products to deliver**: Selecting and developing existing and new products, markets and technologies for future differentiation and customer value creation.
2. **Professionals to lead**: Investment in a business building attitude, training programs and leadership skills, and cultivating a workplace where their employees can get the best out of themselves.
3. **Communities to build**: Strengthening existing relations, internal and external, and creating new partnerships to keep on building business and to stimulate innovations.
4. **Business systems to perform**: Operational collaboration between their offices and with their partners, all on one platform. Improving business intelligence and a "first time right" attitude.

In January 2022 ECC reorganized themselves and created a matrix structure within the organisation, shown in Figure 1, which is coherent with "Next Generation Logistics Strategy". In the horizontal stream of Product Management, under Product Intelligence (*RFQ, Solutions, Pricing, Implementations and BI*) in Figure 1, is the department where this project takes place. Product Management is responsible for the development of ECC's asset-based network and its products and its development and continuous operational excellence. The Product Intelligence department has as one of its core tasks to continuously improve the current processes within ECC, but also to support other departments with projects in a technical aspect. Product Intelligence supports the asset-based organization by providing relevant and state-of-the-art technologies, i.e. improving its network and linkages. This project is set in the department Product Intelligence, with support from *Product Development & Product Design* where the network specialists reside, and is focused on the program *Products to deliver* of the *'Next Generation Logistics'* strategy. Currently there is a lack of insight into the efficiency rate of the network organization, since there is no technological support available yet. As the focus in this program lies on new technologies for further differentiation the question here arises: *Is it possible to perform a network simulation to have a technological advantage ready for the future?* This advantage will be two-fold: firstly, it will give insights in how the network performance is right now and consecutively in a more optimized situation. Secondly, via these insights the operational side can be modeled to perform more efficiently in the future. With a yearly budget of approximately 380,000,000€, even an improvement of 1% can have a significant influence on the profit.

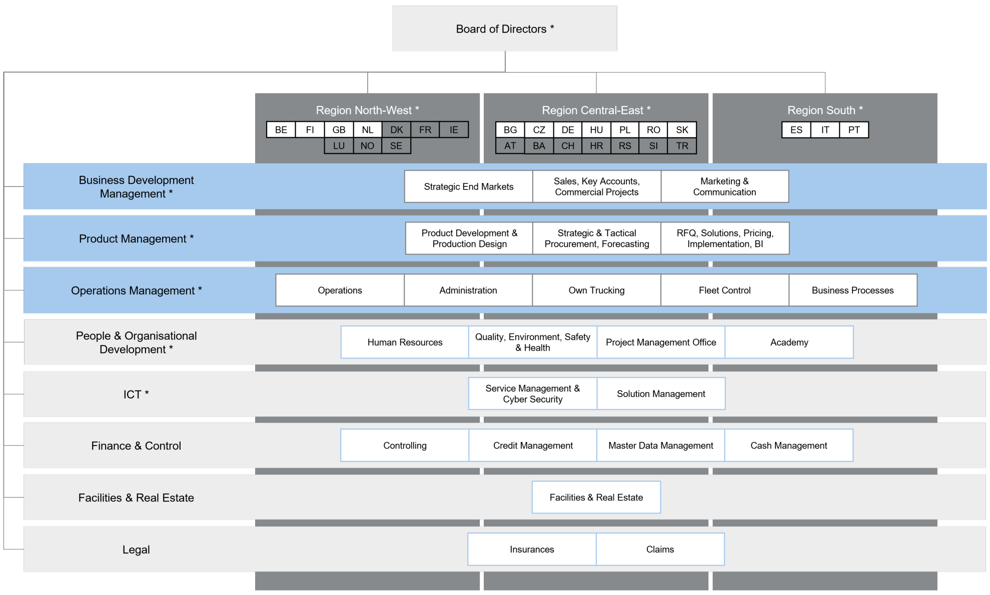

Figure 1: Organisation structure of Ewals Cargo Care (ECC) *Source: Ewals Cargo Care*
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1.2 Group FTL

Within ECC there are six different product lines, namely:

1. **Part Loads (LTL)** combines ECC's own and their partners' network of connected cross-docks and warehouses with the strengths of local offices, to ship clients groupage and LTL loads.

2. **Project Loads** focuses on express, oversized-freight, high-value and event logistics.

3. **Control Tower** operates the complete logistics of a client in the clients name. This way clients can focus on their core business.

4. **Value Added Logistics** offers also internal (e.g. pre-production and assembly) and external logistics (e.g. Storage & warehousing, Warehouse On Wheels) as extra products next to transporting goods from origin to destination.

5. **Global Forwarding** forwards shipments across the whole world with air and container shipments.

6. **Full Loads (FTL)**: Full Loads is ECC's biggest revenue product and focuses on transporting FTL loads.

Full Loads is ECC's biggest revenue product, the department that is responsible for all multimodal FTL transports is Group FTL. Group FTL, which resides across whole Europe, has as core task to oversee and offer on multimodal shipments across Europe on behalf of ECC. The modality options in ECC's network consist of short-sea ferries, rail and road, or a combination of the aforementioned options.

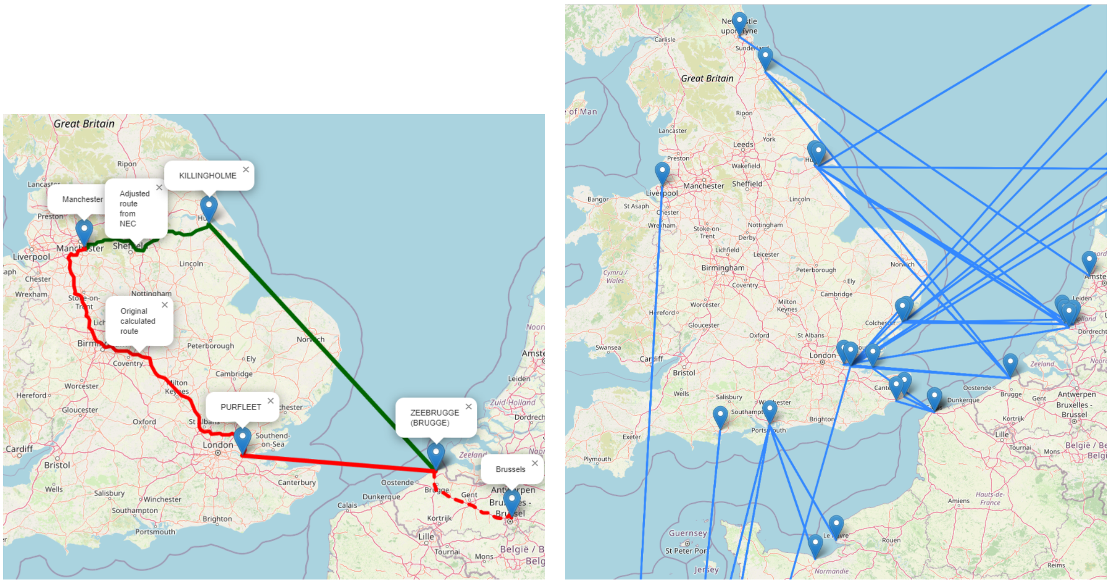
Short-sea ferries have the option to transport trailers manned and unmanned, the latter meaning that truck and trailer are separated at the embarking port. Rail transports are always unmanned as rail-cars are made to transport only the trailer. Unmanned transport is cost-efficient as truck and truck-driver are not employed while being transported on another modality, and thus can be utilized somewhere else. While this is cost-efficient, the drawback of this setup is that the complexity of the planning increases as another truck and driver have to pick up the trailer at the disembarking port.

By using multimodal transport routes on long distances, prices are lower compared to a road solution where on the whole trip the trailer is being pulled by a truck, and therefore more competitive within the market. Multimodal solutions are also aligns with ECC's endeavour to invest in more sustainable solutions where less CO2 is emitted. However, the complexity of the network increases with multimodal transports as more variables and restrictions (e.g train/ferry fixed departure times, capacity constraints, transport carriers) have to be taken into account in the decision making and operational coordination.

1.2.1 Network Excellence Center

The Network Excellence Center (NEC) is responsible for maintaining and optimizing the multimodal network of Group FTL. One of their activities is finding the best routes by focussing on terminal connections. This means that certain routes are used or avoided based on the NEC's analysis and reasoning (e.g. capacity shortages). Another task entails validating the quotations that are calculated by the Central RFQ and Solution Desk on their practical implementation. For example, a RFQ Analyst calculates a price based on the terminal connection Purfleet-Zeebrugge for a lane from Manchester to Brussels (see Figure 2a). A NEC Engineer then has the task to validate this routing based on historical and current data in terms of ferry capacity and cost of subcontractors in those regions (as subcontractors in popular areas are more expensive than those in less popular areas). An advise could then be to not base the quotation on the route Purfleet-Zeebrugge, but change this quotation on Killingholme-Zeebrugge. Currently this validation procedure is all done manually, and as can be seen in Figure 2b, a vast amount of possibilities are available to transport a shipment between Great Britain and the European continent. The

NEC also assesses opportunities to develop new intermodal connections in collaboration with Product Development & Network Design.



(a) Example of a routing from Manchester-UK to Brussel-BE.

(b) All currently used terminal connections for GB-EU.

Figure 2: Example connections between GB and EU, as explained in Section 1.2.1

1.2.2 Price Calculation Method

This section explains the method of price calculations done by Group FTL and how they cope with market imbalances. Appendix C presents an screen capture of the current pricing tool with the respective variables. Group FTL uses a value added approach to quote on prices, meaning that the sales price is a summation of all cost parameters plus a margin. Sometimes, cost avoidance quoting is also applicable in order to balance the network at certain trajectories. Most of the cost parameters are straightforward direct costs, such as traction, trailer rent, ferry/train or toll. Traction cost are the cost that are payed to the truck driver including fuel (this includes ECC's own truck-drivers). Trailer rent is payed to ECC's Fleetcontrol who are in charge of maintaining all trailers of ECC. Ferry and train cost are the cost payed to the shipping company. Toll costs are payed for specific roads, tunnels or bridges. On top of these direct costs, Group FTL applies surcharges to correct for imbalances or to reserve for cost that occur between transports (empty mileages). The most influential one is called market correction. These market corrections are applied to make sure that quotations are not only focused on costs, but also reflect the current market imbalances between supply and demand to a certain aspect. GB is an example of a consumption country where the market demands more inbound than outbound transportations. The market correction would then be a surcharge on the lanes towards this country to balance the cost that Group FTL is forced to make to retrieve their empty trailers. These imbalances can also be derived from the rates Transporeon Insights collects as shown in Figure 3, or the contract rates from IRU, TI, and Upply (2022) shown in Figure 4. These sources show that rates inbound to the UK are almost double the rates outbound from the UK, which are caused by the imbalance between supply and demand from and to the UK. For this research the market corrections are out of scope as the main focus will only be on the direct cost.

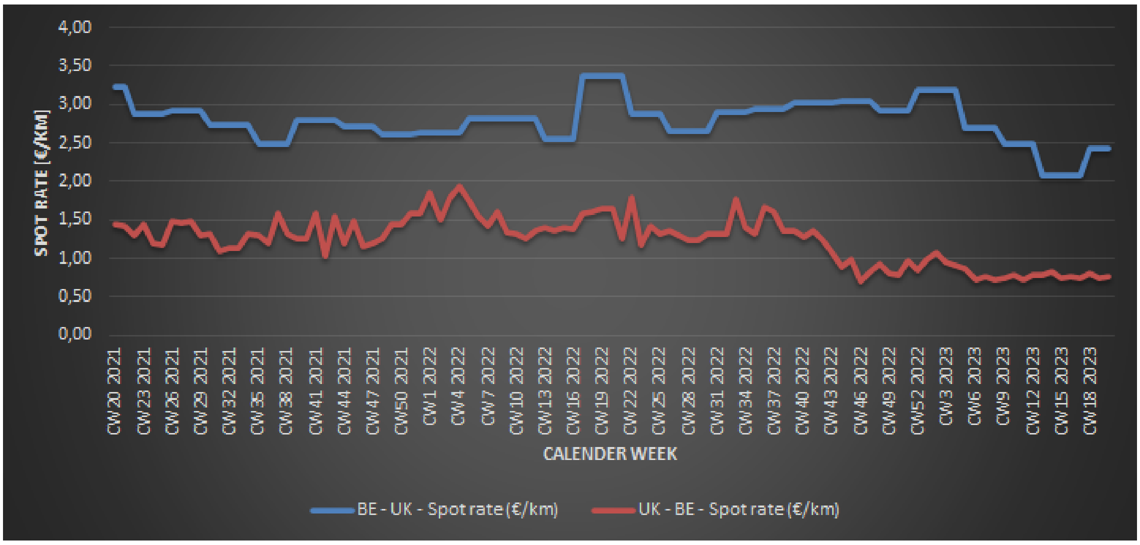


Figure 3: Transport rates Belgium-UK and UK-Belgium (Transporeon Insights (2023)).

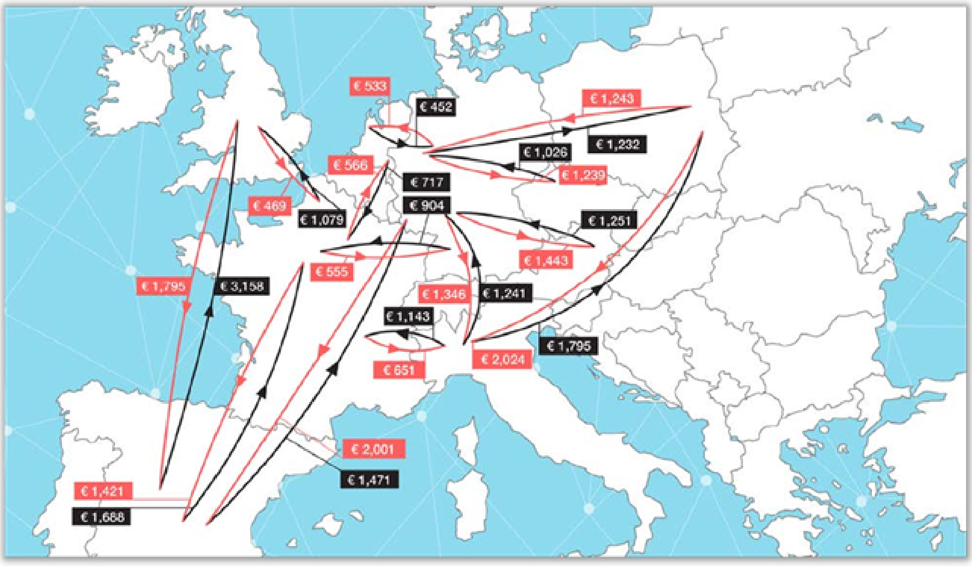


Figure 4: Contract Rates Q2 2022 (IRU, TI, and Upply (2022)).

1.3 Problem description

Because of the size and complexity of the ECC's network, there is a blind spot in assessing how efficient the current operation is performing and where possible improvement lies. The main complexity resides in the "*triangle*"[1] structure of ECC, as a small modification

[1] An important aspect of ECC's network is that trailers do not move back and forth between two locations (say A & B), but move in so called *triangles*. This implies that when a trailer transports a shipment from A to B, it will pick up a new shipment at or close to B and transport it to C, at or close to C it will pick up a new shipment and transport it back to A.

changes the balance of the whole network. In comparison, other LSP use a linear network structure where trailers only move from A to B and back again (B to A). The full consequences of modifications to the network of Group FTL, such as the loss of a client or closing a new ferry connection to GB, are not modeled nor analyzed at this moment. Instead, only partial consequences get solved in an ad-hoc procedure, while knowing the full implications of a modification could help the decision making process in the network in a cost-efficient way. Currently there is a missing aspect of a "helicopter" view that can help NEC engineers to see the consequences more than one step ahead when there are modifications in the network. ECC's wish is that this helicopter view is computer aided, as people are biased and quickly cognitive limited while a computer algorithm is not.

The modifications do not only result in the change of direct cost (i.e. the cost of the new route), but also impact the capacity. For instance, closing or opening a new ferry connection influences the capacity of harbour connections and the utilization of traction. Traction is complex as ECC's own trucks and subcontractors are paid based on different conditions. Subcontractors in GB cost a fixed amount for each day they are hired, regardless of the driven distance. Own trucks have a minimum cost per day (to cover depreciation, among other things), and charge a rate per km. The change in harbour connections has far-reaching consequences in traction cost, as new routes will have to be travelled by road.

Right now Group FTL creates flexibility to GB by having multiple connections and using multiple ports as remarked in Figure 2b. This way there is always an option available for the planning department to transfer a trailer from or to GB. As a result, the complexity of planning and procuring traction increases. A truck with driver is sometimes procured for short triplegs, or this truck has to drive long distances between harbours to pickup or drop a trailer, both resulting in a low utilization of traction. Traction is allocated as it is seen fit from day to day in an ad hoc manner. The NEC states that centralizing these harbour connections would decrease the flexibility in ferry connections, but increase the flexibility in planning traction resulting in a higher utilization of traction. The flexibility in traction would come from the increase of quantities at the centralized harbours. The traction at each port would therefore only serve a specific region instead of having to drive all over GB. However, the NEC and Group FTL have no process in place to research the feasibility of how the direct cost or lead-times are influenced when centralizing harbours.

Because prices are cost based, a more efficiently operating network of ECC will result in less costs, and therefore quotations will be more competitive within the market. This will result in more business that can be won via commercial campaigns/tenders. In other words, striving for operational excellence (Treacy and Wiersema (1993)), resulting in ECC becoming cost leader in the logistics industry. This research will therefore describe a model with the main focus on minimizing the direct cost of transports.

1.4 Scope

Because of the vast network Group FTL (see Section 1.3) has in place across whole Europe, the initial scope will be reduced to the inbound and outbound transports of

GB. Firstly, because here lies the greatest imbalance between inbound and outbound demand for transports within Group FTL's network, around 600 trailers are shipped back empty from to GB to the EU mainland per month. Secondly, 30% of ECC's business is connected to GB making this area of big interest for ECC. Thirdly, because GB is an island, there are only a limited amount of connections in and out of GB, which makes this part of the network uncluttered. This also implies that Group FTL will always offer a multimodal solution, therefore all trailers are routed via harbours [2]. Lastly, in order to have a feasible solution within the given time frame. Transport between GB and Ireland (including Northern Ireland) are out of scope as this is not a product from Group FTL, but a product of the local business unit ECC Colchester.

Outsourcing of transports to third party LSPs will not be considered in this project, because the focus lies on ECC's Asset Based transportations. Within outsourcing, the company that executes the transports uses his own assets and will only get payed the negotiated price, regardless how the transport is executed and therefore not applicable for this research.

Empty trailer movements or the repositioning of empty trailers will not be included in this simulation, because the current strategy is to move all empty trailers in GB back to Calais. From here they are distributed again to a new origin in the EU. Both Crainic (2000) and Wieberneit (2008) argue that the repositioning of empty vehicles is a separate part of planning, and should be done to be ready for future demand.

1.5 Stakeholders

Together with the company supervisor Freek Heesen, three other direct stakeholders within ECC are identified that are deeply involved in this project. These stakeholders and their respective job titles are:

- Stephan Verheijden, Analyst Continuous Improvement
- Rene Snijders, Manager NEC
- Sjoerd Versteeg, Business Intelligence Engineer

Mr. Heesen is responsible for the organisational part of the project, Mr. Snijders', Mr. Versteeg's and Mr. Verheijden's input is based on their knowledge of ECC and experience in their respective workfield. Mr. Snijders' input will be on the operational side of the simulation, as each outcome still should be feasible in the real world. Mr. Versteeg's input will be about the data, i.e. which data-sets to use, how to retrieve the data and help to validate the feasibility and reliability assessment of the data. Mr. Verheijden's expertise lies within Continuous Improvement, he will therefore help to reflect on the current situation and help to identify new opportunities within ECC. Together Mr. Heesen, Mr. Snijders, Mr. Versteeg and Mr. Verheijden form the Steering Committee (SteerCo). The

[2]the Channel Tunnel (the only other connection to GB outside ferries) is only used as an ad hoc solution, e.g. to accomplish certain lead-times.

SteerCo will help to lead the project in the right direction and will meet on a monthly basis. Apart from these individuals, the Network Excellence Center (NEC) and Group FTL will be the main stakeholders as this research will support their current processes.

1.6 Research-questions

As already mentioned in the previous section, this project will focus on the transports between GB and the European mainland, where the goal is to give insights in the current situation and consecutively to optimize this situation when centralization of harbours takes place. This leads to the main research question:

How can the network of Ewals Cargo Care's Group FTL between the European continent and Great-Britain be analyzed and improved when centralization of harbours takes place?

Several sub-questions have been defined to gradually create an answer to the main research question. First, the current situation has to be identified, where the focus will lie on the current day to day business and processes of Group FTL. For example, how are decisions made right now and what data gets logged and in what way. This will be answered with **SQ1**. To be able to model the current performance and analyze changes to this, a simulation model will be made, the answer to **SQ2** will give insights how to do this. Because the output of the simulation model is only a reflection of the real world, the results will have to be validated. This will be done to be certain that the results are feasible. The validation of the model will be answered with **SQ3**. Once the simulation model is validated, an optimization process will be started to increase the performance of the network. This optimization process will be done by applying several heuristics to the model, what heuristics will be used and how these heuristics perform will be answered by **SQ4**. What recommendations and insights that can be retrieved from all simulations for ECC after this project will be answered in **SQ5**.

1. What is the current situation in ECC's Group FTL department in terms of processes, data availability and data reliability?
2. How to setup a network simulation model for ECC's Group FTL?
3. What is the reliability of the simulation model and its output?
4. What scenarios and heuristics need to be considered and what is their respective performance?
5. What insights can be retrieved from the results and what are the corresponding recommendations for these results?

1.7 Report outline

The report outline is as follows. Section 2 will start with defining the KPIs where the simulation will be measured on. Next, the different datasets used for this research will be explained. Lastly, the KPIs of the status quo will be discussed. Section 3 will start by describing the main assumptions of the simulation, followed by the explanation of the simulation algorithm itself. The performance of the simulation algorithm and the procedure towards retrieving this performance will be given in section 4. In section 5 the different simulation heuristics will be shown and the results will be discussed. In section 6 the main research question will be answered after an analysis of the results, and recommendations will be given for ECC.

2 Current Situation Analysis

This section will analyze the current situation regarding teh current operations and the data availability. subsection 2.1 presents the definitions of KPIs, subsection 2.2 presents the used data its availability and subsection 2.3 presents the current performance of Group FTL.

2.1 Definitions of KPIs

The goal of this research is to make analyze and consecutively improve the network between GB and EU continent.

The main KPI will be cost, as reducing cost is not only good for increasing the margin of Group FTL, but also to improve the market position by offering a lower price, as in line with operational excellence (Treacy and Wiersema (1993)). Next to cost, the gross margin[3] (Equation 1) and lead-time will be given. The gross margin will be given to benchmark the cost against the turnover. The lead-time will be analyzed as a new routing could change the lead-time for certain origin-destination pairs. The lead-time is defined as in (Equation 2) and expressed in days. In the logistic industry lead-times are expressed as *A-A* for a load that is loaded and delivered on day A, and has a lead-time of 1 day. *A-B* gives the lead-time for a transport loaded on day A and delivered on day B, as a lead-time of 2 days. Therefore a value of 1 day is added in Equation 2, as the time points are expressed to the minute. This is also in line with ECC's definition of lead-times. Next to that, the main KPI used by Network Development department within ECC to measure the performance of the network is *Margin per trailer day* (see Equation 3), which could also change. This KPI will also be analyzed. Lastly, because harbour connections will be changed, the inbound and outbound quantities of the harbour will be analyzed.

$$Gross\ Margin = Turnover - Cost \tag{1}$$

$$Lead\text{-}time = t_{arrival} - t_{departure} + 1day \tag{2}$$

$$Margin\ per\ trailer\ day = \frac{Gross\ Margin}{\lceil Lead\text{-}time \rceil} \tag{3}$$

$$Relative\ Margin = \frac{Gross\ Margin}{Turnover} \tag{4}$$

[3] In this report *margin* and *gross margin* will be used interchangeably

2.2 Data Assessment

ECC manages their data in the a central data-warehouse. The datasets used for this research are at three different levels. The first level is on trip level, this dataset describes all basic information such as routing, total cost and revenue per trip. The second level is on tripleg level, which describes the information per tripleg. The third level is on Purchase Invoice Line (PIVL) level, this data describes per tripleg the cost that are invoiced to ECC. In Table 1a, 1b and 1c the data for one trip is given on trip-, tripleg-, and PIVL-level in, respectively. Here it can be seen how the level of detail increases from trip to PIVL-level. The row labels consist of *Trip, Tripleg, PIVL*, these stand for the trip number/ID, the tripleg number and the PIVL number, respectively. This way each row can be uniquely identified.

Table 1a shows the attributes of a trip including the overall cost, turnover, country-relationship, origin, destination, and the start and end date. The trip in Table 1a consists of three triplegs. Table 1b presents the cost, transport mode, origin, destination, and the start and end date for each tripleg. What should be noted is that the sum of the tripleg cost do not equal the cost of Table 1a. That is because there are some cost that cannot be appointed to a specific tripleg. These cost can be distinguished in Table 1c on the most detailed level. **ALL* stands for costs that apply to the whole trip and cannot be appointed to a specific tripleg. The PIVL-level presents the cost that are invoiced to ECC per tripleg or trip (i.e. **ALL*).

Table 1: Example data on Trip, Tripleg and Purchase Invoice Line level.

(a) Information on trip level

Trip	Cost [€]	Turnover [€]	Routing	Origin	Destination	Start	End
081008756	752.55	654.76	GB-NL	GB NN17 5UE	NL 3336	2022-01-05 12:10:00	2022-01-10 15:20:00

(b) Information on tripleg level.

Trip	Tripleg	Cost [€]	Transport Mode	Tripleg Start	Tripleg End	Origin	Destination
081008756	**001**	265.48	Road	2022-01-05 12:10:00	2022-01-05 20:30:00	GB NN17 5UE	GB CO12 4QG
	002	271.78	Maritime	2022-01-05 20:34:00	2022-01-06 07:30:00	GB CO12 4QG	NL 3197
	003	61.07	Road	2022-01-10 13:28:00	2022-01-10 15:20:00	NL 3197	NL 3336

(c) Information on Purchase Invoice Line level.

Trip	Tripleg	PIVL	Cost [€]	Km-rate [€/km]	Terminal from	Terminal to	Transport Mode	Costcode
081008756	***ALL[4]**	**A**	114.00	0			*ALL	Trailerrent (Intercompany)
		B	40.22	0			*ALL	Day Rate
	001	**A**	34.14	1.061			Road	Trucking
		B	231.34	1.061			Road	Trucking
	002	**A**	20.00	0	HAR	EUR	Maritime	Ferry Charges
		B	251.78	0	HAR	EUR	Maritime	Ferry Charges
	003	**A**	13.46	1.035			Road	Trucking
		B	47.61	1.035			Road	Trucking

The data has been cleaned by deleting all trips where the triplegs did not follow a consecutive route. A consecutive route is defined as a route where the destination of a tripleg is equal to the origin of the next tripleg. In Table 1b a correct example of a consecutive route is given in the columns *Origin* and *Destination*. This filtering has been done to create understandable routes for the model, otherwise the model will not perform properly. Next, trips that have a tripleg start date and time that is greater than the tripleg's end date and time are deleted, to prevent calculations with negative

[4] **ALL* stands for costs that apply to the whole trip and cannot be appointed to a specific tripleg

lead-times. In total 3499 of the total 39211 trips were deleted.

2.3 Analysis of KPIs

Figure 5 presents all KPIs shown per month for the year 2022 for inbound traffic (Inbound), outbound traffic (Outbound) and overall. The KPIs are split in inbound and outbound to reflect on the imbalances as discussed in Section 1.2.2. The KPIs are shown per month to investigate if there are any patterns throughout 2022. The raw data can be found in Appendix D.

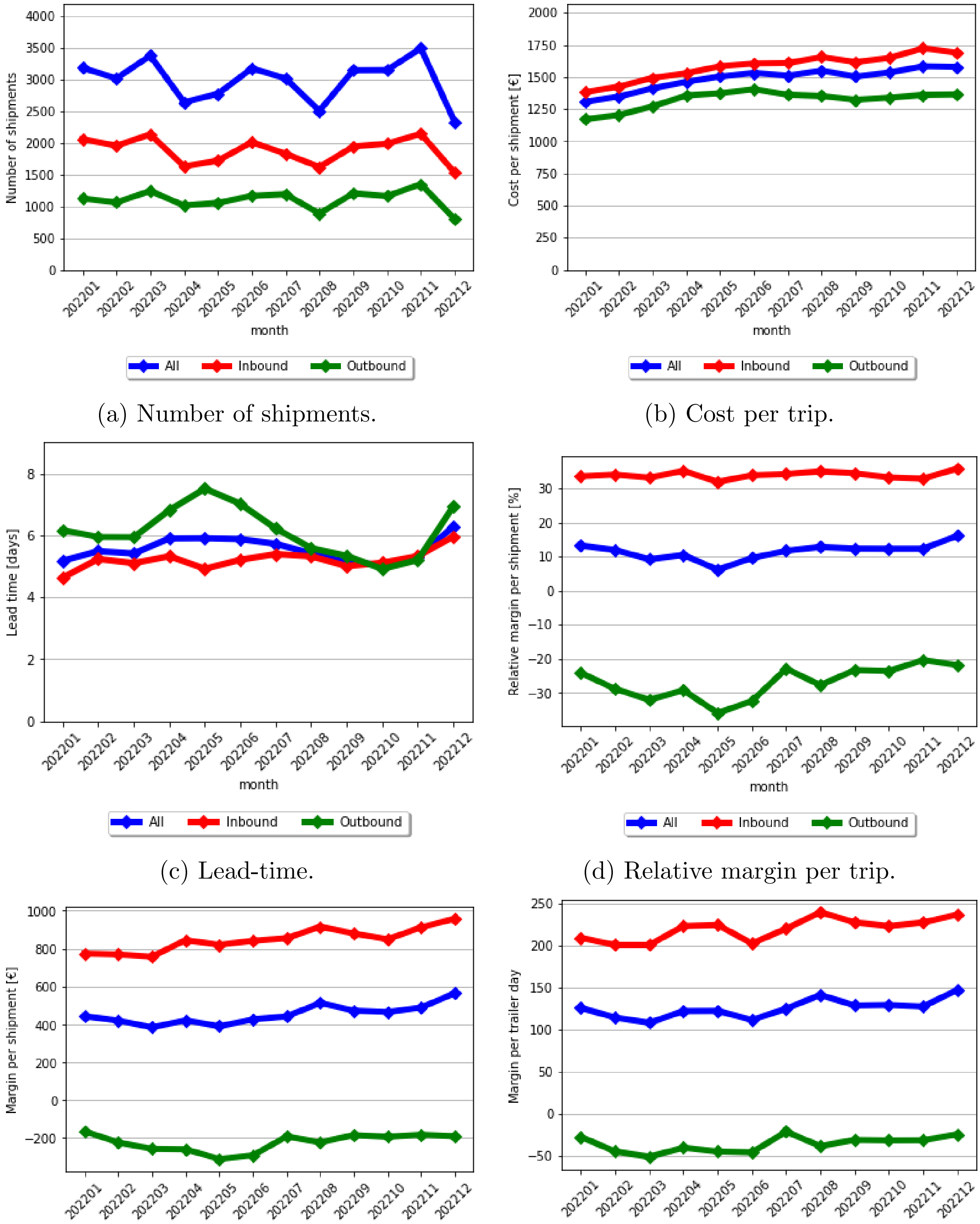
Figure 5a presents the number of trips per month. Here two distinct dives can be seen in August and December, which can be explained by summer and Christmas holidays. The cause of the dive in April could be explained together with cause for the the longer lead-time in this period.

Figure 5b presents the average cost per trip. This figure shows no direct seasonality impacts, but an overall increase of around 20% from January to December. As diesel prices exploded in 2022 and the overall inflation was around 10% (*CBS Statline-Consumentenprijzen* (2022)), the increase is a logical consequence of the development of the diesel and the economy over 2022. Especially diesel prices can influence the cost of a transport, as diesel is the second biggest cost driver (after the truck drivers salary) taking up 30% of the total cost according to ECC.

Figure 5c presents the average lead-time per trip. Especially around May a distinctive peak can be seen. Around this peak there were a lot of uncertainties around P&O Ferries which is *'one of UK's largest ferry services'* according to Anonymous (2022a). P&O Ferries normally operates one third of the connections with the European mainland. In Anonymous (2022b) it is also expressed that other shipping companies could not cope with the extra demand and on top of that the British Customs had to cope with technical problems. These articles relate to March and April, but the same can be seen in Juli in Anonymous (2022d) and Anonymous (2022c). This could explain the longer lead-times around May in Figure 5c, as not only the mentioned connection in Dover would be influenced, but also as clients of P&O Ferries would look to other alternatives, which in turn would put pressure on those connections. These uncertainties together with bank holidays (Eastern, Pentecost, Ascension day) in this period could be the cause that less shipments are transported as shown in Figure 5a.

Figure 5e and Figure 5d present the average margin per shipment and the average relative margin, respectively. In Figure 5e it can be seen that the inbound margin increases over 2022. The relative margin in Figure 5d stays stable, this means that the turnover per shipment also increased over the 2022 according to the definition of Equation 4. The outbound margins are more volatile compared to the inbound margins. This is displayed in Figure 3 where the rate to the UK are much more stable than the rates from the UK. The cause can be found in the narrow market, as explained in Section 1.2.2.

Figure 5f presents the average margin per trailer day. This figure looks to follow Figure 5e but more smoothly, this can be explained by the fact that the overall Lead-time of outbound trips takes longer than inbound trips.



(a) Number of shipments.

(b) Cost per trip.

(c) Lead-time.

(d) Relative margin per trip.

(e) Margin per trip.

(f) Margin per trailer day.

Figure 5: KPIs per month over 2022.

3 Simulation Model Setup

This section describes the setup of the simulation model and its assumptions.

3.1 Simulation setup and assumptions

Law (2014) argues that most complex, real-world systems cannot be described accurately by a mathematical model. However, in a simulation a computer is used to evaluate a model numerically, and data is gathered in order to estimate the desired true characteristics of the model. A simulation is often the only type of investigation possible in real-world systems. Another strength of a simulation is the *what would if* concept, this allows simulation developers to test the status quo to different scenarios to get the best idea of the consequences of certain adjustments to a system. ECC would prefer a simulation that can compare there current way of business of their network to different scenarios.

In the simulation models the cost are decomposed to their purchase invoice line level. In the simulation models not only the ferry tripleg are changed, but also the tripleg towards the embarking terminal and the tripleg from the disembarking terminal are changed by the model. Therefore, for the transfer itself and the tripleg before and after the connection new cost and duration (lead-time) are calculated. While the tripleg cost for a short-sea ferry is a fixed tariff dependent on the season, cost for road trip-legs are variable and dependent on the distance. These variable road or traction cost are called the km-rate, expressed in €/km. A distinction is made in the model between the km-rate in the tripleg towards the embarking terminal and the tripleg from the disembarking terminal. This is because the km-rate on a road tripleg is dependent on the place of origin. In a popular place of origin, where much traction is required, the km-rate is higher than in an unpopular region, this also follows from supply and demand logic. Km-rates on tripleg towards the embarking terminal are retrieved from the data on the tripleg itself. Km-rates from the disembarking terminal are an average rate, calculated from all triplegs that started at the respective harbour in the respective month. The new ferry cost and duration are determined by calculating the mean cost and duration for each ferry connection per month. The km-rate and ferry cost are averaged per month to take into account the seasonality patterns.

3.2 Simulation algorithm

For each tripleg $t \in T$ the cost c_t are calculated as in Equation 5, this is the km-rate v_t times the road distance d_t plus the fixed cost f_t. The road distance d_t and driving times τ_t are acquired follows from an API connection with PTV Group[5]. For intermodal triplegs, where the modality m_t is not equal to *Road* ($m_t \neq Road$), only f_t is applicable as the road distance $d_t = 0$. For each trip $T \in \mathcal{S}$ the cost c_T are defined as the sum of all

[5]PTV Group is a software company that specialises in developing software and consulting services for LSPs

tripleg cost plus fixed cost f_T as in Equation 6. These fixed cost are cost that can not be appointed to a specific tripleg but apply to the whole trip such as administration cost or trailer rent. All variables are listed below.

- $\mathcal{S}$: set of trips T
- $\mathcal{C}_{\mathcal{S}}$: total cost of $\mathcal{S}$
- $|\mathcal{S}|$: number of trips
- $A_{\mathcal{S}}$: average cost of $\mathcal{S}$
- c_T: cost per trip
- f_T: fixed cost on trip $T \in \mathcal{S}$
- o_T: origin of trip $T \in \mathcal{S}$
- i_T: departure time point of trip $T \in \mathcal{S}$ at o_T
- p_T: destination of trip $T \in \mathcal{S}$
- j_T: arrival time point of trip $T \in \mathcal{S}$ at p_T
- τ_T: lead-time of trip $T \in \mathcal{S}$
- t: triplegs in T
- c_t: cost per tripleg $t \in T$
- f_t: fixed cost on tripleg $t \in T$
- d_t: distance [km] on tripleg $t \in T$
- v_t: trucking rate per km on tripleg $t \in T$
- m_t: modality on tripleg $t \in T$, $m \in (Road, Ferry, Train)$
- τ_t: lead-time of tripleg $t \in T$
- o_t: origin of tripleg $t \in T$
- i_t: start time point of tripleg $t \in T$
- p_t: destination of tripleg $t \in T$
- j_t: end time point of tripleg $t \in T$

$$c_t = d_t * v_t + f_t \tag{5}$$

$$c_T = \sum_{t \in T} \Big(c_t \Big) + f_T \tag{6}$$

The main algorithm is described in Algorithm 1. The only difference between the simulation scenarios are the heuristics which will be described later. The heuristic defines which terminal connection is chosen. Once the new connection is chosen, the respective cost and duration are determined. Because only the tripleg before ($t_{to\_crossing}$) and after ($t_{after\_crossing}$) the terminal connection are influenced by the heuristic, both are recalculated. For $t_{to\_crossing}$ first the new destination p_t is determined. For the new origin-destination pair the distance d_t and duration τ_t are requested via PTV. The variable cost are extracted from the tripleg data. If this is the first tripleg of the respective trip, the new start time point i_t stays the same, otherwise the start point is set to the previous' tripleg end time point. The new end time point j_t is the new start point plus the duration τ_t. The new tripleg cost are calculated via Equation 5. The same procedure holds for the tripleg after the crossing, but then the procedure starts with defining the new origin of that tripleg. When all triplegs have been calculated, the new cost and lead-time can be calculated accordingly as in Equation 6 and Equation 2, respectively.

Algorithm 1 Simulation

```
for T ∈ S do
    identify t_{crossing}, where m_t = Ferry
    set new o^{new}_{t_{crossing}}, p^{new}_{t_{crossing}} via HEURISTIC  ▷ set new ferry connection via heuristic
    define τ^{new}_{t_{crossing}}, c^{new}_{t_{crossing}}  ▷ cost and lead-time for the crossing
    for t ∈ T do:
        if t is before t_{to_crossing} then  ▷ tripleg towards the first terminal
            define p^{new}_t, from t_{crossing}
            define d^{new}_t, τ^{new}_t = PTV(o_t, p^{new}_t)  ▷ (acquire d^{new}_t, τ^{new}_t from PTV Group)
            get v^{new}_t  ▷ from trip-leg data
            get f_t purchase invoice line data
            c^{new}_t = d^{new}_t · v^{new}_t + f_t
            if t = t_1 then  ▷ for the first tripleg the start time-point i_t stays the same
                j^{new}_t = i^{old}_t + τ^{new}_t
            else
                i^{new}_t = j^{new}_{t−1}  ▷ new start point is the end point of the previous tripleg
                j^{new}_t = i^{new}_t + τ^{new}_t
            end if
        else if t is after t_{after_crossing} then  ▷ tripleg from the last terminal
            define o^{new}_t, from t_{crossing}
            define d^{new}_t, τ^{new}_t = PTV(o_t, p^{new}_t)  ▷ (acquire d^{new}_t, τ^{new}_t from PTV Group)
            get v^{new}_t  ▷ from data, km rates after terminal
            get f_t from PIVL data
            c^{new}_t = d^{new}_t · v_t + f_t
            i^{new}_t = j^{new}_{t−1}  ▷ new start point is the end point of the previous tripleg
            j^{new}_t = i^{new}_t + τ^{new}_t
        else
            c^{new}_t = c^{old}_t
            τ^{new}_t = τ^{old}_t
            if t = t_1 then  ▷ for the first tripleg the start time-point i_t stays the same
                j^{new}_t = i^{old}_t + τ^{new}_t
            else
                i^{new}_t = j^{new}_{t−1}  ▷ new start point is the end point of the previous tripleg
                j^{new}_t = i^{new}_t + τ^{new}_t
            end if
        end if
    end for
    c_T = Σ_{t∈T} (c_t) + f_T
    i^{new}_T = i^{old}_T
    j^{new}_T = j^{new}_{t_{end}}
    τ^{new}_T = j^{new}_T − i^{new}_T + 1
end for
define new KPIs as in Equation 1 to 3
```

4 Model Validation

This chapter describes the validation approach of the algorithm and elaborates on the output of the validation.]

4.1 Validation approach

The simulation algorithm described in Algorithm 1 is validated by not using a specific heuristic, but all routes are *rerouted* via their original terminal connection. This entails that the new triplegs cost and duration are calculated via the calculation in Algorithm 1. Together with the stakeholders, the acceptable deviations per month is set to be in the interval [-5%, 5%] compared to the original values. The validation is analyzed based on the lead-time and cost as all other KPIs discussed in subsection 2.1 follow directly from these. The validation takes into account the Confidence Intervals (CI) to show the variation of the output. The CIs are calculated as in Equation 7 (Montgomery and Runger (2014)). Here μ is the mean of the sample, z the confidence level value, σ the standard deviation of the sample and n the sample size.

To review the output in more detail, the validation results are show per region in Figure 6. The four regions have been identified as Scandinavia (Scandinavian Peninsula), Iberia (Iberian Peninsula), Western Europe and Eastern Europe. Scandinavia and Iberia have been selected with the NEC as such because of their operational aspects. From these peninsulas specific ferry connections are in use to and from GB. Western Europe has been identified as the countries where the most transports from and to GB occur (see Figure 7). Also, these countries are approximately within a driving day from a harbour with a ferry towards GB. As can be seen in Figure 8 only the northern part of Italy is in utilized, the layout of these zones will be elaborated on in subsection 5.4. Eastern Europe is identified as countries with approximately more than a driving day from a harbour with a ferry towards GB. The total number of transports per region can be found in Table 2.

$$CI = \mu \pm z\frac{\sigma}{\sqrt{n}} \tag{7}$$

Region	Outbound[6]	Inbound	Total
Western-EU	18998	11893	30891
Iberia	1804	823	2627
Eastern-EU	1212	479	1691
Scandinavia	486	16	502
All	22500	13211	35711

Table 2: Trips per Region.

[6]relative to the Region. e.g. *Iberia outbound* means from Iberia to GB.

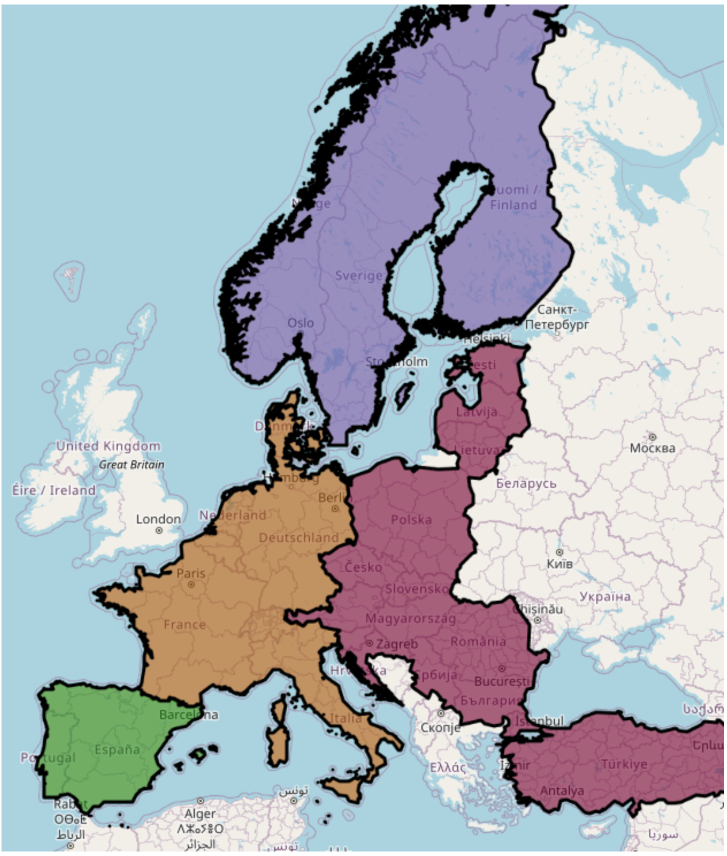
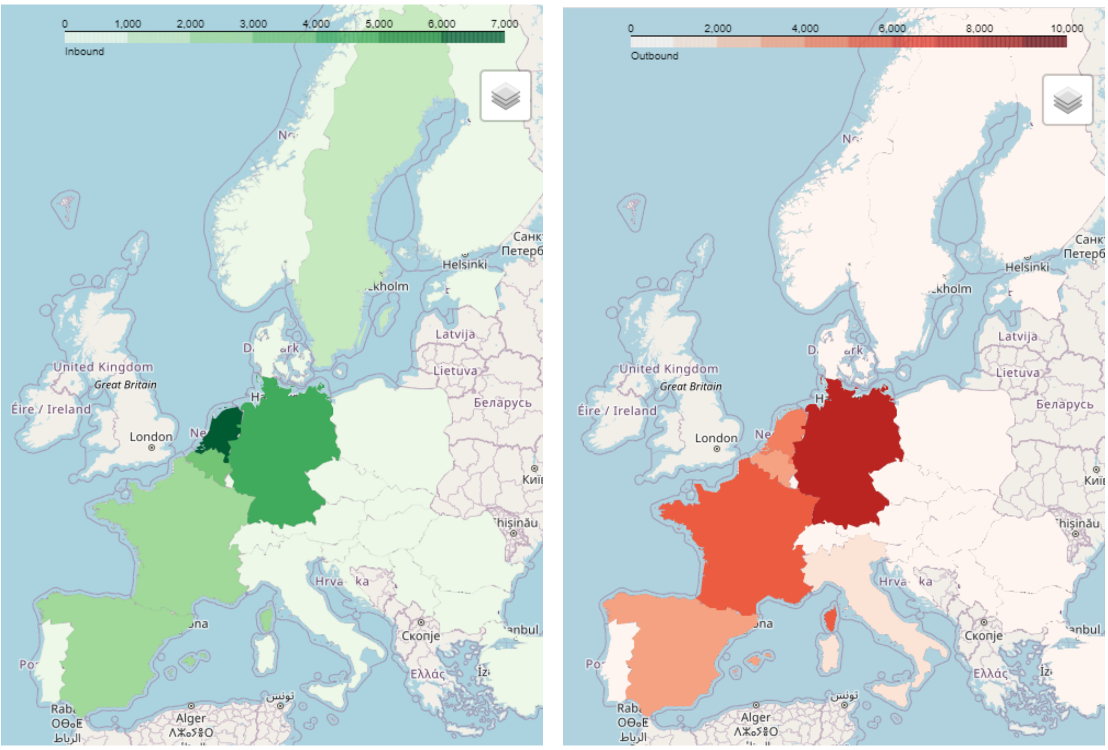


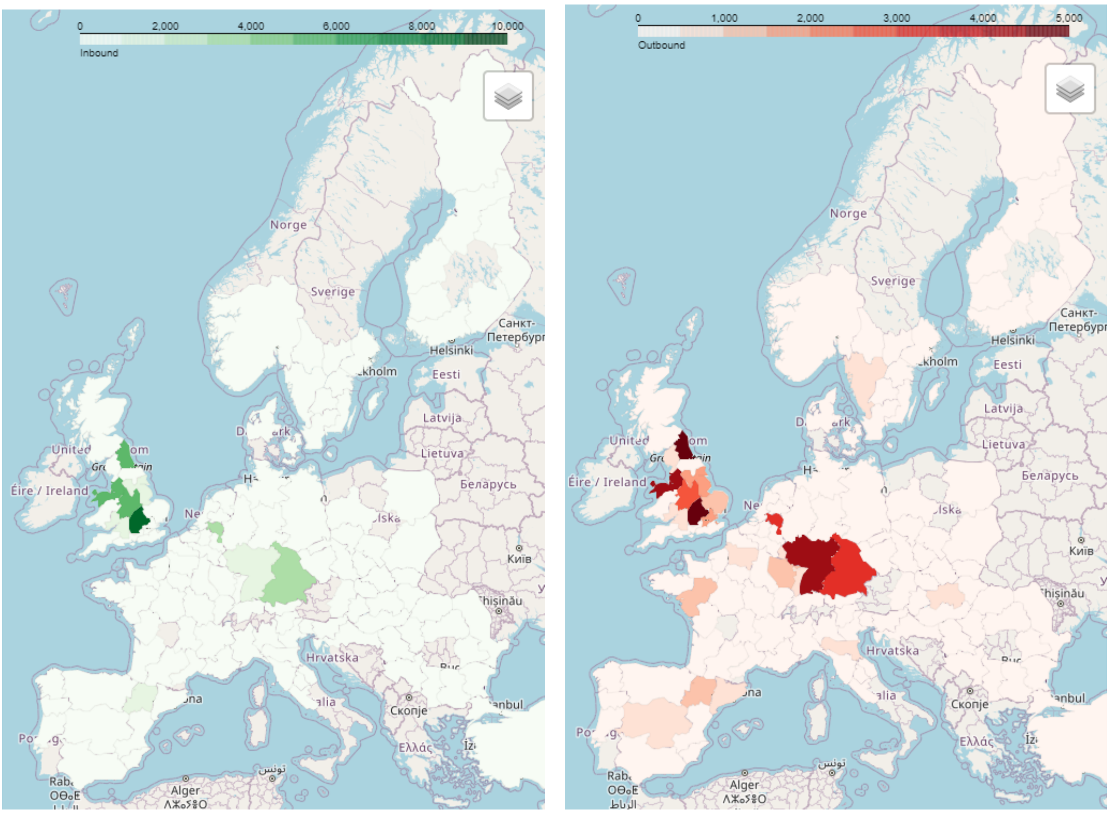
Figure 6: The four regions identified for the analysis.



(a) Inbound quantities per country transported from GB.

(b) Outbound quantities per country transported to GB.

Figure 7: Inbound and outbound quantities per country transported from and to GB.



(a) Inbound quantities per zone. (b) Outbound quantities per zone.

Figure 8: Inbound and outbound quantities per zone transported.

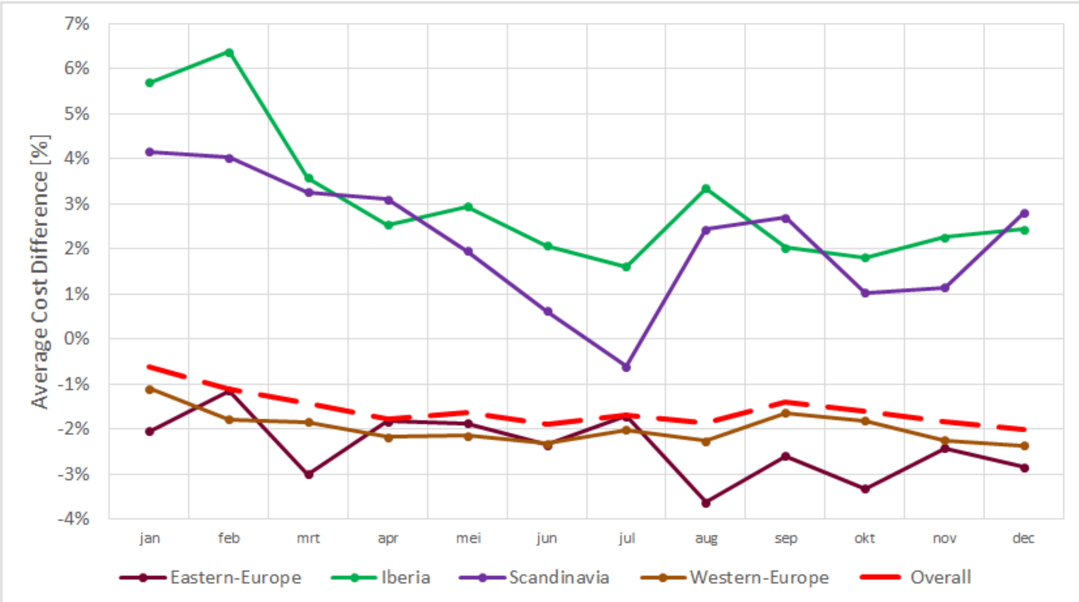
4.2 Validation output

Figure 9a and Figure 9b show the relative deviations from the actual cost and lead-time for each region and overall, respectively. In Figure 9a the cost difference of Iberia overwrites the boundary of 5% for the months January and February. The cost difference for Scandinavia is also quite high here. After looking into more detail, the cause lies in the trucking cost towards a terminal. Because the overall cost difference is well within bounds as are the Confidence Intervals and the trips in Iberia represents only 7,4% (Table 2) of all trips, the model is not rejected based on this cost difference. Several attempts have been made to get these values within margin, but this negatively influenced the outcome of the other regions. Figure 9b also shows some fluctuations for Iberia and Scandinavia but no values are out of bounds.

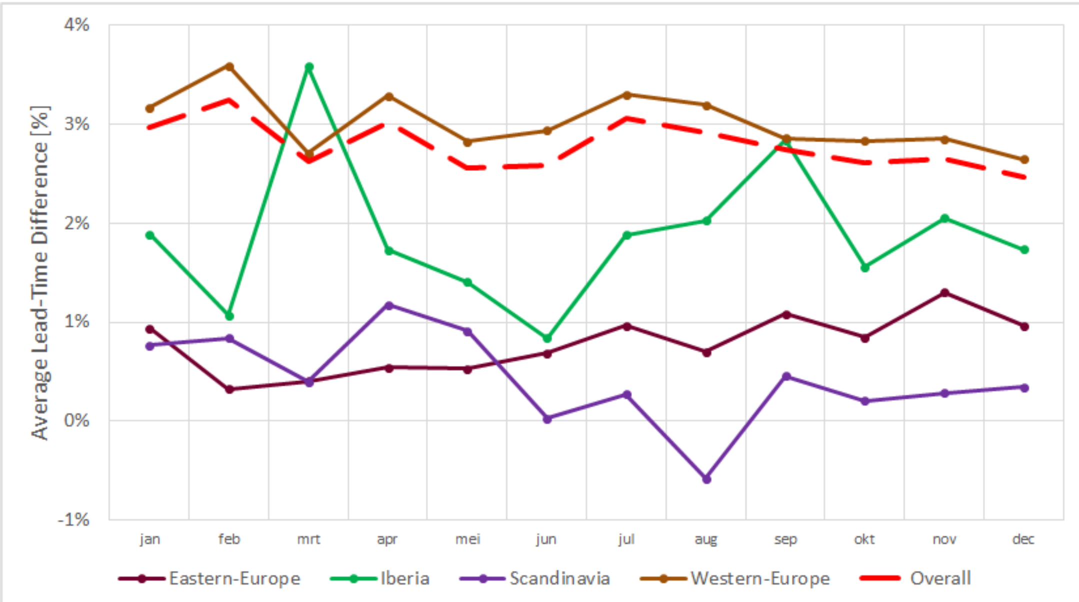
Figure 10 presents all output retrieved from the validation process. Figure 10a shows the actual average cost and simulated average cost per month. Figure 10b the actual average lead-time and simulated average lead-time per month. Figure 10c and 10d show the simulated cost and lead-time, respectively, with their 95% CI per month. Figure 10e depicts the difference between the simulated and actual cost and the difference between the simulated and actual lead-time, with their 95% CI.

On first sight, the simulation results in Figure 10a and Figure 10b show no strange patterns compared to the original cost and lead-time. The upper and lower CI show no extreme deviations from the mean in Figure 10c. Figure 10d shows some larger deviations of the CI in January, February and October, but this is nothing out of the ordinary when looking at the relative diFigure 10e.

Figure 10e shows the relative difference compared tot the originals cost and lead-times, here it can be seen that all values are within the acceptable range. The only value just outside the accepted range of [-5%, 5%] is the Lower cost CI of the cost in December. As this concerns only the lower CI, the simulation algorithm is accepted.

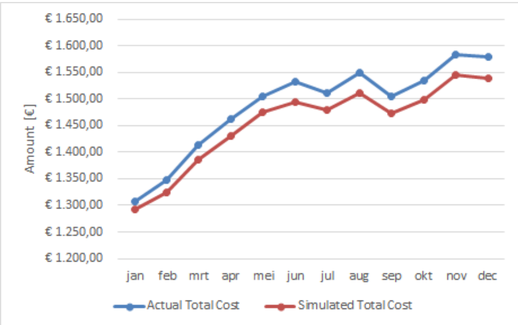


(a) Average cost difference per region over 2022.

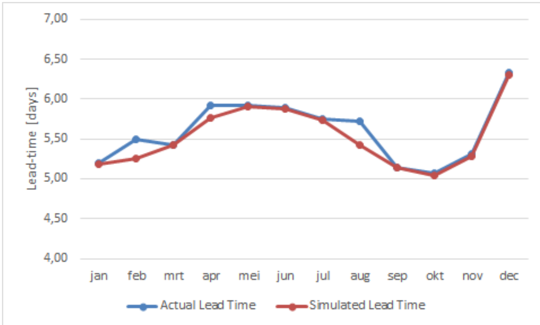


(b) Average lead-time difference per region over 2022.

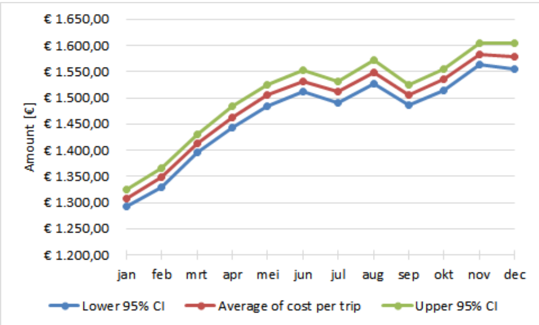
Figure 9: Validation output per region compared to the actual output



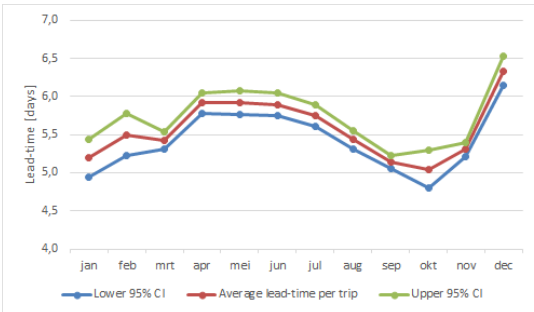
(a) Cost comparison.



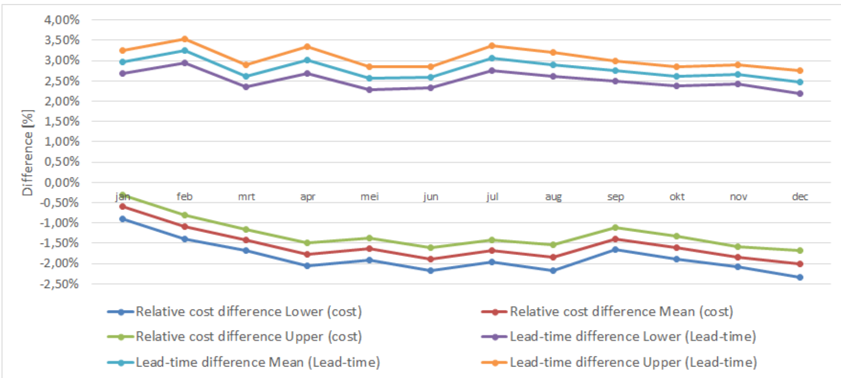
(b) Lead-time comparison.



(c) Simulated cost with CI.



(d) Simulated lead-time with CI.



(e) Relative difference of the simulation output with CI.

Figure 10: Validation output

5 Analysis and diagnosis

This section will describe the chosen simulated heuristics. For each model the chosen heuristic will be explained whereafter the outcomes will be presented.

5.1 Model 1: Single Connection

5.1.1 Model setup

This model has been setup together with the Steering Committee to review to what extent the overall cost are effected in the most extreme version of centralizing ferry connections between GB and EU. This model provides the answer to the question: *What happens to the cost of ECC's network when all transports from and GB are centralized via one harbour connection?*.

In Figure 11 the top 10 (of the 48 total) ferry transfers are shown from and to GB. On the left axis the absolute usage in number of shipments per connection is given and on the right axis the respective cumulative percentage. In Figure 12 these connections are visually represented. The definition of the harbour names can be found in Appendix D. These 21% harbour connections represent 83% of all ferry transfers between GB and the EU, which is in line with *the law of the vital few* (Krajewski, Malhotra, and Ritzman (2015)). Model 1 focuses on these *vital few* connections. Figure 12 shows that the most used harbours in the EU are already centralized in Zeebrugge and around Rotterdam. This is in line with the locations where the bulk of all transports occur (see Figure 7). The simulation of model 1 has been used over ten iterations, where in each iteration only one connection is used, meaning that all transports are routed via this connection in the respective iteration.

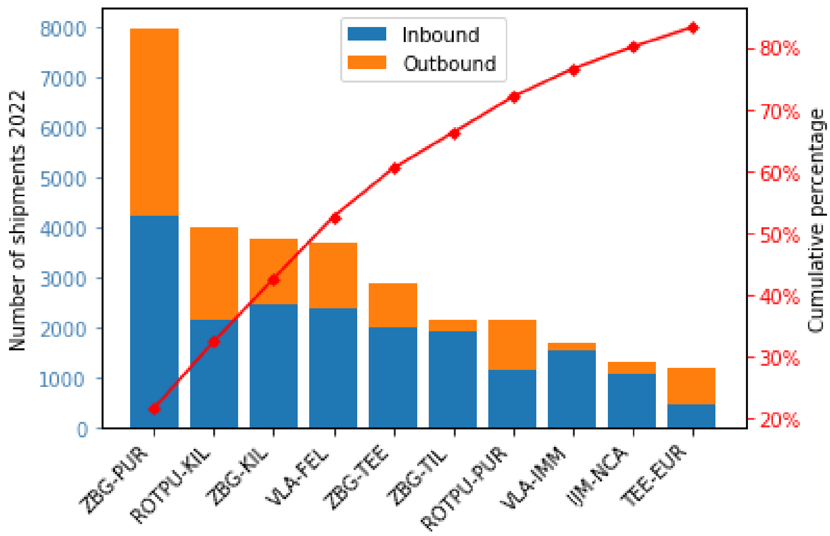


Figure 11: Number of shipments per harbour connection and the respective cumulative percentage for the top 10 harbour connections in 2022 from and to of GB.

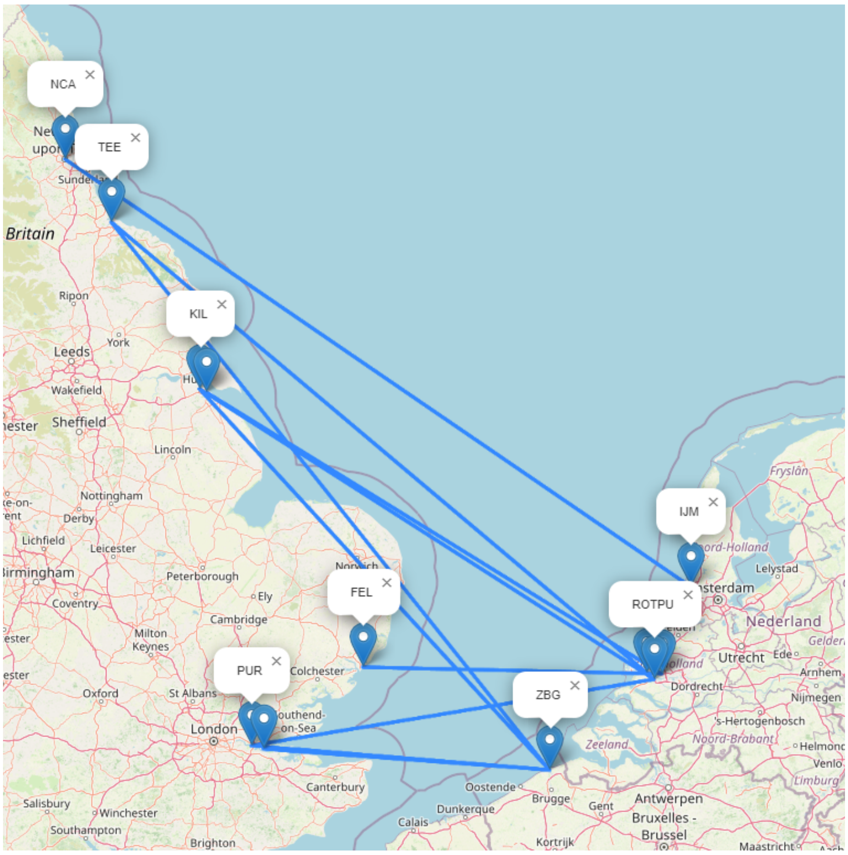


Figure 12: Top 10 terminal connections. Note: Near *ROTPU* are *EUR,VLA*, near *PUR* is *TIL* and near *KIL* is *IMM*

5.1.2 Results of Model 1

The main results are given in Table 3, they are presented relative to the status quo (see Appendix D for the raw model output). The average cost per trip and average lead-time per trip are also given in Table 4, for a deeper analysis. From this follows that only opening one connection is not feasible in direct cost, as the increase of costs ranges between 5.3% to 28.7% compared to the cost of the status quo. What should be noticed is that the cheapest connection *ZBG-PUR*, in terms of ferry cost as presented in Figure 13, results in the best model in Table 3. For ECC a positive conformation can be made that *ZBG-PUR* is correctly their most used connection, as this is also gives the best single connection result. Concerning the lead-times, in particular the connections *EUR-TEE* and *ZBG-TEE* have the most increase. This trend holds for all the regions in Table 4. A possible cause for this is a combination of the location of *TEESPORT (TEE)*, as this is harbour located more to the North of GB and a lot of kilometers have to be covered to the South of GB, where most transports are destined or origin (see Figure 8). Furthermore, the ferry between *TEESPORT* and the EU is one of the longest connections together with *NEWCASTLE UPON TYNE (NCA)*. What can be noticed is that the lead-times are not in the same degree influenced by the model when routing all transports via *IJM-NCA*. The cost however have the most increase by routing all transports via *IJM-NCA*. When comparing the increase in cost and ferry rates, an observance is that the average cost increase look to follow the average ferry rates. This is depicted with the green line in Figure 13.

In Table 4 it can be seen that the lead-times for all regions are increased when routing all transports via a single connection, independent which connection is used in the model. The lead-times in Eastern-Europe are the least or almost not influenced. The lead-times from Scandinavia are the most influenced in a negative manner, while the cost are decreased quite substantial in some scenarios. This table also shows that Iberia and Western-Europe are the most negatively influenced in the cost when using a single connection. A cause for the increase of cost for Iberia and the increase of the lead-times for Scandinavia in all scenarios, could be the long distances that have to be driven from Iberia and Scandinavia to the Dutch/Belgium coastline. For Western-Europe no direct relationship can be seen in Table 4 except that it is not feasible to route all transports via only one connection, both in terms of cost and lead-time.

Table 3: Output of Model 1, presented relative to the status quo.

Connection	**Mean cost**	**Mean margin**	**Mean lead-time**	**Mean margin per trailer day**
EUR-TEE	13.1%	-43.0%	8.2%	-55.8%
IJM-NCA	28.7%	-94.4%	4.3%	-89.5%
ROTPU-KIL	11.1%	-36.5%	3.8%	-44.4%
ROTPU-PUR	12.2%	-40.2%	4.1%	-45.6%
VLA-FEL	7.8%	-25.7%	1.9%	-27.9%
VLA-IMM	14.7%	-48.2%	2.5%	-48.7%
ZBG-KIL	11.9%	-39.0%	4.6%	-48.2%
ZBG-PUR	5.3%	-17.3%	2.2%	-21.9%
ZBG-TEE	21.5%	-70.9%	8.5%	-76.3%
ZBG-TIL	5.8%	-19.2%	2.7%	-24.1%

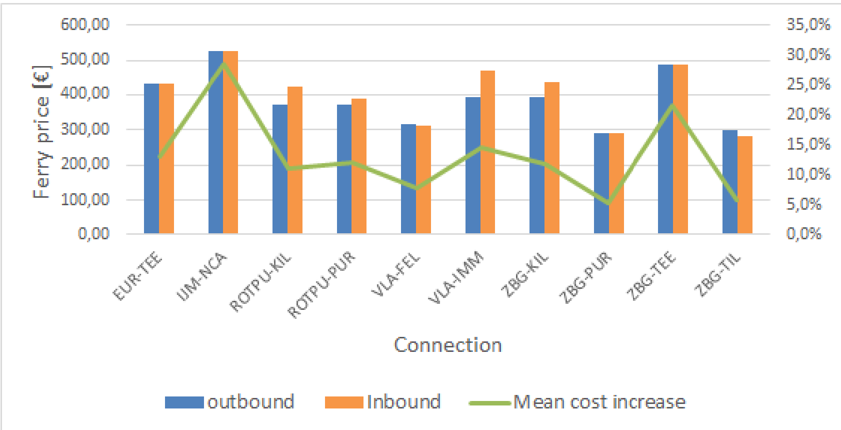


Figure 13: Average ferry prices for the top 10 terminals in 2022 (see Appendix F) and the mean cost increase when routing all transports via the respective ferry connection.

Table 4: Output of Model 1 with the Average Cost and Average Lead-time per region, relative to the status quo.

Region	Eastern-Europe		Iberia		Scandinavia		Western-Europe	
KPI	**Mean cost**	**Mean lead-time**	**Mean cost**	**Mean lead-time**	**Mean cost**	**Mean lead-time**	**Mean cost**	**Mean lead-time**
EUR-TEE	-5.9%	3.4%	17.0%	3.2%	3.5%	8.2%	15.0%	9.9%
IJM-NCA	2.9%	0.6%	34.0%	2.3%	16.3%	7.4%	31.3%	5.3%
ROTPU-KIL	-0.9%	1.5%	15.3%	2.4%	-0.1%	7.2%	12.2%	4.4%
ROTPU-PUR	5.1%	2.3%	15.9%	2.4%	-1.4%	7.1%	12.9%	4.8%
VLA-FEL	1.7%	0.2%	17.8%	1.9%	-2.6%	6.8%	7.5%	2.1%
VLA-IMM	2.0%	0.3%	22.8%	2.0%	2.8%	7.0%	15.4%	3.0%
ZBG-KIL	3.6%	2.6%	15.5%	2.9%	-5.9%	9.5%	12.8%	5.3%
ZBG-PUR	6.5%	1.0%	10.3%	2.4%	-12.3%	8.4%	4.9%	2.4%
ZBG-TEE	3.0%	4.4%	21.6%	3.7%	4.6%	11.2%	24.1%	10.1%
ZBG-TIL	6.9%	1.2%	9.9%	2.4%	-11.7%	8.1%	5.7%	3.1%

5.2 Model 2: Nearest Neighbour Algorithm

5.2.1 Model setup

As discussed in the previous section, the increase of cost for Iberia and the increase of the lead-times for Scandinavia in all scenarios are probably caused by the long distances that have to be driven from and to the Dutch and Belgium coastline. This model tries to take those shortcomings into account by also having a direct connection available from Iberia and Scandinavia to GB. The most used connections for these regions are '*Goteborg (SE)-Immingham (UK)*' for Scandinavia and '*Santander (ES)- Liverpool (UK)*', '*Santander (ES)-Portsmouth (UK)*' for Iberia.

To also allow for more flexibility in choosing connections, all top 10 harbours from Figure 11 are available in this model, since routing all transports via a single connection is not found feasible in Model 1. All possible ferry connections between GB and EU for this model are represented in Figure 14. As a new harbour connection network is introduced to centralize harbour connections the model has to be guided which connection to chose for each trip. In this setup the model chooses the closest embarking harbour from its origin. The basis of this model comes from the *nearest neighbour* algorithm (Harahap and Sawaluddin (2023)) to select the nearest harbour. As some ports have several connections to GB (e.g. ZBG-PUR, ZBG-KIL, ZBG-TEE) the heuristic to choose the new connection is the *cheapest insertion* method (Rosenkrantz, Stearns, and Philip M. Lewis (1977)). To summarize, the heuristic in this model will choose the nearest harbour from its origin. If multiple connection from that port are available, the simulation model will choose the cheapest connection that is available.

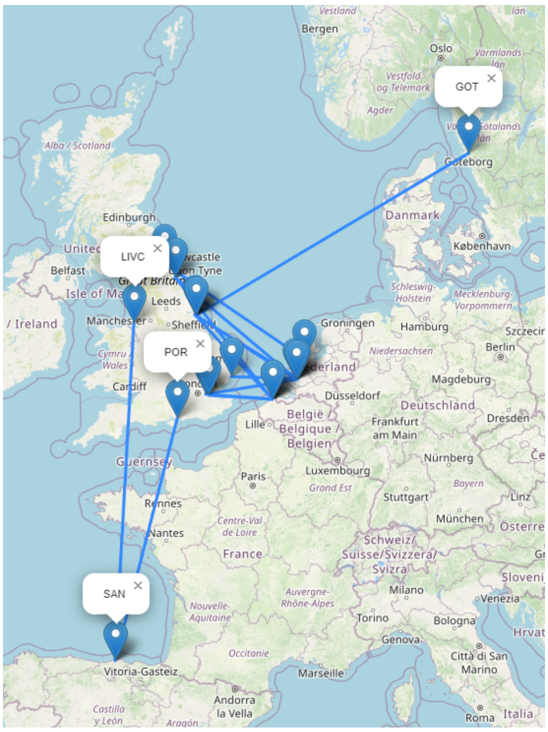


Figure 14: Available harbour connections for Model 2.

5.2.2 Results of Model 2

The results of the harbour usage are presented in Figure 15. The results per region relative to the status quo can be found in Table 5, the full results are presented in Appendix H.

Model 2 has an overall increase in cost of 6.73% compared to the status quo. From Figure 15 several conclusions can be drawn. The main observance is that the used heuristic redistributes the harbour utilization in Figure 15 compared to Figure 11. *EUR* is the closest harbour for most of the trips inbound to GB and *ZBG* is a clear second. *PUR* is the closest harbour for most of the trips outbound of GB. When transports to GB have *ZBG* as closest harbour, the cheapest connection is *ZBG-PUR*, as *ZBG-PUR* is the cheapest connection (see Table 12). An interesting observation is the increased utilization of the connections *LIVC-SAN* and *POR-SAN*. The utilization of these connections can be explained by the transports from the zones around these harbours in GB as shown in Figure 8b. The same holds for *NCA*, *PUR* and *TIL*. Around these harbours in GB the most transports to the EU happen origin close to these harbours. The increase in the harbours *ZBG* and *EUR* also follow from their position towards the origin of the bulk of transports in the EU. The heuristic used in this model does not utilize the harbour connections *ZBG-KIL* and *ZBG-TEE* at all. Because *ZBG*, *KIL* and *TEE* all have alternative connections, these connections are too expensive compared to the alternatives that originates from these ports. All of the above conclusions are logical consequences of the *nearest neighbour* algorithm.

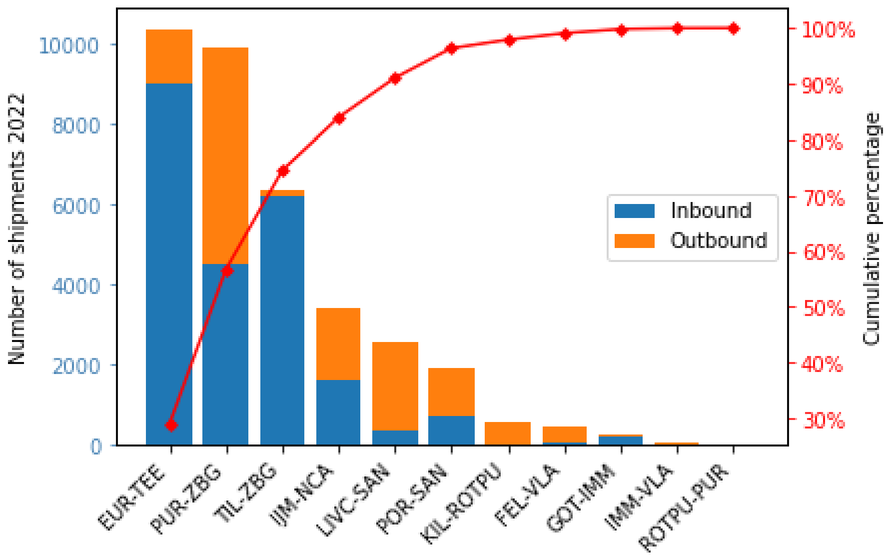


Figure 15: Number of shipments per harbour connection and the respective cumulative percentage for each harbour connection between the European continent and GB in Model 2. Note: inbound is towards GB, outbound is from GB.

However, the used heuristic in this model originates from the increase in cost for Iberia and the increase of the lead-times for Scandinavia in Model 1. The lead-times for Scandinavia did decrease in both directions as shown in Table 5. Interesting is the fact that the reduction in outbound lead-time (Scandinavia to GB) is minimal (0.01%) and that the reduction inbound to Scandinavia is less then expected. A cost decrease for Iberia is not observed within Model 2. In Eastern-Europe a decrease in cost is created with this model, but this is at the expense of the lead-time. This does have a positive impact on the margin per trailer day. In Western-Europe no positive changes are found with this model. Overall, this model does not have an positive impact on the total direct cost or total lead-time, and shows some significant shortcomings.

Table 5: Output model 2, presented relative to the status quo.

Area	Direction[7]	Mean cost	Mean margin	Mean lead-time	Mean margin per trailer day
Eastern-Europe	**outbound**	-2.95%	27.79%	3.94%	26.42%
	inbound	-5.90%	19.26%	2.22%	20.09%
Iberia	**outbound**	8.19%	-14.56%	4.36%	-22.10%
	inbound	14.31%	-79.35%	0.35%	-67.54%
Scandinavia	**outbound**	2.42%	-7.52%	-0.01%	-5.66%
	inbound	-0.02%	0.06%	-1.46%	7.63%
Western-Europe	**outbound**	8.57%	-14.32%	6.41%	-25.57%
	inbound	5.86%	-37.09%	4.91%	-15.19%
Total	**outbound**	7.18%	-13.39%	5.75%	-24.58%
	inbound	5.82%	-34.34%	5.64%	-14.00%

[7] relative to the Region. e.g. *Iberia outbound* means from Iberia to GB

5.3 Model 3: Minimizing Road Distance

5.3.1 Model setup

The main shortcoming in the model 2 is that it uses two greedy heuristics to choose the new routing. With greedy is meant that the model only selects what is best for a specific tripleg and not for the overall route. The nearest neighbour heuristic disregards the road distance after the crossing as can be seen in the example in Figure 16, which shows a route from (Manchester, UK) to (Duisburg, DE). The red line indicates the driven road distance with a total of 1582 km, which occurs with the previous heuristic that selects the connection *Liverpool-Santander* as Liverpool's port is closest to Manchester. The green line shows a better route in terms of cost and lead-time with 360 km over the road.

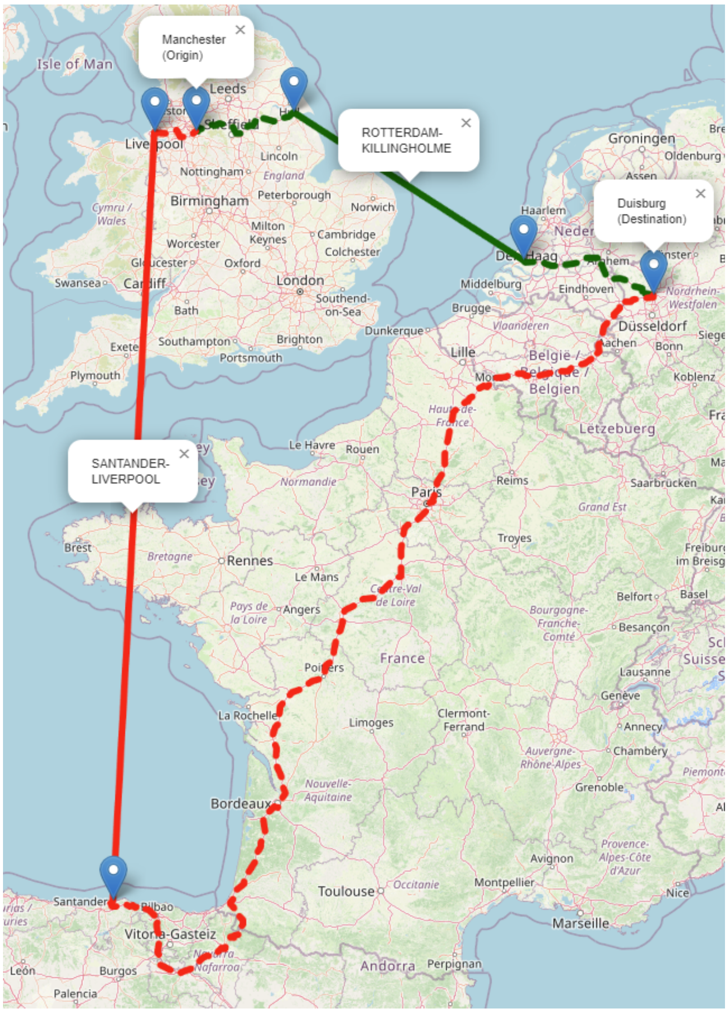


Figure 16: Route from Manchester to the Duisburg. Route calculated with Nearest Neighbour algorithm of model 2 shown in red.

By selecting the cheapest ferry the model disregards the road kilometers it has to make after the crossing. If we consider a route from Paris to Glasgow with Zeebrugge as closest harbour as in Figure 17, the tripleg to Zeebrugge stays equal for all the possible crossings from Zeebrugge. If it is assumed that Zeebrugge-Purfleet is the cheapest connection that will be chosen with the cheapest insertion algorithm, the road cost in GB will be higher

Figure 17: Route from Paris to Glasgow.

compared to Zeebrugge-Teesport or Zeebrugge-Killingholme as the distance to Glasgow is shorter from these two terminals. However, the ferry prices are higher for Zeebrugge-Teesport and Zeebrugge-Killingholme.

Group FTL's core business model is to use multimodal solutions to lower the cost of shipments as already explained in Section 1.2. The reasoning is that ferries are more cost efficient than road solutions on long trips. The model in this section therefore uses the hypotheses that minimizing the total road distance will influences the direct cost in a positive manner. This assumption goes together with the a second hypothesis that less traction (subcontractors and own wheels) has to be used when the road distances are minimized as trucks will drive shorter triplegs. This model also deals with the greediness of the heuristics in the previous model. The available connections in this model will be the same as in model 2.

Using the same example in Figure 17 where the road distances are shown as a dashed line (not taking into account all other connections). The used model will retrieve the distances from Paris to all (available) ports on the continent. Next, it will retrieve the distances from all (available) ports in GB to Glasgow. For each connection the model will calculate the total distance, next it will retrieve the connection with the minimum distance, in this example that would be Zeebrugge-Teesport. The algorithm is shown in Algorithm 2.

Algorithm 2 Duration

create empty list for distances $D = ()$
if *trip* is inbound GB **then**
  for i in connections **do**:
    port1 embarking port in EU of i
    port2 disembarking port in GB if i
    get $d_{origin,port1}$ via PTV
    get $d_{port2,destination}$ via PTV
    $d_i = d_{origin,port1} + d_{port2,destination}$
    append d_i to D
  end for
else if *trip* is outbound GB **then**
  for i in connections **do**:
    port1 is embarking port in GB
    port2 is disembarking port in EU
    $d_{origin,port1}$
    $d_{port2,destination}$
    $d_i = d_{origin,port1} + d_{port2,destination}$
    append d_i to D
  end for
end if $D = (d_0, d_1, d_2, ..., d_n)$ connection = $argmin\{D\}$

5.3.2 Results of Model 3

The results of the harbour usage is shown in Figure 18. The results per region relative to the status quo can be found in Table 6, the full results are given in Appendix H. An overall decrease of 3.2% in cost relative to the status quo has been realized with this model. For ECC a positive confirmation can be made that *ZBG* is correctly their most used harbour, as this is also the most used in this model. In Figure 18 it can be seen *ROTPU-PUR* and *ZBG-PUR* are the most used connections on the mainland. Compared to Figure 11, the quantities for these connections are more equally distributed. Compared to Model 2, the utilization of the connections *LIVC-SAN* and *POR-SAN* is more in line with expectations, as the quantities transported through these connections are closer to the quantities transported between GB and Iberia (see Table 2). The same holds for *GOT-IMM*. This was also the intention of these connections, when they were introduced in Model 2.

Table 6 shows that the used heuristic has a very minor impact on the lead-time. The costs are only negatively influenced for Iberia and outbound Scandinavia. This model has the best impact on transports between Western-Europe and GB. The lead-time increase is neglectable and the cost decrease is substantial (also visible in the Margin), the combination of these also have a good results on the margin per trailer day. Overall this model has shown to be able to decrease the overall cost without increasing the lead-time substantially.

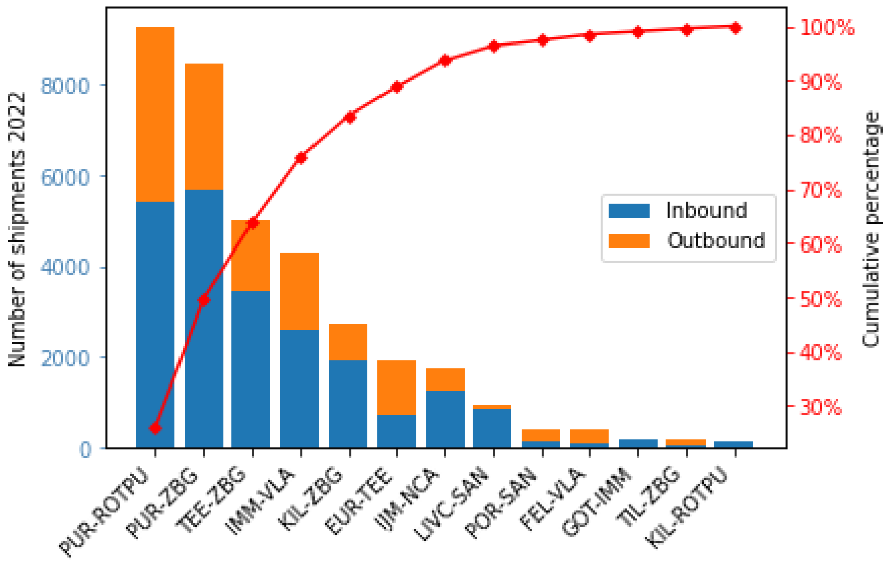


Figure 18: Number of shipments per harbour connection and the respective cumulative percentage for each harbour connection between the European continent and GB in Model 3. Note: inbound is towards GB, outbound is from GB.

Table 6: Output model 3, presented relative to the status quo.

Area	Direction[8]	Mean cost	Mean margin	Mean lead-time	Mean margin per trailer day
Eastern-Europe	**outbound**	-3.6%	34.2%	0.6%	36.6%
	inbound	-7.3%	23.7%	0.9%	25.0%
Iberia	**outbound**	3.3%	-5.9%	5.0%	-17.1%
	inbound	5.8%	-31.9%	0.3%	-20.4%
Scandinavia	**outbound**	2.5%	-7.6%	0.1%	-5.9%
	inbound	-6.3%	17.9%	0.2%	18.7%
Western-Europe	**outbound**	-5.2%	8.7%	4.6%	-5.7%
	inbound	-1.8%	11.7%	2.7%	15.7%
Total	**outbound**	-4.0%	7.4%	4.3%	-6.0%
	inbound	-1.5%	8.9%	2.3%	-15.4%

[8]relative to the Region. e.g. *Iberia outbound* means from Iberia to GB

5.4 Model 4: NEC Zones Manual assignment

5.4.1 Model setup

This model is build together with the NEC. The NEC divides Europe into different zones called *NEC Zones* (see Figure 19). These zones are drafted by the NEC together with the operations department and are based on the aggregation of several postal codes. Together with the NEC, a routing for each NEC zone relation from and to GB is made and set in a matrix. In Figure 12 it is already visible that the 10 most used harbours on the continent are already centralized in Rotterdam and Zeebrugge. From the NEC arises the question what will happen to the network in terms of direct cost, lead-times and harbour balances/usage if only a selected number of harbours on the continent and in GB will be used. On the continent the used ports will be Zeebrugge and Rotterdam and in GB these ports will be Killingholme and Purfleet. Killingholme will be used for the region to the north of Birmingham, Purfleet for all other regions in GB.

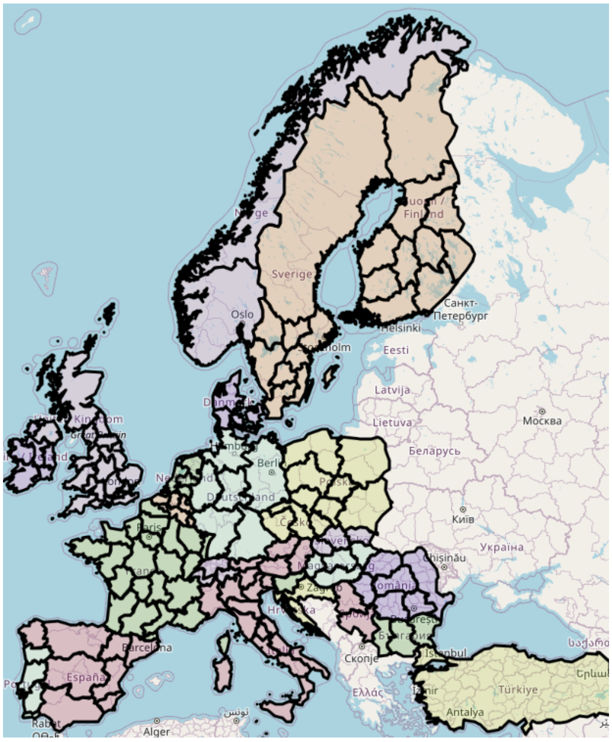


Figure 19: Europe divided in NEC zones (Note: countries not shown are seen as a separate zone or are not part of ECC's product portfolio (e.g Estonia, Greece).

Transports from and to the zones in Iberia will first be routed to Zeebrugge. The connection used between Iberia and Zeebrugge will be dependent of the location in Iberia. The second connection will be dependent of the location in GB, Zeebrugge-Purfleet will be assigned for the South and Zeebrugge-Killingholme for the North. For Scandinavia holds that all routes to the North of GB will directly transferred via Goteborg-Immingham, all others will be rerouted via Goteborg-Zeebrugge-Purfleet. For zones from or to central Europe (i.e. not Scandinavia or Iberia), two options are available on the continent as already mentioned, namely Zeebrugge and Rotterdam. Which harbour is chosen is dependent on a random chance, both Zeebrugge and Rotterdam with a probability of 0,5.

This probability has been chosen together by the NEC, because all other transports are already routed via Zeebrugge, Zeebrugge will still remain the most used as can be seen in Figure 11. An example of this matrix can be found below in Table 7, e.g for routes from *ES - Bilbao* to *GB - London*, the routing Santander-Zeebrugge-Purfleet will be assigned. Note that if the trip is from *GB - London* to *ES - Bilbao* the routing would be mirrored, i.e. Purfleet-Zeebrugge-Santander. The available routings are shown in Figure 20, where the dashed lines represent the reroutings.

Table 7: Example input data for Model 4.

	GB - South	**GB - North**
Scandinavia	GOT-ZBG-PUR	GOT-IMM
Northern-Spain	SAN-ZBG;ZBG-PUR	SAN-ZBG;ZBG-KIL
Southern-Spain	LEBOU-CAL;ZBG-PUR	LEBOU-CAL;ZBG-KIL
Portugal	LEIX-ZBG;ZBG-PUR	LEIX-ZBG;ZBG-KIL
Central-Europe	***-PUR[9]	***-KIL

[9]'***' will be a random choice between Zeebrugge and Rotterdam, both having a probability of 0,5

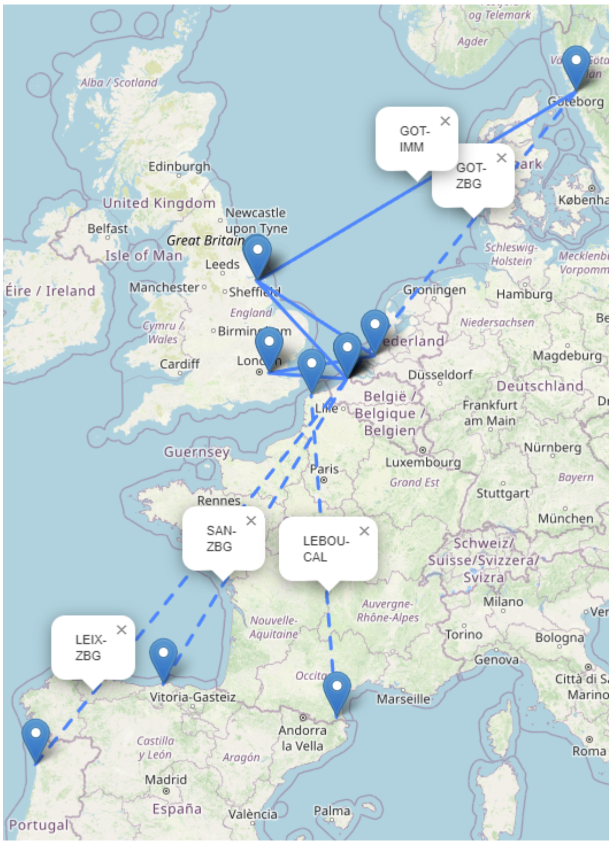


Figure 20: Available ferries for Model 4.

5.4.2 Results of Model 4

The results of the harbour usage are presented in Figure 21. The results per region relative to the status quo can be found in Table 8, the full results are given in Appendix J.

This model has an overall cost increase of 1.9% compared to the status quo. As expected, the harbour usage between *ZBG* and GB is the most popular as all transports from Iberia and Scandinavia are routed via *ZBG* on top of the 50% from the other regions. For Eastern-Europe this model has some small changes in cost and lead-time. For Scandinavia this model shows a positive output as both the cost and lead-time decrease, especially for the inbound traffic. Iberia shows some larger differences. As both the margin and lead-time decrease and the margin per trailer day is already below zero in the status quo for outbound traffic of Iberia, a very large decrease in margin per trailer day for the outbound transports occurs (-295%). This decrease can be explained by the fact that outbound traffic has a negative margin in the status quo, and in this model this margin drops even further below zero. The lead-time is a positive number and decreases also notable, this combination results in the large difference of the margin per trailer day in outbound traffic of Iberia. For Western-Europe this model has a neglectable decrease in cost for the outbound shipments while for the inbound shipments the cost does increase. Compared to the *Single Connection* model in Section 5.1, the cost increases for Western-Europe is closest to transporting all shipments via *ZBG-PUR* which has an increase of 4.9%. *ROTPU-PUR*, *ROTPU-KIL* and *ZBG-KIL* has an increase of 12.9%, 12.2% and 12.8% respectively. This means that for this region this is not a weighted average of some sort, but clearly shows the implications of the traction cost both in GB and the EU.

This model shows that the input of experienced engineers should not be taken lightly. No time consuming algorithm is necessary but a set of rules, set up by experienced engineers, gives a relatively positive output when only using five connection between GB and the EU.

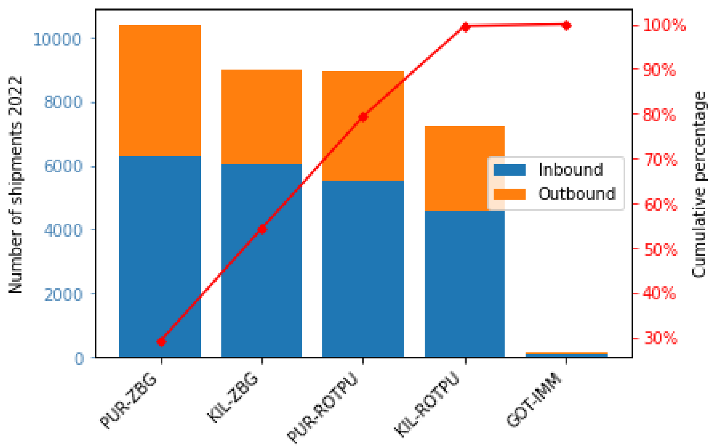


Figure 21: Number of shipments per harbour connection and the respective cumulative percentage for each harbour connection between the European continent and GB in Model 4. Note: inbound is towards GB, outbound is from GB.

Table 8: Output model 4, presented relative to the status quo.

Region	Direction[10]	Mean cost	Mean margin	Mean lead-time	Mean margin per trailer day
Eastern-Europe	**outbound**	0.8%	-7.1%	2.5%	-10.0%
	inbound	-3.4%	11.0%	0.9%	14.0%
Iberia	**outbound**	7.6%	-13.4%	-45.8%	7.7%
	inbound	12.7%	-70.4%	-58.1%	-295.2%
Scandinavia	**outbound**	-12.1%	37.7%	-38.1%	96.3%
	inbound	-54.5%	155.2%	-1.1%	-76.4%
Western-Europe	**outbound**	-0.4%	0.7%	5.3%	-14.1%
	inbound	5.5%	-34.8%	2.6%	-29.8%
Total	**outbound**	0.2%	-0.3%	-4.0%	-11.5%
	inbound	5.4%	-31.9%	-8.2%	-35.7%

[10]relative to the Region. e.g. *Iberia outbound* means from Iberia to GB

6 Conclusion and recommendations

This section will describe the main conclusion from this research. Next, limitations of this research and directions for future research will be given.

6.1 Conclusion

In this research the impact on cost reduction of centralizing harbour connections, and restructuring all routings between Great Britain and the European continent, has successfully been investigated. In order to be able to analyze the impact, four simulation models have been made.

Model 1 explored what would happen in the most extreme scenario when only one connection would be available between GB and the EU. This has been done for the top 10 connection between GB-EU. No cost reduction resulted from this, but some insights were obtained as input for the next model.

The top 10 connections, together with two connections between Iberia and one connection between Scandinavia, were set available in Model 2. The algorithm that guided the model to choose a new connection was the *nearest neighbour* algorithm. If multiple connections were available from the nearest harbour, the cheapest was be chosen. The main shortcoming in this model was that it used two greedy heuristics to choose the new routing. Because of this, several connection were hardly utilized, or not even at all. The greediness was best visible in the connection *Liverpool (UK)-Santander (ES)*. This connection was utilized far from optimal, as all transports originating around Liverpool and Manchester used this connection. This resulted in an extremely long road distances to be covered on the European continent.

Model 2 took the greediness of model 2 into account by minimizing the road distance. This resulted in a decrease of 3.2% in cost compared to the status quo, which is equal to a significant amount of €1,665,683. This did not go substantially at the expense of an increase in lead-time.

Model 4 was setup together with the NEC, where they gave their input in how they wanted to see the network routed between GB and EU. This model yielded a cost increase of 1.9%, equal to €989,999. However, the strength of this model is not about cost reduction, but that only four connections are used. Two harbours in GB, and two on the EU side, with all four connections having a relatively equal utilization. The NEC states that this results in a higher utilization of traction, as a trailer always is available for a hired truck and driver, resulting in less procurement cost of traction. The effective financial impact of procuring traction for model 3 and model 4 is up to the NEC together with the Procurement Department and ECC Colchester, the latter being responsible for the transports within GB. In conclusion:

How can the harbour balances of Ewals Cargo Care's Group FTL between the European continent and Great-Britain be optimized in terms of direct cost when centralization of harbours takes place?

The best way to optimize the network of Group FTL is to only utilize the top 10 connections, together with direct connections between Iberia and Scandinavia, and use a minimum road distance approach to select the best routing for each transport.

6.2 Limitations and Future Research

6.2.1 Limitations

This research is not without its limitations. Firstly, direct capacities are not taken into account as the focus laid on the overall capacities and if they are feasible. In future work, especially when the whole network of Group FTL is simulated, capacity constraints could be applied on terminal connection. The embarking times of ferries, or in other words the ferry rosters are not taken into account. When this research gets more detailed this should be implemented. This research solely focused on the direct cost, the performance of new traction (i.e. the new amount of traction that could be consolidated), has not been taken into account. When taking this in to account its should be aligned with the operations of ECC Colchester with whom Group FTL is in close collaboration. This research focused only on the connections between Great Britain and the European continent. Lastly, this simulation focused on data in the past, and no prediction model is used. This could be done in combination with the extension of the model. Direction for the extension an prediction will be given below.

6.2.2 Data reliability

The data reliability was not considered to be of high quality, as basic validation of data are not in place in the central data-warehouse. Trip-legs did not follow each other chronologically, both in start time and in tripleg number, as would be expected as shown in Table 1b. Furthermore, both on trip and tripleg data the start time point was not always set before the end time point. A validation for these issues should be set in place to accommodate for a better data reliability.

In this research the current pricing methodology (Pricing Calculation Tool (PCT)) was also consulted. Here it was found that data in the data-warehouse used different acronyms for terminal names than the PCT. E.g. in the data-warehouse *FEL* is used to refer to the harbour of Felixstowe, but in the PCT *FLX* is used. Preferably a single naming process should be used, but at this moment a transformation matrix should suffice to be able to compare both naming methodologies.

6.2.3 Price methodology

At the beginning of this research a feasibility analysis was done in order to validate if the simulations could be done with the pricing tools, both the old and new version. Several shortcomings were found as a result of which the simulation was performed as stated in this research. Firstly, at the start of this research the old pricing tool, in the form of an

Excel Macro file, was still in use and was not centrally logged. In parallel to this research, positive steps have been made with the introduction of the new pricing tool (the PCT). A big logging issue remains as each update does not only include a new data version, but occasionally also a new calculation logic with new rules. A new feasibility study can be performed to test whether the PCT is suitable to use for simulations.

6.2.4 Future research

For future research several extension possibilities are possible. Firstly, expanding the area of GB-EU step-by-step to finally cover the whole network of Group FTL in a simulation model. Secondly, including a prediction algorithm to also act on future developments. This could be done via an algorithm as described in Janssen (2022), or preferably to align this with the project that is in progress within ECC: Group Budget Steering Model. The goal of this project is to review which capacities should be procured for the future based on predicted product developments. With capacity is meant both ECC's traction components and trailers, but also the capacities on ferries and trains. The prediction of this model could then be the input for a full scale network simulation to review how capacity is required.

The extension of this simulation could go in two different directions. The first option is to extent the model as presented in this research, the second option is to use the PCT for this. If the PCT is chosen, a large scale validation process should take place to compare the calculated cost with the actual cost that incur during transports. This should be done to ensure the simulation accuracy. Both choices could be used in combination with the Group Budget Steering Model.

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Appendices

A Ewals Cargo Care

Figure 22: Ewals Cargo Care company information.

B Next Generation Logistics

Figure 23: Next Generation Logistics.

C Screenshot Pricing Calculation Tool

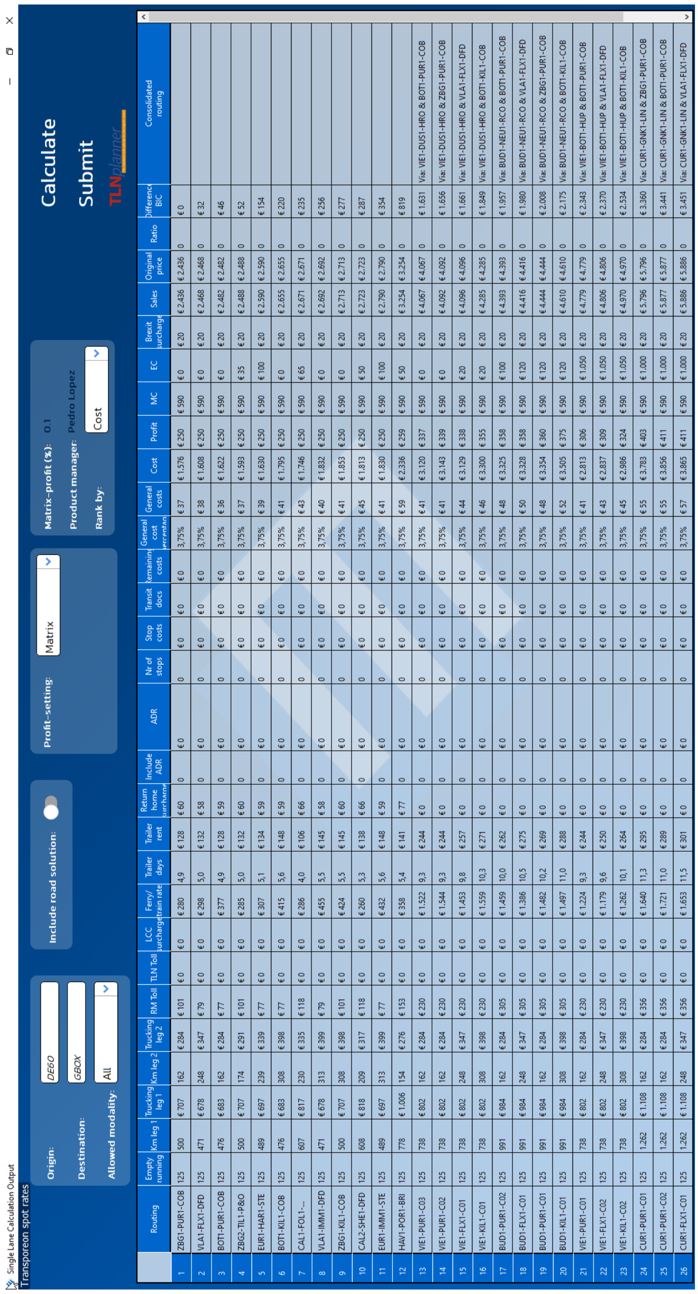

Figure 24: Screen capture of the Pricing Calculation Tool for a trajectory from Frankfurt to Oxford.

D Full results Status quo, measured from GB perspective (i.e. inbound is to GB, outbound is from GB)

Table 9: Full results status quo.

Month	Total cost [€]	Total cost inbound [€]	Total cost outbound[€]	avg cost [€]	avg cost inbound [€]	avg cost outbound [€]
202201	4,148,708.43	2,836,666.14	1,312,042.29	1307.50	1381.72	1171.47
202202	4,056,372.16	2,781,279.01	1,275,093.15	1347.63	1425.57	1204.05
202203	4,756,170.02	3,180,424.36	1,575,745.66	1412.58	1493.86	1272.82
202204	3,855,802.24	2,485,992.61	1,369,809.63	1463.30	1529.84	1356.25
202205	4,160,994.02	2,714,891.97	1,446,102.05	1504.88	1584.88	1374.62
202206	4,851,243.63	3,220,057.66	1,631,185.97	1532.29	1606.01	1404.98
202207	4,549,132.92	2,932,009.2	1,617,123.72	1511.84	1609.23	1362.36
202208	3,872,210.11	2,677,043.72	1,195,166.39	1548.88	1656.59	1352.00
202209	4,722,514.81	3,133,575.34	1,588,939.47	1504.46	1616.91	1323.01
202210	4,820,397.07	3,270,988.72	1,549,408.35	1535.16	1649.52	1339.16
202211	5,517,656.95	3,685,825.38	1,831,831.57	1583.71	1723.96	1360.94
202212	3,668,624.39	2,582,414.36	1,086,210.03	1579.26	1691.17	1364.59
Month	**avg margin [€]**	**avg margin inbound [€]**	**avg margin outbound [€]**	**avg margin [%]**	**avg margin inbound [%]**	**avg margin outbound [%]**
202201	441.53	773.42	-166.85	13.23	33.59	-24.09
202202	419.14	769.25	-225.88	11.96	34.08	-28.79
202203	383.52	757.37	-259.41	9.21	33.19	-32.01
202204	420.68	844.78	-261.66	10.47	35.14	-29.21
202205	388.33	818.99	-312.94	6.12	31.91	-35.88
202206	425.09	841.12	-293.38	9.57	33.86	-32.36
202207	441.37	855.48	-194.28	11.70	34.22	-22.86
202208	512.35	915.81	-225.19	12.84	35.01	-27.68
202209	471.62	879.49	-186.55	12.36	34.45	-23.29
202210	464.37	849.27	-195.31	12.32	33.26	-23.56
202211	488.81	912.60	-184.35	12.32	32.89	-20.35
202212	563.72	957.79	-192.24	16.09	35.82	-21.77
Month	**avg lead-time [days]**	**avg lead-time inbound[days]**	**avg lead-time outbound [days]**	**avg margin [€/day]**	**avg margin inbound [€/day]**	**avg margin outbound[€/day]**
202201	5.30	4.82	6.18	107.12	179.71	-25.95
202202	5.62	5.43	5.96	98.30	174.03	-41.21
202203	5.42	5.11	5.96	93.00	174.57	-47.27
202204	5.91	5.33	6.84	104.16	192.57	-38.09
202205	5.93	4.94	7.53	103.77	193.34	-42.07
202206	5.89	5.22	7.04	100.42	183.29	-42.70
202207	5.74	5.41	6.25	107.76	191.82	-21.25
202208	5.42	5.33	5.59	122.72	209.48	-35.87
202209	5.14	5.01	5.34	111.87	199.09	-28.87
202210	5.16	5.12	5.23	111.99	194.57	-29.54
202211	5.29	5.33	5.21	110.91	199.00	-29.03
202212	6.31	5.97	6.96	128.94	208.30	-23.32

Table 10: Number of shipments

Month	Total shipments	Total shipments inbound (to GB)	Total shipments outbound (from GB)
202201	3173	2053	1120
202202	3010	1951	1059
202203	3367	2129	1238
202204	2635	1625	1010
202205	2765	1713	1052
202206	3166	2005	1161
202207	3009	1822	1187
202208	2500	1616	884
202209	3139	1938	1201
202210	3140	1983	1157
202211	3484	2138	1346
202212	2323	1527	796

E Terminal names meaning

Table 11: Terminal abbreviation meaning and location

Shortname	City	Country
ZBG	ZEEBRUGGE (BRUGGE)	BE
PUR	PURFLEET	GB
ROTPU	BOTLEK ROTTERDAM	NL
KIL	NORTH KILLINGHOLME	GB
VLA	VLAARDINGEN	NL
FEL	FELIXSTOWE	GB
TEE	TEESPORT	GB
TIL	TILBURY	GB
IMM	IMMINGHAM	GB
IJM	IJMUIDEN	NL
NCA	NEWCASTLE UPON TYNE	GB
EUR	EUROPOORT ROTTERDAM	NL

F Average Ferry rates

Table 12: Average ferry prices for the top 10 ferry connections

Connection	**inbound GB [€]**	**outbound GB [€]**
ndtable **EUR-TEE**	432.36	431.66
IJM-NCA	524.43	526.88
ROTPU-KIL	373.47	421.78
ROTPU-PUR	370.19	386.94
VLA-FEL	317.20	313.55
VLA-IMM	393.33	471.16
ZBG-KIL	391.36	434.10
ZBG-PUR	289.92	290.42
ZBG-TEE	488.38	489.30
ZBG-TIL	300.18	283.40

G Full results Model 1

Table 13: Full results Model 1, measured from GB perspective (i.e. inbound is to GB, outbound is from GB)

Connection	Total cost	Total cost inbound	Total cost outbound	avg cost [€]	avg cost inb [€]	avg cost outb [€]
Status quo	52,982,290.20	35,503,943.80	17,478,346.40	1,483.10	1,576.97	1,323.11
EUR-TEE	59,894,559.07	38,860,619.65	21,033,939.43	1,676.59	1,726.06	1,592.27
IJM-NCA	68,166,485.77	44,748,457.98	23,418,027.78	1,908.14	1,987.58	1,772.75
ROTPU-KIL	58,854,154.94	38,867,211.91	19,986,943.03	1,647.47	1,726.36	1,513.01
ROTPU-PUR	59,443,041.00	38,938,860.15	20,504,180.86	1,663.95	1,729.54	1,552.17
VLA-FEL	57,119,913.27	37,074,358.37	20,045,554.91	1,598.92	1,646.72	1,517.45
VLA-IMM	60,743,294.09	40,766,536.49	19,976,757.59	1,700.35	1,810.72	1,512.25
ZBG-KIL	59,260,555.59	38,894,751.45	20,365,804.12	1,658.85	1,727.58	1,541.70
ZBG-PUR	55,762,997.65	36,469,017.29	19,293,980.37	1,560.94	1,619.84	1,460.56
ZBG-TEE	64,382,474.58	42,313,663.82	22,068,810.73	1,802.22	1,879.44	1,670.62
ZBG-TIL	56,066,873.17	36,799,439.57	19,267,433.59	1,569.45	1,634.51	1,458.55

Connection	avg margin [€]	avg margin inbound [€]	avg margin outbound [€]	avg lead-time [days]	avg lead-time inb [days]	avg lead-time outb [days]
Status quo	450.35	846.17	-224.26	5.56	5.23	6.13
EUR-TEE	256.85	697.07	-493.42	6.02	5.74	6.49
IJM-NCA	25.30	435.56	-673.90	5.80	5.46	6.39
ROTPU-KIL	285.98	696.78	-414.16	5.77	5.47	6.28
ROTPU-PUR	269.50	693.60	-453.31	5.79	5.51	6.27
VLA-FEL	334.52	776.41	-418.60	5.67	5.34	6.22
VLA-IMM	233.10	612.42	-413.39	5.71	5.36	6.28
ZBG-KIL	274.60	695.56	-442.84	5.82	5.57	6.25
ZBG-PUR	372.50	803.30	-361.72	5.69	5.39	6.19
ZBG-TEE	131.23	543.70	-571.76	6.04	5.79	6.44
ZBG-TIL	364.00	788.63	-359.69	5.72	5.43	6.19

Connection	avg margin [€/day]	avg margin inb [€/day]	avg margin outb [€/day]
Status quo	125.01	219.87	-36.67
EUR-TEE	55.32	137.48	-84.54
IJM-NCA	13.17	90.74	-118.94
ROTPU-KIL	69.57	153.13	-72.58
ROTPU-PUR	68.04	153.91	-77.77
VLA-FEL	90.08	183.10	-67.95
VLA-IMM	64.16	142.15	-68.38
ZBG-KIL	64.82	147.93	-75.31
ZBG-PUR	97.68	189.59	-57.12
ZBG-TEE	29.66	104.33	-96.62
ZBG-TIL	94.89	184.94	-56.77

H Full results Model 2

Table 14: Full results Model 2

Area	Direction[11]	mean cost [€]	mean margin [€]	mean lead-time [days]	mean margin per trailer day [€/day]
Eastern-Europe	outbound	2,845.01	398.02	7.46	58.67
	inbound	2,470.09	-649.82	8.34	-85.89
Iberia	outbound	2,165.23	962.16	10.32	133.69
	inbound	2,373.11	-671.49	17.27	-36.76
Scandinavia	outbound	2,346.59	680.94	7.70	98.24
	inbound	2,712.74	953.14	11.30	92.87
Western-Europe	outbound	1,554.77	733.83	4.90	177.48
	inbound	1,287.97	-263.36	5.53	-40.33
Overall	outbound	1,690.24	732.90	5.53	165.83
	inbound	1,400.17	-301.33	6.48	-41.81

I Full results Model 3

Table 15: Full results Model 3

Area	Direction[11]	mean cost [€]	mean margin [€]	mean lead-time [days]	mean margin per trailer day [€/day]
Eastern-Europe	outbound	2,825.01	418.03	7.22	63.38
	inbound	2,433.97	-613.69	8.22	-80.62
Iberia	outbound	2,067.91	1,059.48	10.39	142.34
	inbound	2,195.48	-493.86	17.26	-26.42
Scandinavia	outbound	2,347.42	680.12	7.70	98.03
	inbound	2,542.75	1,123.14	11.48	102.42
Western-Europe	outbound	1,357.32	931.27	4.82	224.79
	inbound	1,194.31	-169.70	5.42	-29.50
Overall	outbound	1,514.64	908.50	5.46	206.72
	inbound	1,303.27	-204.43	6.27	-31.02

J Full results Model 4

Table 16: Full results Model 4

Area	Direction[11]	mean cost [€]	mean margin [€]	mean lead-time [days]	mean margin per trailer day [€/day]
Eastern-Europe	outbound	2,953.60	289.44	7.36	41.75
	inbound	2,536.56	-716.28	8.22	-92.49
Iberia	outbound	2,152.59	974.80	5.36	184.86
	inbound	2,339.74	-638.12	7.21	-86.71
Scandinavia	outbound	2,013.70	1,013.84	4.77	204.44
	inbound	1,234.91	2,430.98	11.34	-20.37
Western-Europe	outbound	1,426.52	862.07	4.85	204.91
	inbound	1,283.52	-258.92	5.41	-45.46
Overall	outbound	1,579.58	843.56	5.02	194.48
	inbound	1,394.70	-295.87	5.63	-49.77

[11] relative to the Region. e.g. *Iberia outbound* means from Iberia to GB