Investigating end-to-end logistics

A strategic analysis of intermodal transportation

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Preface

Dear reader,

You are about to read the master thesis 'Investigating end-to-end logistics: A strategic analysis of intermodal transportation'. This research is executed at Bolk Business Improvement in Hengelo as the final assignment for my master Industrial Engineering and Management at the University of Twente.

At Bolk Business Improvement (BBI), I have gained a lot of new insights and experiences, and I am grateful for this opportunity. I want to thank everyone who was involved in this research from BBI, Bolk, CTT, and other companies for their massive help. Without the help and expertise of everyone, I was not able to finish this thesis.

A special thanks to my supervisors Niek Tijink and Hein Langeveld, who guided me during the research. I want to thank them for their trust, already when I was still in Sweden. Moreover, Niek and Hein were always available for questions and helped me a lot during the whole research. Each meeting was very nice and big thanks for all the feedback! On top of that, they were flexible and thoughtful during the internship. Also thanks to Sander, Cas, and Stijn for all the nice talks we had at the office in Hengelo.

Without a doubt, I would like to thank my UT supervisor Alessio Trivella. I enjoyed our meetings, and he was always helpful and patient with me. Without his extensive feedback, insights, and tips, I was not able to finish this thesis, thanks a lot. Due to this, I was able to improve my thesis. I would also like to thank my second supervisor Eduardo Lalla for his enthusiasm and feedback.

At this point, my study time in Enschede does also come to an end. I want to thank my family, friends, and housemates for their support, not only during the research but during my whole study period. I really enjoyed my five years of studying at the University of Twente. I especially want to thank Chiel Nijhuis. He helped me to keep motivated and provided me with extensive feedback and opinions about the research.

I hope you, as a reader, enjoy reading this master thesis!

Laurens Kok

Enschede, July 2023

Management summary

This research has been performed at Bolk Business Improvement (BBI) in Hengelo. BBI achieves improvements in production- and logistics processes through intelligent usage of knowledge and data. BBI is a daughter company of Bolk Transport. Bolk is an innovative transport company with diverse activities, clients, and collaborations. Bolk executes logistics operations by Bolk logistics, transportation by Bolk transport, container transport by truck via Bolk container transport, and container barge transport by Combi Terminal Twente (CTT). At BBI the question rises of how to offer these transport and logistics services combined as one offer, named end-to-end (E2E) logistics. The problem is that no customers choose this end-to-end logistics solution. Because there are no customers yet, we zoomed out and tackled this problem from a strategic perspective by finding out in which geographic region potential customers might be located. The core problem that is solved is therefore: 'It is unknown what end-to-end logistics can provide for Bolk's geographic competitive position. To even go one step further, we were interested in how we can maximize this position. Therefore, the main research question addressed in this thesis is formulated as follows:

How can Bolk's geographic competitive position be maximized, based on end-to-end logistics?

A context analysis is executed to understand the situation at the company. Transport and logistics flows are investigated in case end-to-end logistics will be applied. The focus of the research is on container transport from a deepsea port to the final end customer. This can be done by intermodal transportation, making use of barge, rail, or truck. Bolk's end-to-end logistics covers container transport from Rotterdam to Twente by barge, warehousing directly located next to the terminal, and last-mile transport by Truck. Since Bolk has warehouses directly next to the terminal, the distance between the terminal and the warehouse is negligible. Therefore, a major focus in the research was on intermodal transport because it covers a larger part of the end-to-end logistics solution. Bolk is a shareholder of two container terminals located in Almelo and Hengelo. Around these terminals, other competitive terminals in The Netherlands and Germany are located. These competitors and the different transport options for customers are investigated. Moreover, the considerations for potential customers for selecting a transportation option are investigated.

After the context analysis, a literature study is performed to get an understanding of intermodal transport networks and especially how to map them. Moreover, methods are investigated to maximize Bolk's geographic competitive position. Based on the probabilistic hinterland and the LAMBIT model, taking into account revenue management, a model is formulated. Next, price, time, and emissions are selected as KPIs to take into account the model. A simple comparison model is formulated, generating Bolk's position on price, time, and emissions separately. Around Bolk's facilities, around 1280 zip codes are selected to be investigated by assuming a zip code as a potential customer. For each customer, container transport from a port to the end customer by rail, barge, truck, and Bolk is determined. The model maps the customers for which Bolk is the best option based on the selected KPI.

Next, the optimization model is formulated. By making use of the geographic position of a potential customer, a weighted utility score is calculated for each of the modalities, taking into account the KPIs price, time, and emissions combined, and assigning weights to these KPIs. Based on a calculated utility score, the model determines the corresponding optimal price for a customer. The model provides practical insights by visualizing the outcomes on a map. After the optimization, an uncertainty factor of whether a customer accepts Bolk's offer or not is added by using a probability of acceptance. This is called the stochastic part of the optimization model.

Experiments are performed to test the model under different real-time scenarios that can occur. First, the model is tested under a base instance. After that, four scenarios are worked out. The impact of price fluctuations at Bolk is tested as a result of low water levels in the river and the availability to use an extra layer of containers on the barge. Next, the effects are measured in case an additional competitor is added to the model. Fourth, the effects of changes in rail transport are tested in the investigated region. Last, the effects of changes in emissions at competitors and at Bolk are measured. An implementation and evaluation plan is set up to make sure that based on the insights of the research, end-to-end logistics customers can be found.

Using the results of the experiments and the insights of the research, we were able to list the main conclusions:

- Using the optimization model, we are able to determine Bolk's maximized region. By making use of GIS software, the region is mapped. Moreover, the optimized price for each potential customer is determined based on the model.
- For actively searching for end-to-end logistics customers, Bolk can make use of the compiled list of locations.

- In the case of a low-water scenario, Bolk's region can potentially shrink by as much as 40%, caused by a corresponding price reduction of 33.3%.
- In case CTT is able to transport by barge with three layers of containers, Bolk's region has the potential to increase up to 55% for a price decrease of 33.3%.
- Reduction in Bolk's region in case of an operating barge terminal in Deventer will be minor; 5.73%. This percentage can increase to 16.7%, dependent on how much a customer is focussed on emissions. The loss is on the southeast side of Bolk's facilities.
- The rail terminal in Osnabrück has a minor impact on Bolk's competitive position.
- Subsidies for rail transport in order to decrease the price for rail transport have approximately no impact on Bolk's region.

Based on the performed research and stated conclusions, recommendations are made for Bolk Business Improvement. The main recommendations are as follows.

- Use the optimization model for determining the optimal price for a customer, as a decision-helping tool. To actively help a company select the right transport and logistics solution, it is recommended to make use of the tool.
- To execute E2E logistics as prepared as possible, we recommend formulating a tactical and operation plan for E2E logistics, starting with tactical. The focus should lie on communication between BBI, CTT, Bolk logistics, and Bolk container transport. Moreover, in the plan also the alignment between the technical details of the different IT systems should be described. The daily tasks should be explained in the operation plan. BBI should take the lead.
- To expand the competitive region, we recommend Bolk to focus on reducing emissions by barge transport. A decrease of 20% emissions by barge can cause an increase of 11% in Bolk's region. To further enhance the region, we secondly recommend focusing on reducing truck emissions for reducing the total CO_2 caused by the E2E logistics.
- We recommend using the list with locations in which potential customers might be located for actively searching for E2E logistics customers.

Lastly, it is advised to focus on information sharing between the different companies within the Bolk group to keep optimizing the processes and performing like Bolk's slogan: *'Moving forward together'*.

Contents

Reader's guide

Along the eight chapters, we described how the research at Bolk Business Improvement is performed. We shortly introduce the chapters.

Chapter 1: Introduction
The research is introduced in the first chapter. First, the company description is given. Second, motivation for the research as well as the research problem is provided. The action and core problem are described. Last, the design of the research is explained.

Chapter 2: Context analysis
This chapter provides insights into the research by executing a context analysis. First, Bolk's end-to-end logistics structure is explained. Second, the intermodal transport network in the region is described. Third, different types of transport are explained. Last, uncertain occasions in intermodal transportation are described.

Chapter 3: Literature study
First, theory about intermodal transportation and logistics is discussed. Second, different transport systems are described. Last, different methods are explained which might be suitable for maximizing Bolk's competitive position.

Chapter 4: Bolk's Competitive position
In the fourth chapter, a simplified transportation network is defined. By making use of a comparison model, Bolk's competitive position is determined and visualization in terms of price, emissions, and time separately.

Chapter 5: Solution method
The optimization model in order to maximize Bolk's competitive position is formulated in the fifth chapter. A model outline is provided to describe how to model is built up. After the mathematical formulation, model details are explained.

Chapter 6: Experiments
Different experiments are formulated and executed to test the performance of the model under different scenarios. These scenarios are based on real-life occasions that occurred or can occur in the future. Results provide more insights into Bolk's region.

Chapter 7: Implementation and evaluation
How the solution method can be implemented and evaluated overtime at the company is described in chapter seven. First. the need for implementation is addressed, moreover, it is explained how the solution method can be evaluated.

Chapter 8: Conclusions, recommendations, and future research
Conclusions and recommendations about the performed research are given in the last chapter. Moreover, how the research contributes to the literature as well as to practice is explained. Last, limitations and potential future research is described.

List of acronyms

Acronyms

API Application programming interface.

BBI Bolk Business Improvement.

CTT Combi Terminal Twente.

E2E End-to-End.

GIS Geographic Information System.

GLEC Global Logistics Emissions Council.

IWW Inland waterway.

LAMBIT Location Analysis Model for Belgian Intermodal Terminals.

MIQP Mixed Integer Quadratic Program.

MNL Multinomial logit model.

TEU Twenty Equipment Unit.

1 Introduction

This master's thesis is conducted at Bolk Business Improvement (BBI). The focus of the research is on end-to-end logistics, which represents the full logistics and transportation solution chain offered by Bolk. Section 1.1 introduces the reader to the company. The motivation for the research is provided in Section 1.2. The problem identification is given in Section 1.3, in which the core problem addressed within this research is identified. Last, the research design is given in Section 1.4.

1.1 Company description

The master thesis is executed at Bolk Business Improvement (BBI), located in Hengelo, The Netherlands. BBI achieves improvements in production- and logistics processes through the intelligent use of knowledge and data. Examples are achieving improvements in warehousing, transportation, production, and distribution. BBI is a spin off company of Bolk Transport B.V. (further referred to as Bolk), which is a transportation company. Bolk was founded in 1934 as a family company located in Almelo. In 1985, the company started to transport containers by train from Rotterdam to Almelo. Since the last decade of the previous century, containers are not transported by train anymore from Rotterdam to Twente, so Bolk needed to invest in other modal transport ways. Therefore, Combi Terminal Twente (CTT) was founded to transport the containers by barge from Rotterdam to the region of Twente. Bolk is 33% shareholder of CTT. Besides that, the company also focuses on warehousing, by introducing warehouses in Almelo and Hengelo and in different other countries in Europe (Bolk, 2023).

Bolk has become a stable and innovative transport company with diverse activities, clients, and collaborations (Bolk, 2023). Bolk provides clear added value in every aspect of transport. Special transport, logistics, and distribution are the three main areas in which Bolk operates. The company is specialized in special transport, including exceptional transport in for example the wind power industry. Windmill turbines are transported all over Europe by Bolk. Besides special transport, Bolk also transports a lot of containers. Bolk Container Transport provides daily container transport as an in-house carrier for among others Combi Terminal Twente (CTT) in Hengelo, CTT Almelo, and CTT Rotterdam. Bolk Container Transport accommodates all sizes of containers in a highly professional way. By doing so, they are active within intermodal transportation, the transportation of containers via different modal types. They aim to provide innovative and sustainable transport by road, water, and rail. Next to transportation, the company also operates in logistics. From order and colli picking, loading and unloading containers to stocking pallets and piece goods are all activities Bolk logistics performs. The last area Bolk is active in is business improvements. Bolk Business Improvement (BBI), a start-up within the Bolk firm was founded in 2021 (Bolk, n.d.). Bolk is a 50% shareholder of BBI Figure 1 shows an overview of Bolk's different companies related to this research. CTT Hengelo and Bolk's warehouse, in which BBI is located, are shown in Figure 2.

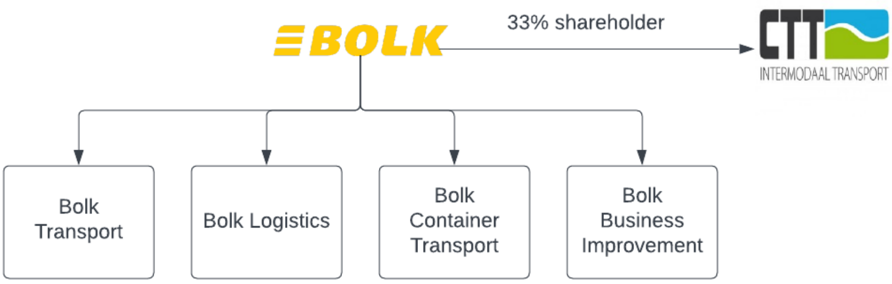

Figure 1: Overview of Bolk's different companies related to the research.

Figure 2: CTT Hengelo (left) and Bolk's warehouse (right)

1.2 Motivation for research

This subsection outlines the motivation for the research. According to Caris et al. (2013), intermodal transportation demonstrates, by its nature, an increased complexity due to the use of multiple modes of transportation and the involvement of multiple decision-makers and stakeholders. Moreover, intermodal transport implies integration between different operators in the transport chain and different transport modes should not only be optimized separately but should also be attuned to one another (Caris et al., 2013). On top of that, intermodal transport is being stimulated at multiple policy levels to guarantee a sustainable freight transport system in the future. The impact on the environment plays a key role in decision-making for intermodal transport. These challenges and complexity are also elements BBI encounters. The need for research arises in the realm of understanding the intersection of being sustainable, cost-efficient, and attractive for new customers. As explained, the facilities are there: Container terminals in Rotterdam, Almelo, and Hengelo, and multiple warehouses directly connected to them. The issue rises that the services offered by the facilities are not combined as one package, called end-to-end logistics, and the company thinks that there is an opportunity for doing so. In the warehouses, there is place for new clients, but research is needed on how to attract these new clients by offering all the services combined and in which region the services are most attractive to customers.

1.3 The research problem

BBI is focusing on improving and renewing logistics and transportation processes. Continuously mapping the needs, wishes and requirements of their own organization and their customers' and partners' in the field of operations and supply chain management, as well as making improvement proposals to optimize processes and directing their implementation, is part of daily business for BBI. Offering their solutions are defined as container transport, warehousing, and transportation combined. Combining these services is called end-to-end (E2E) logistics by the company. Companies can choose multiple transport and logistics solutions and these are chosen based on different parameters such as price and emissions. The more strategic question rises within BBI in what region around the facilities Bolk's end-to-end logistics is interesting for companies to choose from. This region is called the geographic competitive position of the company. In this area, there is a need for research and understanding the bigger picture. To summarize, BBI wants to investigate Bolk's geographic competitive position, based on end-to-end logistics solutions. Moreover, they want to expand this position as far as possible and therefore the question is how to maximize the geographic competitive position. To better understand the problem context, the action problem is defined in Section 1.3.1. After that, in Section 1.3.2, the problem identification is given for defining the core problem. In Section 1.3.3, the core problem selection is provided.

1.3.1 Action problem

As Figure 1 shows, Bolk consists of different sub-companies, such as Bolk Transport, Bolk Logistics, Bolk Container Transport, and Combi Terminal Twente. CTT is responsible for transporting the containers by barge from Rotterdam to Hengelo and Almelo. Bolk Logistics can handle the freight and store them in the warehouses, where Bolk Transport and Bolk Container Transport can transport the freight to the end customer. By combining these services the end-to-end logistics service can be offered by Bolk. The problem is that 'no customers make use of these combined services'. This situation can be seen as an action problem.

Anything or any situation that is not how you want it to be is an action problem (Heerkens and Winden, 2017). It is the discrepancy between the norm and the reality, as perceived by the problem owner. The problem owner is Bolk Business Improvement. In this case, the norm is that a customer chooses all Bolk's services combined, the reality is that this does not happen at the moment. Most customers choose partly Bolk's services. For example, transporting containers by CTT or the warehouse solutions of Bolk Logistics. The concrete solution will be that customers will choose all the services combined. To summarize, the following problem is selected to be the action problem and the aim of the research is to solve this.

'No customers that make use of Bolk's end-to-end logistics'

1.3.2 Problem identification

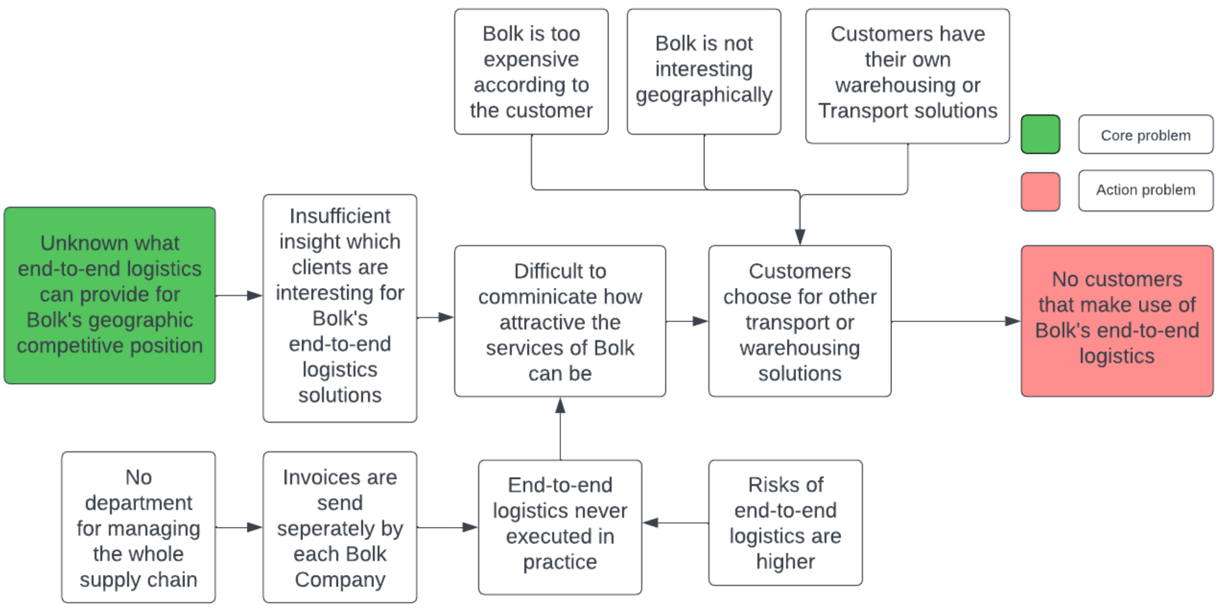

Figure 3: Overview of the problem cluster at Bolk Business Improvement

In order to understand what the cause of this problem is, a problem identification is needed. An observation study has been executed, by means of conducting interviews, to understand the underlying problems related to the described action problem. To identify the root of the action problem, a problem cluster to map all the related problems with their connections is made. The aim of this problem cluster is to identify potential core problems (Heerkens and Winden, 2017). The problem cluster is shown in Figure 3.

In Figure 3, the action problem 'no customers that make use of Bolk's end-to-end logistics', is caused by another problem. First of all, customers choose other transport or warehousing solutions. This means that customers select for example one of the Bolk services, such as barge container transport by CTT, warehousing and/or transport is selected to be done by another company or by the customer themselves. One of the reasons for this is that Bolk's services are too expensive in the eyes of the customer. If customers choose other transport or warehousing solutions this can also just be caused by the geographic position of Bolk's warehouse, which might not be optimal for the end customer.

During the time this research is conducted, it is difficult for Bolk to communicate to potential customers how attractive the services of Bolk can be. Bolk thinks that by offering end-to-end logistics, they can be a very attractive logistics and transportation party. Details about this feeling are not available and therefore it is difficult to communicate this to the potential new customers. The cause of this is the fact that Bolk never executed end-to-end logistics in practice. They offered end-to-end logistics, but customers did not choose it, for various reasons. This has several causes. First, the risks of offering the solution are high, since Bolk is responsible for the whole logistics chain. If something happens in the supply chain, for example, a delay, Bolk should bear the potential involved costs. Second, when offering such a solution at the moment, invoices are sent separately by each Bolk company. According to Bolk's logistics manager, this is a problem because it can be an obstacle for companies to choose end-to-end logistics solutions by Bolk. The reason that there is not one invoice for the services is that there is no department for managing the whole supply chain.

The challenge of communicating the attractiveness of Bolk's services is caused by insufficient insights into which clients are interested in Bolk's end-to-end logistics solutions. Each client has its own transport preference based on different parameters. The best customer profile is unknown. BBI is interested to know what geographic positions of customers are interesting. This problem is caused by another problem. For BBI, it is unknown what end-to-end logistics can provide for Bolk's geographic competitive position. It is unknown in what region companies lie in which the end-to-end logistics solution is the most interesting choice to choose for a company.

1.3.3 Core problem and motivation

A closer look is taken at the problems which do not have a cause by themselves. These are important and can be seen as possible core problems. A core problem is selected if it can be influenced. In the problem cluster, six potential core problems can be determined. The fact that Bolk is not interesting geographically for certain customers cannot be changed during the research. It is not possible to change the location of the company in the short term. Nevertheless, it is possible to make suggestions at the end of the research for potential new interesting locations for the company. The second and third potential core problems are the problems that Bolk is too expensive according to the customers and the fact that customers have their own warehousing or transport solutions. The fact that Bolk might be too expensive is a commercial problem. Customers who have their own warehousing or transport solutions cannot be changed, because that is up to the customer themselves.

The fourth and fifth potential core problems are the fact that risks are high when executing end-to-end logistics and that there is no department for managing the whole supply chain. Risks can be tackled by contracts, according to Bolk's commercial manager. How to make these contracts is not within the scope of the research. The same holds for the fact that there is no department for managing the whole supply chain.

The last potential core problem is the problem that it is unknown what end-to-end logistics can provide for Bolk's geographic competitive position. BBI defines end-to-end logistics as the combined transport and logistics services offered by Bolk. This is explained further in Chapter 2. The geographic competitive position is defined as the region in which Bolk's end-to-end logistics are the preferred choice of a customer compared to other transport options in the region. Different parameters are taken into account to make this comparison, such as price, time, and emissions. The problem is solved by performing research on what the competitive position is based on end-to-end logistics and how this position can be maximized based on existing infrastructure. Maximizing is defined as making sure that the number of customers in the region around Bolk for which Bolk's end-to-end logistics is the preferred choice is maximized. This is established by making use of price differentiation, which is explained in more detail in Chapter 5. By solving this problem, BBI gets more insights into which companies might be interested in end-to-end logistics, and can actively attract them for selecting the solutions. Getting to know the answer to this problem, is the gap in which research plays the central role.

To conclude, the following problem has been selected as the core problem of this master thesis:

'Unknown what end-to-end logistics can provide for Bolk's geographic competitive position.'

1.4 Research design

The structure of this research is based on the methodology designed by Heerkens and Winden (2017). The steps, and corresponding order, taken into account are: Defining the problem, formulating the approach, analyzing the problem, formulating (alternative) solutions, choosing a solution, and implementing and evaluating the solution. These steps are integrated into this research and based on that research questions are formulated. First, Section 1.4.1 provides an overview of the stated research questions. Second, the approach is provided in Section 1.4.2. Third, the scope of the research is given in Section 1.4.3. Fourth, the stakeholders in the research are shortly defined in 1.4.4. Last, the intended deliverables are explained in Section 1.4.5.

1.4.1 Research questions

Based on the problem identification, together with the stakeholders, the main research question is formulated. The question focuses on solving the core problem and moreover an expansion on that by asking how to maximize the geographic competitive position of the company. The following research question is formulated:

'How can Bolk's geographic competitive position be maximized, based on end-to-end logistics?'

In order to answer the stated main research question and to solve both the action and core problem, research is conducted by answering research questions. For each question, the main steps and their purpose are given. The following questions are stated:

1. *What is the current transport network offered by Bolk?*
    - What is Bolk's current end-to-end logistics structure?
    - What is the intermodal transport network in the region in general?
    - What are the modal options and how do they relate to intermodal transportation?
    - What are uncertain factors influencing intermodal transportation?
2. *Based on the literature review, what are applicable techniques and methods for mapping the geographic competitive position and maximizing it?*
    - According to the literature, what are the key elements of intermodal freight transportation?
    - What are the relevant components in applying hinterland logistics and end-to-end logistics?
    - Which techniques are suitable for mapping the geographic competitive position?
    - Which optimization model or techniques can be used for maximizing the competitive position?
3. *How can Bolk's competitive position geographically be mapped?*
    - How can the basic model be formulated?
    - What input data is required and available?
    - What conclusions can be made from the mapping?
4. *How can Bolk's competitive position be maximized?*
    - How can the optimization model be formulated?
    - What is the type of model we use?
    - What calculations are made for using the model?
    - What conclusions can be made from the optimization model?
5. *What experiments can be employed to investigate the performance of the model, and what are the corresponding outcomes or findings of these experiments?*
    - How is the model performing under a base instance?
    - Which scenarios are interesting to be investigated, and what are the corresponding outcomes?
    - How can the outcome of the model be verified and validated?
6. *How can the solution method be implemented and evaluated?*
    - How can the model be implemented in a practical way for Bolk?
    - How can the model be used by BBI?
    - How can the model be implemented for other companies?
    - How can the model be evaluated over time?
    - What conclusions can be made from the implementation and evaluation phase?
7. *What recommendations and conclusions can be made from conducting the thesis at Bolk Business Improvement?*
    - What are the main conclusions from conducting the thesis?
    - What are the main recommendations for conducting the thesis?
    - What are the theoretical and practical contributions of the research?
    - Which limitation can be formulated related to the research?
    - In which area is further research needed?

1.4.2 Approach

To solve the action problem, insights into the current situation and context are obtained. Context analysis is conducted by means of a descriptive study. Interviews with different stakeholders are performed to understand the context. All the different stakeholders are described as well as different flows. Details can be found in Chapter 2 and the first research question is answered. A closer look is made at the current end-to-end logistics structure of the company. Moreover, more insights are created within the intermodal transport network.

A literature study is performed to find out what relevant methods and theories are for first mapping the geographic competitive position and second how to maximize it. This is done by taking a broader picture of the concepts of intermodal transportation and mapping solutions geographically. Moreover, a literature study is performed to find suitable optimization models to maximize the competitive position. The results are described in Chapter 3.

Next, insights from the literature are applied in order to map Bolk's geographic competitive position on end-to-end logistics. It is important to first define the parameters for selecting the best modal choice for a region. After that, comparisons between the modal choices for the region around the company is made, programmed and mapped. The results are explained in Chapter 4.

The fourth research question focuses on the solution method of this research. An optimization model is formulated. This model needs to maximize the competitive position. In order to do so, parameters, objectives, decision variables, and constraints are first are defined. Second, a sensitivity analysis is made to find out how the results can be interpreted. This is described in Chapter 5.

Next, the implementation and evaluation of the solution method are described. It is described how the model can be used in practice and how it can be adapted to other situations or companies. This is explained in Chapter 7.

The answers to the last research question gives recommendations and conclusions from the research. Moreover, a look is taken to what extent the research goal has been achieved. last, the limitations of the research are discussed. It is explained in which area further research is needed. This can be found in Chapter 8.

1.4.3 Scope

As mentioned in Section 1.2, intermodal transportation and logistics are quite complex. To get reliable and useful results out of the research, and stay within the time limit of one academic semester, a scope is needed. By means of multiple brainstorming meetings with BBI, the scope of the research is determined. The biggest part of the end-to-end logistics solutions is covered by intermodal transportation. Moreover, Bolk's warehouse is directly located next to the container terminal, and the distance between them is negligible. Therefore the research focuses mostly on a broader picture of modal transport choice for customers in the region of Bolk's geographic position. The intermodal transport options covered in the research are road, inland waterway, and rail transport. Air freight transport and pipelines are left out in this research. A major focus in the research is therefore on intermodal transport, because it covers a larger part of the end-to-end logistics solutions, and a minor focus is on warehousing. The three modal choices are compared in the region around Bolk. The region that is investigated are the municipalities around Bolk's locations in Hengelo and Almelo, to municipalities that lie close to the nearest other container terminals. The nearest container terminals are Nijmegen, Doesburg, Meppel, Coevorden, Emmerich, Osnabrück, Kampen, Groningen, and Dörpen. Because of the rising questions about sustainable transportation, the environmental impact of transportation is central to the research. Environmental impact has been defined in the research as the CO_2 emissions. Since we investigate first in which regions potential E2E logistics customers are located, we tackle this problem from a strategic perspective, instead of either tactical or operational.

1.4.4 Stakeholders

The main stakeholder in this research is Bolk Business Improvement. Because multiple Bolk companies are involved, Bolk's director's team as well as CTT's management are defined as stakeholders in the research as well.

1.4.5 Deliverables

Together with the stakeholders in the research, deliverables are defined which are presented to them at the end of this master thesis execution. The following intended deliverables are defined.

- A geographic map in which the competitive position can be seen based on end-to-end logistics and what the maximized position is.
- A dashboard in which the company can easily change input parameters and see what the result on the region would be.
- A general model which can be applied in other areas or for other companies as well.
- Recommendations and conclusions in order to reach a maximized competitive position for Bolk.
- This master thesis to read how the research has been executed.

2 Context analysis

In this chapter, a context analysis is provided about the current situation at Bolk. The following research question is answered in this chapter:

What is the current transport network offered by Bolk?

This is done by answering the following sub-questions:

- What is Bolk's current end-to-end logistics structure?
- What is the intermodal transport network in the region in general?
- What are the modal options and how do they relate to intermodal transportation?
- What are uncertain factors influencing intermodal transportation?

The chapter is built up as follows. First, Bolk's end-to-end logistics structure is explained in Section 2.1. Second, Section 2.2 provides insights into the intermodal transport network in the region. Third, within intermodal transportation, modal selection is important. In Section 2.3, information about the modal selection is given. Fourth, in Section 2.4, uncertainty in intermodal transportation is explained. The discussion and conclusion are finally given in Section 2.5.

2.1 Bolk's end-to-end logistics structure

In this section, the different actors within Bolk's end-to-end logistics structure are described. These are CTT Rotterdam (Section 2.1.1), CTT Hengelo (Section 2.1.2), CTT Almelo (Section 2.1.3), Bolk Logistics (Section 2.1.4), Bolk Transport (Section 2.1.5) and finally Port of Twente (Section 2.1.6).

2.1.1 CTT Rotterdam

Bolk Transport is one of the three shareholders of Combi Terminal Twente (CTT), a company owning container terminals. CTT has three locations in which containers can be handled, Rotterdam, Hengelo, and Almelo. These locations are important since the transport flow of the containers starts at CTT Rotterdam, following transport by barge to either CTT Almelo or Hengelo. The locations are explained in more detail. First of all Rotterdam: this terminal is located in the Port of Rotterdam, the largest port in Europe and one of the largest in the world. At CTT Rotterdam, containers can further be transported to the hinterland by barge, rail and truck. The railroad has a direct connection to rail terminals in Poland, Belgium, and Switzerland. The intermodal connectivities to the hinterland are shown in Figure 4. The terminal is located attractively from high-frequency deep-sea and short-sea connections. It is also possible to travel to various other terminals in Rotterdam (CTT, 2023).

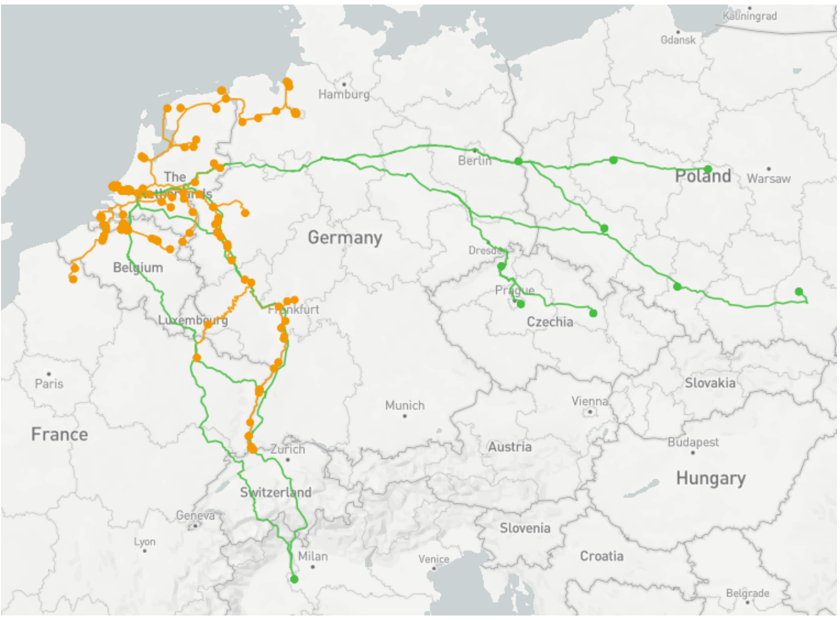

Figure 4: CTT Rotterdam's intermodal connectivities to hinterland (Routescanner, 2023). Green lines represent the connections by rail and the orange lines are barge connections. The dots are container terminals.

2.1.2 CTT Hengelo

Combi-Terminal Twente is located at the Twente Kanaal, which is a channel flowing into the IJsel river, which in itself is connected to the bigger rivers in The Netherlands and the Port of Rotterdam. Therefore it is possible to transport freight via the inland waterways from Rotterdam to Hengelo. In Hengelo, one of the most modern inland container terminals in The Netherlands can be found. The terminal is attractive to companies because of multiple reasons. First of all, it is directly located next to the highway, with only a short drive to Germany. It will take approximately 20 hours by barge from Rotterdam to Hengelo. This route is shown in Figure 5a. Moreover, directly next to the terminal, Bolk's 25.000 m2 warehouse is located. This offers the possibility to store goods from the containers in the warehouse. On top of that, Bolk is also able to do last-mile delivery to the end-customers (CTT, 2023).

2.1.3 CTT Almelo

CTT Almelo is connected with a special river branch from the Twente Kanaal. This means that in the end it is as well connected to the main rivers and the port of Rotterdam as in the situation in Hengelo. The terminal is next to Almelo business XL-Park, where multiple large manufacturers and logistics companies are located. Moreover, it is close to the highway as well. Rotterdam-Almelo by barge will take 20 hours. This logistics hotspot is in full development, with the opening of multiple large warehouses and production facilities of different companies. As in Hengelo, Bolk has a warehouse directly located next to the container terminal in Almelo (CTT, 2023). The waterway route can be seen in Figure 5b.

(a) Connection Port of Rotterdam to CTT Hengelo.

(b) Connection Port of Rotterdam to CTT Almelo

Figure 5: Barge connections of CTT locations Hengelo and Almelo (Routescanner, 2023).

2.1.4 Bolk Logistics

Bolk logistics is a company within the Bolk group which operates all the warehouse activities. As explained, Bolk has two warehouses of approximately 27,000 m2 located in Hengelo and Almelo, directly next to the container terminals. Therefore, the transportation distance from the container terminal to the warehouse is negligible. Bolk logistics is specialized in all warehouse activities, such as order picking and handling of container freight.

2.1.5 Bolk Transport

The next company in the supply chain is Bolk Transport. As explained in the introduction chapter, this was Bolk's first company. Different kinds of transport can be defined within the company, such as conventional, exceptional, distribution, and container transport. In this research, we focus on container transport by Bolk Transport. The company can transport all kinds of sizes of sea containers. Bolk Transport provides daily container transport as in-house carrier for among others CTT Hengelo and CTT Rotterdam (Bolk, 2023). In general, these containers are transported to the hinterland in a radius of 75 kilometers around Hengelo, as stated by CTT.

2.1.6 Port of Twente

The similarity between the different companies of Bolk is the fact that most of them are located in the region of Twente. Twente is a region in the province of Overijssel, in the east part of the Netherlands. The common association between the port operators, companies located in the region, government and educational institutes is Port of Twente. A manager within the Port of Twente has been interviewed to get more insights about the port and the region. Port of Twente is a logistics hotspot within the Netherlands. The region is well connected to the highway, inland waterways, railway, airport and container terminals. Because of this strategic location to the hinterland, mostly in Germany, different production and distribution companies are located in Almelo and Hengelo. In Almelo, the so-called 'XL business park' is located, which is located next to the 'Twente Kanaal' and the highway. As explained, also Bolk is located on this location because of its strategic location. In 2022, the Port of Twente was ranked 9 on the ranking list of logistics of hotspots in the Netherlands (Logistiek.nl, 2022). The association wants to grow on this list in the upcoming years. According to Bolk's commercial director, the region of Twente will also be attractive in the upcoming years. Purchasing ground is relatively cheap compared to the rest of The Netherlands. Moreover, jobs can still be filled, despite all the problems with searching new employees in society. Manufacturers who are still growing are located in the area around Twente. As stated by the manager of Port of Twente, the region is most popular for international companies who want to establish a location in Europe, or in The Netherlands in particular. For these international companies, the exact location does not matter that much, they want to be well-connected to the infrastructure and their partners. For national companies, Twente could be less interesting, because it is not central in the country and not well connected to other parts of corners of the country.

2.1.7 Bolk's Intermodal transport network

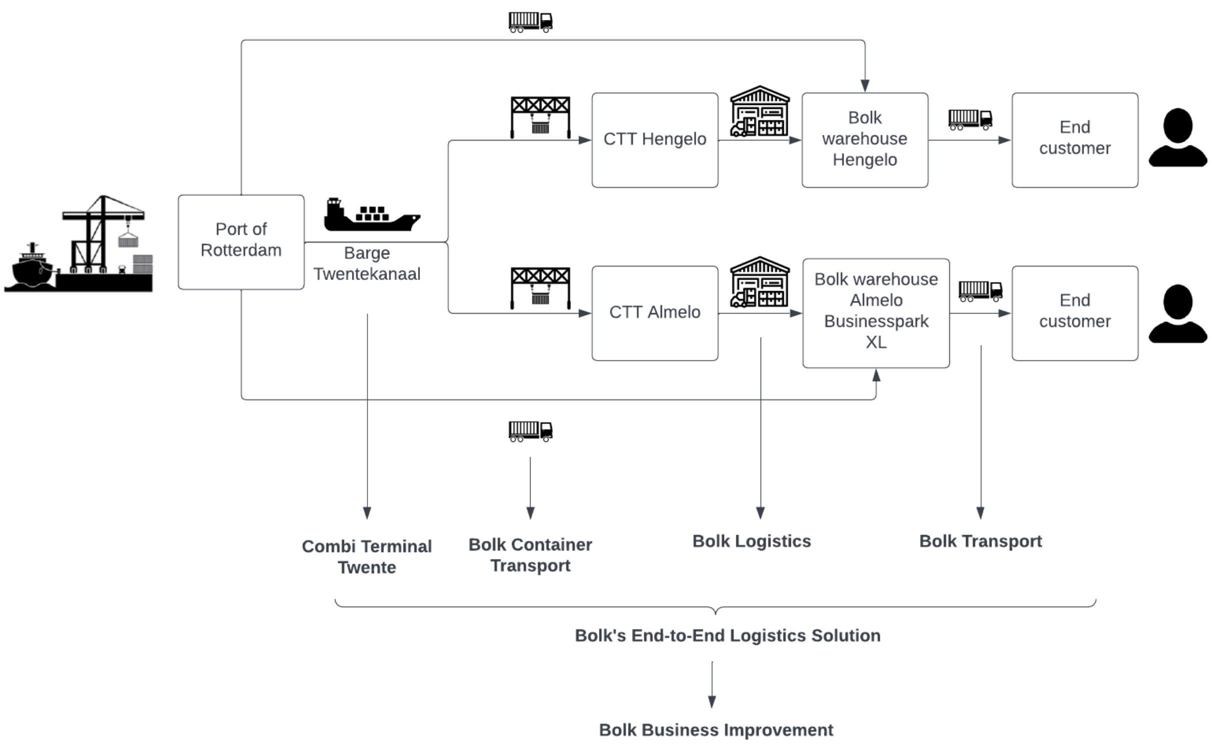

Figure 6: Overview of the intermodal transport network of Bolk's end-to-end logistics services

How the different companies are connected within the intermodal transport network of Bolk, is shown in Figure 6. The transport of one container is explained as follows. Bolk's transport network starts with a delivery of a container in the port of Rotterdam. This container is transported via the Twentekanaal by barge to the Port of Twente, this is done by CTT. The barge will arrive at either CTT Hengelo or Almelo. The selection between Hengelo and Almelo is based on the final destination of the container, so the location of the end customer and the availability at the container terminal. The barge will be handled by CTT. Due to the fact that Bolk's warehouses are directly next to the container terminal, it is only a very short drive to the warehouse. This is done by Bolk Container Transport. It is also possible to make use of a truck to transport the container by truck from Rotterdam to Twente. This option can be selected in case the container needs to be transported in a fast way. The next step is warehousing, this is all done by Bolk Logistics. This means that Bolk Logistics is able to operate all the warehousing activities. The last-mile delivery to the customer is finally done by Bolk Transport.

There are multiple variants possible to the end-to-end logistics solutions offered by Bolk. In Figure 6, the import situation can be seen. This means that an end customer wants to import freight from somewhere in the world and to be transported to their facility. The export process is the other way around, so the end customer wants to export their freight from their facility to a seaport. The last option is that a customer wants to make use of both import and export. In this case, freight will be transported by Bolk to the end customer. When arriving at the customer, Bolk will take freight that needs to be transported back and make sure that it will be transported back to Rotterdam for example. As can be seen in the Figure, all Bolk's companies are involved in the process. CTT is responsible for the container handling in the terminals and for making sure that the container will be transported by barge from Rotterdam to Almelo or Hengelo. Bolk Container Transport is responsible for transporting the container from the terminal to the warehouse. The material handling and storage will be done by Bolk Logistics, and the last-mile transport is done by Bolk Transport. All these activities can be summarized as Bolk's end-to-end logistics solution. Bolk Business Improvement is responsible for the overall support when it comes to organizing and optimizing the supply chain.

2.2 Intermodal transport network in the region

To create an understanding of the current situation within the supply chain solution offered by Bolk, a look at the bigger picture around intermodal transport network in the region is made. In this section, first, an overview of intermodal transportation in the Netherlands is explained. This is described in Section 2.2.1. Next, in Section 2.2.2, a more detailed look is made at the region of Twente. Third, the intermodal transport solutions in the context of Bolk are explained in Section 2.2.3.

2.2.1 The Netherlands

To gain a deeper understanding of the intermodal transportation network and Bolk's competitive position, it is imperative to conduct a comprehensive analysis of the regional network. In Figure 7 shows an overview of all barge and rail container terminals in the Netherlands. As shown in the figure, the origin of the waterways and railways are the port of Amsterdam, Antwerp (Belgium), and Rotterdam. From there, containers are transported via train and the rivers to the hinterland. Rotterdam is the biggest port in Europe, and therefore the connections to the hinterland are important. It is possible to transport via rail, road, inland waterways, and in the case of liquids, pipelines. Via rail from Rotterdam, containers can be transported to most of the countries within Europe. With a transshipment in The Netherlands, it is also possible to go all the way by train to China. The second option to transport the containers is by barge. Using the rivers, the freight can be transported to Belgium, Luxemburg, France, Germany, and Switzerland. The last option is to use trucks to transport the containers and freight.

Figure 7: All barge (orange) and rail container terminals (green) in The Netherlands with corresponding connections (Routescanner, 2023).

In Figure 7, all the orange points are barge container terminals in the Netherlands. According to Bolk's director, the main competitor of Bolk's inland container freight system by barge is container transport by road. These are operators who transport containers directly from the port of Rotterdam to the hinterland by truck. This mode of transport is a faster way of transport compared to for example the barge. Besides that, the main competitors in the region are other container terminals in the area. In the next section, a closer look at the region of Twente is made.

2.2.2 East-Netherlands

A closer look at the area of east-Netherlands is shown in Figure 8. Three main container terminals are shown. First of all, in the top right of the figure rail terminal, Coevorder can be seen. Containers will come by train from the port of Rotterdam. In Coevorden the containers can be picked up by a truck, or further transported to Scandinavia by Train. The second terminal is the barge terminal in Meppel, which has a direct connection to the port of Rotterdam as well. Third, the container terminals in Nijmegen and Doesburg, are in direct connections with the port of Rotterdam, Antwerp, and also Basel in Switzerland. According to Bolk's director, the oval around the container terminals in Twente is the current approximation of the area in which the containers are transported from Hengelo and Almelo.

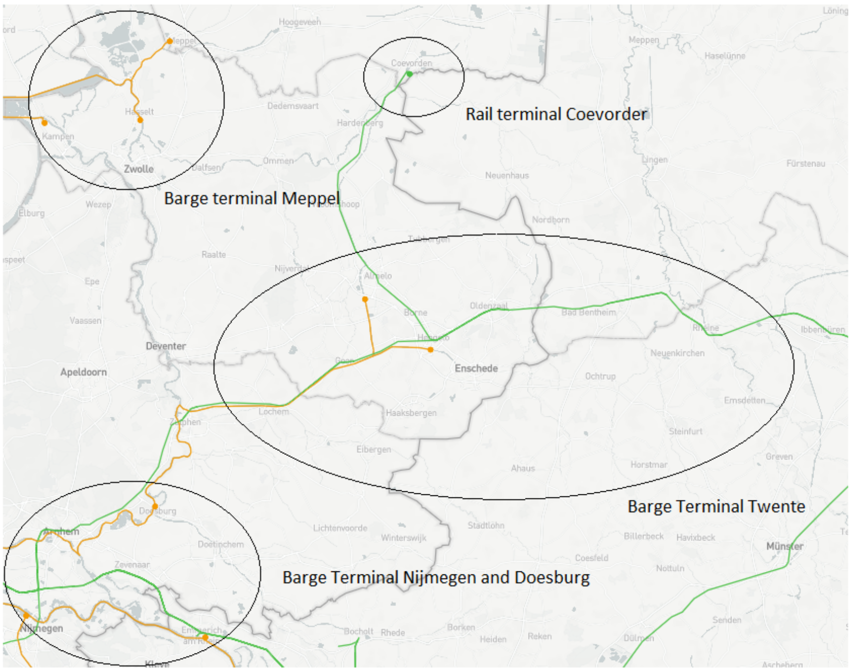

Figure 8: Container terminals around the region of east-Netherlands

2.2.3 Intermodal transport solutions

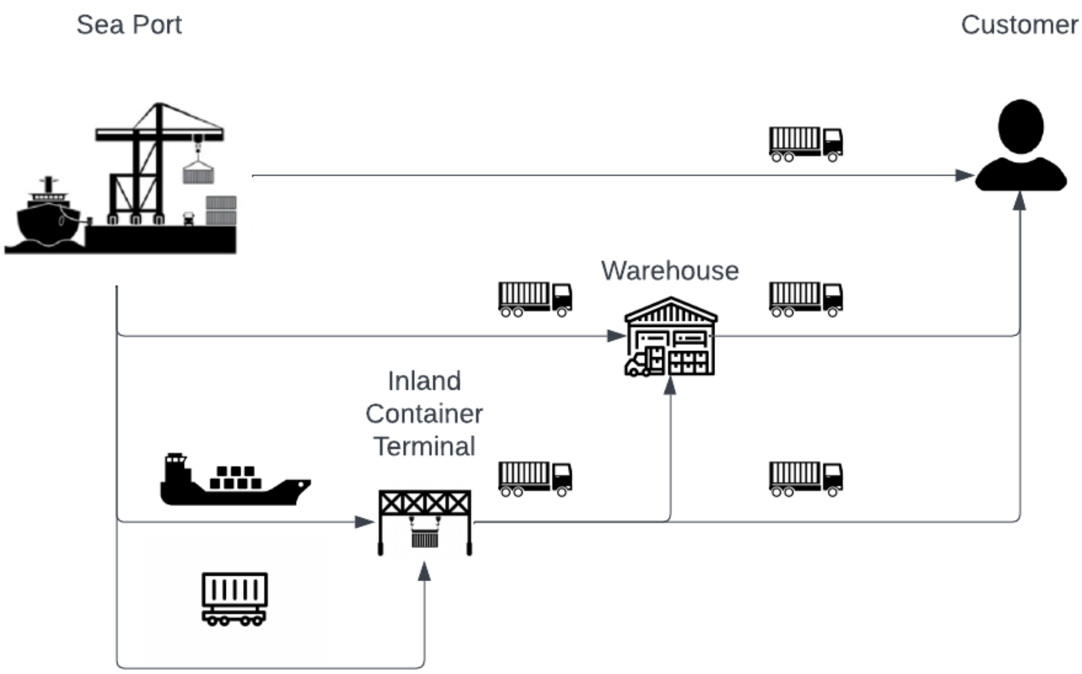

Figure 9: Simplified network design

Figure 9 shows a simplified network design of the area around Bolk's facilities. There are multiple ways to transport containers from the seaport to the end customer. In this section, four different options are discussed on how to do this.

Seaport - Customer
The first option is to transport freight directly from the seaport to the end customer. In order to execute that, a truck will pick up the container at the seaport to drive it directly to the end customer. The transport can

be done by a transportation company, such as Bolk, or by the own transport of the end customer. Containers arrive at the port being transported by big container vessels. By making use of big cranes the containers are transshipped from the vessel to the storage place in the port. From there the containers can further be transported to other storage locations in the port from where they can be loaded on trucks.

Seaport - Warehouse - Customer
The second option is to transport freight, combined with warehousing. In this specific situation, all the transport from the port to the warehouse and finally to the customer is done by road transport. The warehouse can be located at various locations, for example, close to the port of Rotterdam, to directly store the goods after arrival at the port. The warehouse can also be located in the area of the end customer.

Seaport - Inland Container Terminal - Warehouse - Customer
Transporting containers from the seaport to an inland terminal is the third option. This can be done by rail or barges. Rail transport to the east part of The Netherlands is not done by CTT, but by other operators. Mostly, this is done from a German port, like Hamburg or Bremen, to a rail terminal around the west side of Germany. The train will arrive at an inland container terminal and be transshipped to a truck, which drives to the warehouse. In the case of the barge network of CTT, containers are transported by rail from the container terminal to the container terminal of CTT within the port of Rotterdam. From there, containers are transshipped to the barge. The barge will go to an inland container terminal. At the inland terminal, the container will be handled by a crane that stores the container. Trucks can pick up a container. Next, the freight can be transported to a warehouse. After warehousing, the freight will be transported by truck to the end customer. In the case of Bolk, the transportation distance from the inland container terminal to the warehouse is minimized due to the fact that the warehouse is directly located next to the inland container terminal. As explained this is the situation in both Hengelo and Almelo.

Seaport - Inland Container Terminal - Customer
The last option looks like the previously explained one, but in this case, a customer will not choose a warehousing solution. Containers are transported from the seaport to the inland container terminal and finally to the end customer by road transport.

2.3 Modal selection

In this section, it is explained which factors are important when choosing a type of transport mode. This is useful in order to get better insights into the geographic competitive position of Bolk because companies can define different parameters which are important for selecting the right modal choice. In general five types of modal choices can be seen in the context of intermodal transportation: air, rail, road, water, and pipelines. Air freight transport and pipelines are out of the scope of this area, as explained in Section 1.4.3. In this section, the focus is on road transport (Section 2.3.1), inland waterway Transport (Section 2.3.2), and rail transport (Section 2.3.3). In Figure 10, the modal split of four main ports in Europe; Rotterdam (NL), Antwerp (BE), Bremen (GER), and Hamburg (GER), is shown to better understand the distribution of the modal choices around different the four biggest ports in Europe. Modal selections are dependent on variables such as costs and time, but also on geography. As the Figure shows, the share of inland waterway transport in the Netherlands and Belgium is way higher compared to the ports in Germany, because of the relatively fewer river distance in Germany.

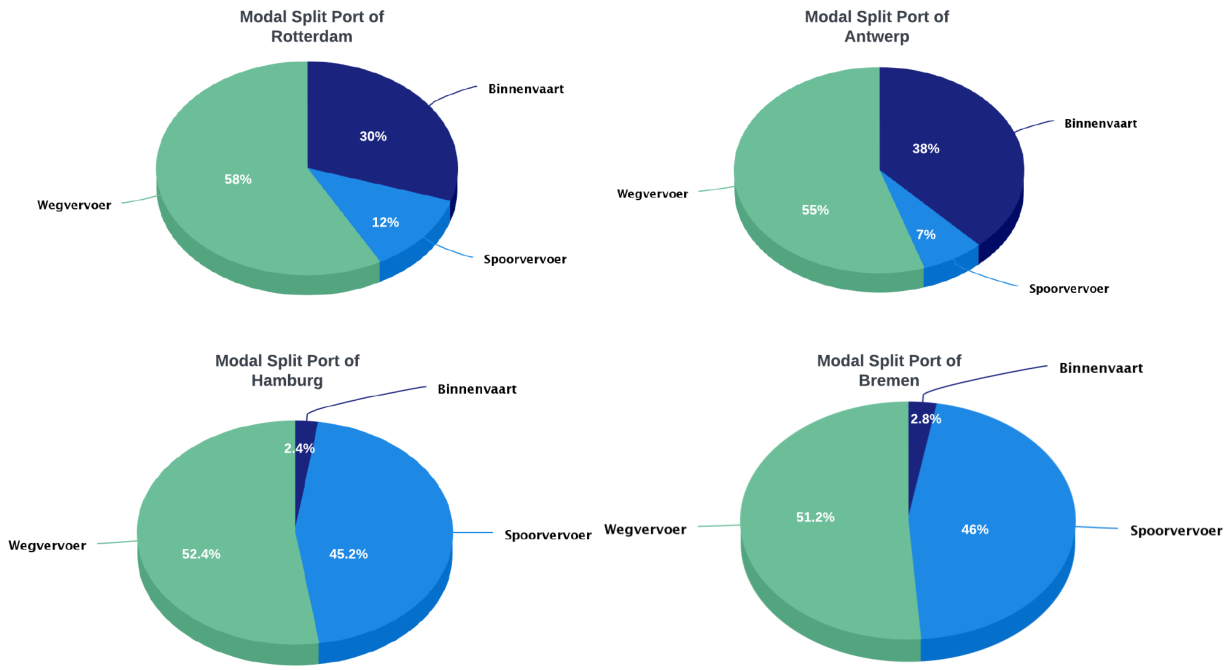

Figure 10: Modal split of four main ports in Europe. In the Figure, green represents road transport, Dark blue inland waterway transport and light blue rail transport (Binnenvaartcijfers, 2017).

2.3.1 Road transport

Port hinterland services mostly rely on road transport in Europe, however, the enduring growth in port traffic is challenging the dominance of road for hinterland services because of costs, congestion and growing environmental constraints (Frémont and Franc, 2010). Fast delivery, flexibility, a door-to-door service are reasons why truck transport is often preferred. Especially when it comes to short distances and small quantities (Macharis et al., 2011). Using road transport, a container can be transported in a fast way, directly to the end customer without a transshipment. For instance, a container can be picked up in the port of Rotterdam, and transported within three/four hours to the customer in Twente. Road transport is also flexible, if a road is blocked for some reason, it is quite easy to take another route instead. This is a more flexible modal choice than for instance rail transport, with fixed railways. Trucks can deliver containers to any location, including remote areas with no rail or waterway access. If small quantities are required, road transport can be ideal, it can be transported directly with the truck to the end customer. There are also disadvantages of road transport. First, road transport can be affected by traffic congestion, which can lead to delays and increased transportation costs. Second, road transport could have a higher environmental impact compared to inland waterway and rail transport. Third, road transport has capacity limitations. Compared to a barge or train, a truck can transport less freight, which also results in higher costs. Road transport can therefore be seen as fast, but costly.

2.3.2 Inland waterway transport

The second transport mode is inland waterway (IWW) transport. Combined transport must still demonstrate that it can compete with road transport. A shared dynamic, which is the outcome of several factors, leads to the use of combined waterway-road for hinterland services from maritime ports (Frémont and Franc, 2010). IWW is mostly used in the Netherlands, Belgium and Germany. These three countries were accountable for more than 93% of the total EU flow of full containers on IWW (Roso et al., 2020). The main reason for this is geographic, the center of gravity in IWW lies in the Rhine corridor, through the Netherlands and Germany Konings (2003). This is due to the precondition for a considerable market share of inland waterway transport; the availability and quality of infrastructure in terms of waterways and ports. IWW transport has the following advantages. First, it has low energy consumption, compared to road transport, and moreover low emission of air pollutants. Second, capacity efficiency is high, since a typical European barge can replace 30-60 trucks with containers. It is also considered a safe transport mode since only a few accidents happened in the past. The main disadvantages of IWW transport are time and dependency on the required infrastructure. First, barging containers is a slow mode of transport, compared to rail and truck. Second, IWW transport is only possible if an area has a deep enough river and moreover container terminals are required to transship the containers for last-mile transport by truck.

2.3.3 Rail transport

The third modal choice is rail transport. Rail transport has several advantages and disadvantages. It is least affected by for example weather conditions such as rain or fog compared to other modes of transport. Moreover, it has fixed routes and schedules. In general, if the distance increases, rail transport gets cheaper. Last, the capacity is high, and can easily be increased by adding more wagons for instance. Rail freight transport is often electrically powered, and therefore avoids fuel consumption which benefits a more environmentally friendly way of transportation. On the other hand, there are also disadvantages. For rail transport, large investments are needed in order to get the infrastructure and are mostly done by governments. Also, the costs of maintenance are higher than compared to other modes of transport. As expressed, rail transport is less flexible, due to fixed tracks and schedules. Moreover, it also does not have a door-to-door connection to the end customer. Last-mile delivery by truck is mostly required. For short distances, rail transport is slower and more expensive.

2.3.4 Modal choice variables

Actors within the intermodal transportation network need to make decisions about which modal to choose in order to transport freight. Decisions are based on objectives and variables. The following parameters can be defined as the most important in the modal choice process. These are based on literature and interviews with different stakeholders and companies (Meers and Macharis, 2014, 2015; Reis, 2014; ITF, 2022). We distinguished parameters as fixed if they cannot be changed and variable, in case the company can change the value of the parameter. This is determined together with the stakeholders. Moreover, the parameter is assigned to the customer or the carrier. In this context, Bolk is the carrier.

- Cost/price [Variable, carrier]; In general the most important variable is related to the cost or price of the transport. The cost of intermodal transport is a broad concept since it exists of different kinds of costs, such as handling and transport costs. The parameter is variable since each customer can have different prices determined by the carrier.
- Transit time [Variable, carrier]; The time requires to transport a container from one place to the other by a certain type of modal. The time is variable since transport can have delays, caused by for example congestion. The carrier is responsible for the time.
- Volume [Fixed, Customer]; The number of containers that need to be transported. It is assumed that it is a fixed number assigned by the customer. This can be the number of containers per year for example.
- Capacity [Fixed, carrier]; The capacity of a barge, train, or truck, as well as the capacity of an inland terminal. This is a fixed number, assigned by the carrier.
- Good Characteristics [Fixed, customer]; The type of goods transported, such as general cargo or reefer container (temperature controlled). This is a fixed parameter and is determined by the wish of the customer.
- Transport distance [Fixed, carrier, customer]; The distance that needs to be transported. This is a fixed parameter and is determined by the distance between the location of the customer and the carrier.
- Reliability [Fixed, carrier]; The factor of how reliable a modal choice is, dealing with delays and disruptions. Moreover, it can also be seen as how reliable a carrier is, for example how often the freight is delivered on time. It is assumed that it is a fixed parameter.
- Frequency [Fixed, customer]; How often the freight needs to be transported and the service offered. It can be seen as a fixed number determined by the customer.
- Safety [Fixed, carrier]; The level of transport safety; how safe the goods can be transported. This is assumed to be a fixed parameter, affected by the carrier.
- Infrastructure [Fixed, carrier]; the available infrastructure, such as inland waterways, roads, rail, and terminals. Infrastructure is fixed, and mostly determined by the government. Where terminals are located is affected by the carrier.
- Emissions/ sustainability [Variable, carrier]; Emissions of a modal selection, such as CO_2 per Kilometer. The emission is variable since different types of trucks can for example be used and is affected by the carrier.

- Urgency [Fixed, customer]: The level of urgency that the freight is needed for the customer. It is assumed to be fixed and determined by the customer.

Interviews are performed with Bolk Transport, Bolk Logistics, CTT, and some of the potential customers to understand the importance of the parameters. The stakeholders address that each customer will have their own preference, but in general, price is the most important one. Sustainability issues are getting more and more important for customers. Taking all these parameters into account, a customer can select a preferred mode.

2.4 Uncertain events in intermodal transportation

As explained in Section 2.3.1, road transport benefits from its flexibility and adaptability to sudden disruptions and uncertainties. According to Delbart et al. (2021), to facilitate a modal shift towards intermodal transport, it is crucial to improve its resilience (capability to resist and recover from sudden disruptions) and define supply chain disruptions as unplanned and unanticipated events that disrupt the normal flow of goods in a supply chain. Interviews and a brief literature study are performed to identify uncertain events in intermodal transportation. The purpose of this is to gain a deeper understanding of how events can impact the selection of transportation modes. Section 2.4.1 explains the low water levels. Container prices are described in Section 2.4.2. Third, Section 2.4.3 gives an explanation of infrastructure maintenance. Fourth and fifth, respectively new regulations (Section 2.4.4) and supply chain disruptions (Section 2.4.5) are described.

2.4.1 Low water levels

In the summer of 2022, the water levels in the Twente kanaal were very low, due to warm weather in combination with little rainfall. Because of the low water level, barge container ships could not anymore come to Twente. If this occurs, a modal shift should be made. Containers might then be transported to Twente by train or by truck from another inland container terminal. This also means that there will be a shift in volumes. An example of this was the container terminal in Almelo, where volume increased as a result of volume decreasing at other terminals. Due to climate change, the general expectation is that low water levels will occur more often in the future (NOS, 2022).

2.4.2 Container prices

Due to the covid-19 pandemic, container prizes increased to extremely high levels and afterward decreased to lower levels. This influences the whole supply chain, and so does the modal choice as well. The rapid increase in the global container freight rate index is shown in Figure 11.

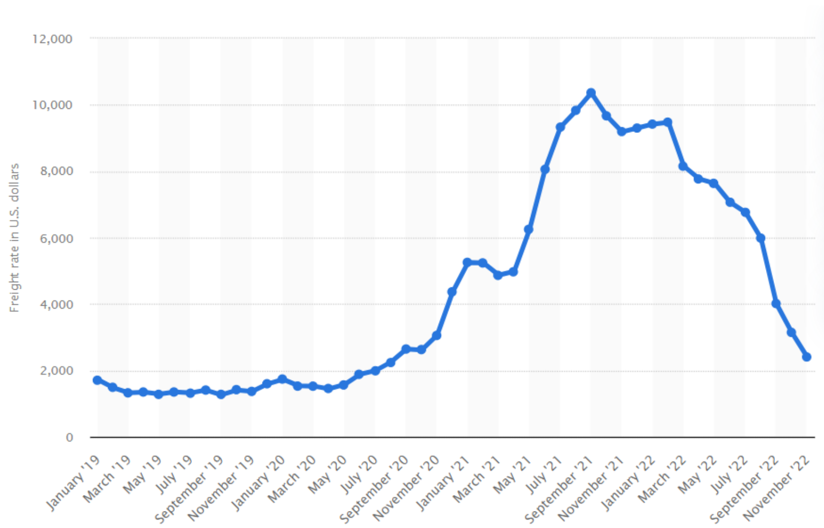

Figure 11: Global container freight rate index from January 2019 to November 2022 (Placek, 2022)

2.4.3 Maintenance infrastructure

Maintenance of the infrastructure is the next uncertain event. Due to low water levels in the river, locks and dikes need to be maintained. If maintenance occurs, inland waterway transport might be slowed down, and therefore a modal shift is required. On the other side, big infrastructure maintenance is planned around the port of Rotterdam, which will create extra congestion. Companies might consider a modal shift because of this.

2.4.4 New regulations

The European Union stated the ambition on reducing greenhouse gas emissions to at least 55% below 1990 levels by 2030. In order to gain this target, new regulations about emissions will come from governments. This influences the transportation sector a lot. Talking about intermodal transportation, new regulations by governments will have an influence. For example to make sure barges will get more environmentally friendly, as well as trucks. When new regulations will come has to do with political issues, and therefore the impact of the regulations is uncertain.

2.4.5 Supply chain disruptions

In general, bigger supply chain disruptions have an impact on intermodal transportation as well. Some examples of recent years are the Suez canal blockade, the war in Ukraine, the trading war between the United States and China, Brexit, and the Covid pandemic. These events have an impact on the global supply chain and bring uncertainty to the transportation chain, resulting in uncertain lead times.

2.5 Discussion and conclusion

In this chapter, we have answered the research question *'What is the current transport network offered by Bolk?'*. First, we described Bolk's current end-to-end logistics structure. The company is a shareholder of three container terminals in Hengelo, Almelo, and Rotterdam. Besides that, the company owns two warehouses, operated by Bolk Logistics, and the last-mile transportation is done by Bolk Transport. An overview is created and shown in Figure 6.

Second, insights into the intermodal transport network in the region around the company are given. We looked into the Netherlands and a closer look into east-Netherlands. Moreover, the intermodal transport solutions are explained. The three modalities road, rail, and inland waterway transportation are central to this research. A closer look into these types of transport is taken. On top of that, modal choice variables are explained which are important for companies in order to make a modality choice.

Lastly, uncertain events in intermodal transportation are explained. Low water levels, container prices, maintenance on infrastructure, new regulations, and supply chain disruptions are determined as uncertain events affecting the modal choice.

3 Literature review

A literature study is executed to find more insights into the concepts of intermodal transportation and geographical methods to map the modal choices. Moreover, methods are found how to maximize the geographic competitive position of Bolk. This chapter focuses on theories and methods related to concepts of intermodal transportation, intermodal logistics, transport systems, and pricing models. The following research question is answered in this chapter:

'Based on the literature review, what are applicable techniques and methods for mapping the geographic competitive position and maximizing it?'

As described in Chapter 1, the geographic competitive position is defined as the region in which Bolk's end-to-end logistics are the preferred choice of a customer compared to competitive alternatives. Moreover, maximizing is defined as making sure that the number of customers in the region around Bolk choosing Bolk's end-to-end logistics as their preferred choice is maximized. To get insights into relevant methods and theories a literature study is performed. Insights into intermodal transportation and logistics are provided in Section 3.1. After that, transport systems and how they are mapped are explained in Section 3.2. Last, optimization models and techniques are described which can be applied in the research. This is described in Section 3.3. This is all done by answering the following sub-questions:

- According to the literature, what are the key elements of intermodal freight transportation?
- What are relevant insights in applying hinterland logistics and end-to-end logistics?
- Which technique is suitable for mapping the geographic competitive position?
- Which optimization model or techniques can be used for maximizing the competitive position?

3.1 Intermodal transportation and logistics

Intermodal transport is defined as the combination of at least two modes of transport in a single transport chain, without a change of container for the goods. This intermodal transport may include various types of transport modes, such as rail/road or waterways/road combinations, using containers as loading units (Macharis et al., 2011). The main characteristic of intermodal freight transportation is the fact that the goods are moved in one loading unit or vehicle and are not handled when changing modes (Crainic et al., 2018). In this section, first the advantages and disadvantages of intermodal freight transportation are explained in Section 3.1.1. Next, the environmental sustainability of intermodal transportation is described in Section 3.1.2. Third, concepts of hinterland logistics and end-to-end logistics are respectively described in Sections 3.1.3 and 3.1.4.

3.1.1 Advantages and disadvantages of intermodal freight transportation

In this section, the advantages and disadvantages of intermodal freight transportation are explained. In 1995, the European Commission had already recognized the unsustainable growth of road transport and called for a significant modal shift (Reis, 2014). That is where intermodal transportation could play a crucial role. Intermodal transportation provides the flexibility to choose how goods will be transported. Moreover, the shipper has the opportunity to be creative in finding the most efficient way to move freight. According to Kubáňová et al. (2020), there are several advantages of intermodal transport. Firstly, it offers the advantage of a relatively low cost compared to other methods. Secondly, over long distances, it reduces truck driver capacity requirements. Moreover, the standardization of containers has permitted equipment to be designed anywhere in the world to support intermodal transportation. The standardization has also enabled possibilities for reduced handling, costs, and transit time. One of the most advantages and opportunities is that intermodal transportation increases the sustainability of the entire supply chain.

On the other hand, intermodal freight transportation gives also some disadvantages. The main disadvantage is the speed, any time cargo is transferred to a comparatively slower means of travel (Kubáňová et al., 2020). Take for instance trains, which operate on fixed rails that may not offer as direct routes as the roads a truck uses, it slows down. Another disadvantage is damage. The moment cargo has to be shuffled around, carriers risk the possibility of damage as the freight is transferred from one method of transportation to another. The third disadvantage is the high infrastructure costs. It is easy to shift a container from one mode of transport to the other one, but for doing so heavy-duty cranes and equipment are necessary to transship large containers. Moreover, the intermodal transits require heavy planning by shippers due to transit being slower than a typical truckload (McGuire, 2021). In this research, these advantages and disadvantages are taken into account.

3.1.2 Environmental sustainability

The European freight transport sector faces the challenge to catalyze economic growth by facilitating the increase in freight transport demand while retaining a sustainable transport system. Therefore, European hinterland freight transport policy over the past two decades has aimed at a modal shift towards sustainable modes such as rail, inland waterway, and sea transport (Zhang and Pel, 2016). The concerns related to the challenge of sustainable development have become increasingly important in freight logistics, with issues related to transport mode share and the internalization of transport external costs featuring strongly. Therefore, sustainable or green freight logistics systems are concerned with the movement of goods, taking into account the negative environmental and social impacts of operations (Iannone, 2012). According to del Mar Agamez-Arias and Moyano-Fuentes (2017), an intermodal system can minimize environmental impact by as much as 57% in terms of CO_2 emissions compared to a unimodal (haulage) system.

The European Commission sets the goal to reduce transport-related greenhouse gas emissions by 60% by 2050 compared to 1990 levels. An important objective of the commission, therefore, is to increase the share of intermodal rail and barge transport through efficient use of co-modality and moreover a 50% shift of freight from road to rail and to waterborne transport (Macharis et al., 2011), (Zhang et al., 2022).

According to ITF (2022), there are many environmental factors to consider when selecting mode choice to create sustainable supply chains, among others greenhouse gas emissions, local air pollution, and noise pollution. Inland waterway transport can be seen as an environmentally friendly modal choice. There are three widely accepted benefits of COB (Container on Barge). Firstly, transporting containers by barge can significantly reduce shipping costs because of the high fuel efficiency compared with truck or rail transportation, and therefore COB is more environmentally friendly compared with other transportation modes. Secondly, container on barge transportation can alleviate port congestion (Bu and Nachtmann, 2021). These insights into environmental sustainability within transportation are taken into account in the remainder of this research.

The question rises of what the best way to measure the environmental impact is. Zhang et al. (2022), measures environmental impact based on CO_2 pollution expressed per Twenty Equipment Unit (TEU), the widely addressed standard for a 20-foot container. The result is the unit $kgCO_2/km$ for each TEU. The Smart Freight Centre and a group of companies associations and programs formed the Global Logistics Emissions Council (GLEC) and together developed the first GLEC framework (GLEC, 2019). The GLEC framework provides boundaries for the emissions to be reported, based on methodologies that can be used (with or without adaption), considerations for the reporting process, and guidance on how to deliver the best output from the information available. The framework also shows users where they can improve calculations in order to reduce the uncertainty of results. The addressed measurement unit by the framework is $kgCO_2$ per kilometer for each TEU ($kgCO_2e/TEU$).

3.1.3 Hinterland logistics

In this research, containers are transported from a seaport to the hinterland or the other way around. In this section, a better understanding is created of the concept of hinterland logistics. Freight and load units arriving at seaports are composed of load units transshipped from other seaports and units to inland destinations, for example, the hinterland. The hinterland is defined as the effective market or the geo-economic space in which the seaport sells its services (Bergqvist and Egels-Zandén, 2012). The logistics related to the hinterland involve many actors and activities and require intense collaboration and coordination to work effectively and efficiently. Both rail and inland waterway transportation to the hinterland present some advantages in terms of decreased environmental impact, economies of scale, faster throughput in ports, and less delay related to road congestion. Maximizing hinterland effectiveness and efficiency in terms of cost, quality and environmental impact is a matter of finding the optimal mix of transport setups and modes (Bergqvist and Egels-Zandén, 2012).

The complexity of hinterland logistics, in combination with the quest for sustainable and cost-efficient services, highlights the importance of developing hinterland strategies that maximize the combined output in terms of environmental performance, cost-efficiency, and logistics quality (Bergqvist and Egels-Zandén, 2012).

3.1.4 End-to-end logistics

The term ‘end-to-end logistics’ describes a transportation process that encompasses the entire supply chain, depending on the business, it can already start with product design or with procurement, and then covers all related distribution and transport activities, through to delivery to the final customer (Time-Matters, nd). End-to-End logistics solutions, ranging from packaging, warehousing, and transportation to order fulfillment, help businesses improve supply network efficiency and performance (Allcargo, 2021). End-to-end logistics can have several advantages for businesses. Examples are helping to meet clients' needs, agility, cost savings, flexibility and scalability, faster product deliveries, and sustainability. Companies are using end-to-end logistics solutions that help them efficiently plan their transportation flow so that the movement of goods and products is hassle-free, without any blockages, and that also while maintaining environmental and economic sustainability (3scsolution, 2022). An example of an end-to-end logistics structure is shown in Figure 12. Concepts and theories about end-to-end logistics are very limited described in the literature.

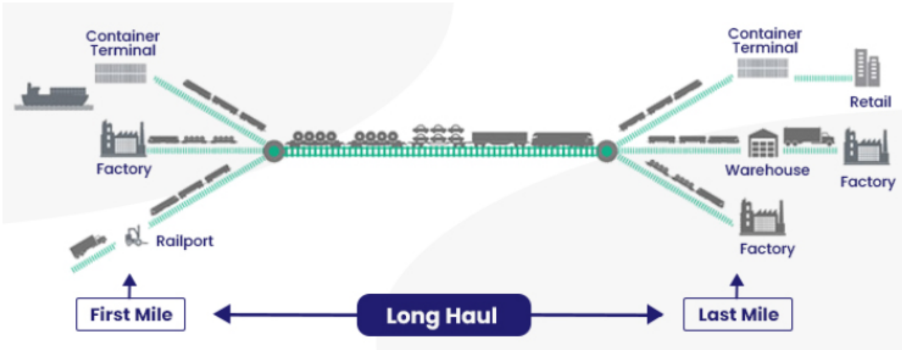

Figure 12: Overview of an end-to-end logistics structure (3scsolution, 2022)

3.2 Mapping the transport system

In this section, it is explained how a transport system can be mapped, and what should be taken into account for doing so. Section 3.2.1 describes the LAMBIT model. The concept of geographic information systems is explained in Section 3.2.2.

3.2.1 Geographic solutions

Meers and Macharis (2014) investigated if additional intermodal terminals are still desirable in Belgium. An allocation network problem has been used to find locations for new intermodal terminals. The developed model is called Location Analysis Model for Belgian Intermodal Terminals (LAMBIT). The model visualizes the market area of intermodal terminals, consisting of the municipalities for which the market price of intermodal transport is lower than the one of road-only transport. In the model, the main hail is performed by rail or barge, while the post-haul is done by truck. The LAMBIT is a network evaluation model that can estimate the impact of changes on transport costs, external costs, modal splits, and service areas, as opposed to network optimization models that try to design networks or services in order to optimize parameters (Monios and Bergqvist, 2017). In Figure 13, the output of the LAMBIT model on the Belgium case can be seen. Potential new places for container terminals are analyzed by making use of the model. The figure is interesting for our research since it shows geographically the area served by a certain container terminal. This might be applied in the context of Bolk as well.

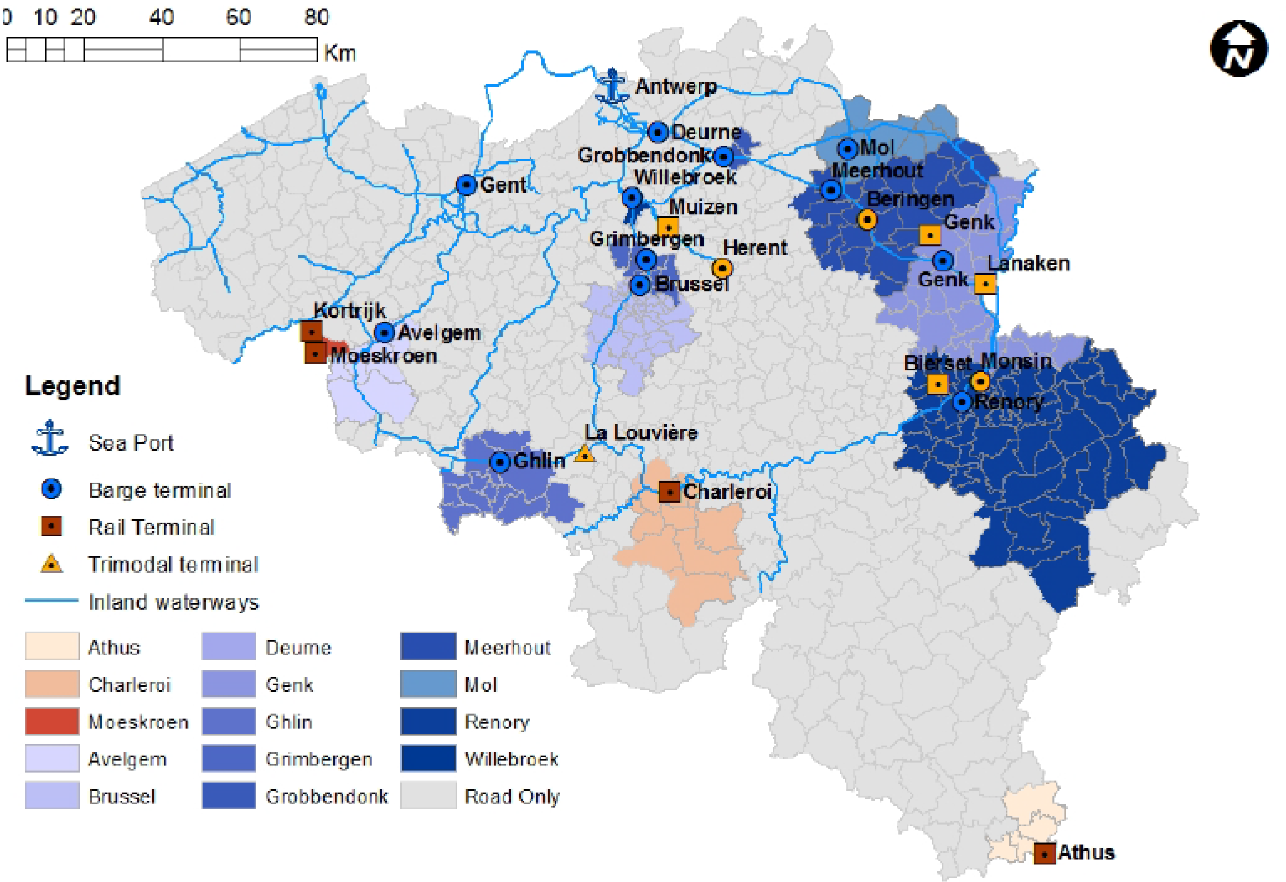

Figure 13: Output of the LAMBIT model on the Belgium case from Meers and Macharis (2014).

In addition to the research of Meers and Macharis (2014), Meers and Macharis (2015) investigated how to determine a region's most suitable freight flows. The so-called LAMBIT model has been used again. The LAMBIT model calculates the cheapest transport alternatives based on the cheapest path algorithm. The paper tackles the research problem of identifying a region's most promising freight flows for modal shift to intermodal transport services. Estimating the modal shift potential of a certain region was the goal of the research. The LAMBIT uses three types of input parameters for simulations of intermodal transport systems. The first input is the transport demand in terms of the goods flows in the studied region. This is translated into an origin-destination matrix. Transport network layers are a second component of the model. The third input is unimodal and intermodal cost functions. To conclude, the methodology facilitates inclusion of all relevant transport modes and transshipment locations for a large-scale study area (Monios and Bergqvist, 2017).

3.2.2 GIS

A geographic information system (GIS) is a computer system for storing, capturing, checking, and displaying data related to positions on Earth's surface (Geographic, nd). GIS technology has begun to play a central role in understanding new freight technologies and new transportation infrastructures. By supporting the mapping of freight movements onto specific transportation routes and through specific transfer terminals, GIS offers cost-effective tools for manipulating a wide range of data on both the spatial and non-spatial aspects of commodity transportation logistics (Southworth and Peterson, 2000). The focus of GIS-based models is mainly the interface of strategic and tactical decisions concerning the infrastructure network evaluation (Monios and Bergqvist, 2017).

3.3 Maximizing competitive position

As explained in Section 2.3, there are many parameters influencing the transport modal choice. Each customer will assign different weights to the parameters. For one, price is most important, and for others sustainable issues. Some parameters are variable and can be influenced by Bolk. By varying the values of the parameters, potentially more companies will accept the services of Bolk. Since price is most important, methods are searched in which price can be influenced. In this section, a closer look is made into theories and methods related to the context of maximizing the competitive position of Bolk. First, the concept of the probabilistic port hinterland is described to sketch a view of the geographical span of customers around a port. This is described in Section

3.3.1. Next, in Section 3.3.2, the logistic chain model is provided. Third, a revenue management model is explained in Section 3.3.3. Last, the concept of logit models is provided in Section 3.3.4.

3.3.1 Probabilistic port hinterland

Wang et al. (2016) did research on a port's hinterland. They defined that the probabilistic port hinterland is a key performance index that reflects the attractiveness and competitiveness of a port, which is determined by a shipper's decision of whether to choose a route passing through a port. Wang et al. (2016) developed a generalized model of probabilistic port hinterland with free distributions of route utilities, estimating boundaries of a port of interest with network effects, and proving theoretical results about the quality of the sample approximation of shippers' choice probabilities. The authors studied the probabilistic hinterland of a port of interest based on transportation flows in an intermodal network. The work introduced a competitiveness index to look into a port's competitiveness from a geographical point of view. A probability distribution, where parameters $\alpha_1, \alpha_2 \in [0, 1]$, that shippers will use that port to transport their containers to a given destination is referred to as the port's probabilistic hinterland. A random utility of an intermodal route is defined as a summation of transportation cost and transport time multiplied by the Value Of Time (VOT) perceived by shippers.

In the research of Wang et al. (2016), a Monte Carlo simulation is proposed for finding the probabilistic port hinterland. The port hinterlands are represented as a series of areas each indicating a range of probabilities that a shipper will select the port. The method is interesting for our research because it addresses the probability a customer will choose a certain service. The higher the probability of acceptance, the more the competitive position will be maximized, working with probabilities is realistic, since every company will have its own opinion about a certain offer. The main limitation of the research of Wang et al. (2016) related to our research is the fact it is applied in a broader context with ports around a whole country, instead of an inland terminal serving a limited set of customers.

3.3.2 Logistic chain

de Jong and Ben-Akiva (2007) developed a logistics model and its application within national freight model systems. The logistics model operates at the level of individual firm-to-firm (send-to-receiver) relations and simulates the choice of shipment size and transport chain. The logistics model with deterministic cost minimization has been constructed. This is done within the logistic chain which is shown in Figure 14. The logistics chain consists of a chain of modes and transshipment locations and is denoted as l. The logistics chain is then written as a series of mode-transshipment location points, one for each leg of the chain, with the last being a mode-receiver location pair. A leg in the chain is a section of a journey. A logistics chain consists therefore of multiple legs and can be described as $l = \{(h_1, t_1), (h_2, t_2), ..., (h_n, n)\}$, in which h represents the mode, vehicle type or loading unit and t the transshipment location. The constructed model of a multimodal transportation system allows for calculating total costs for freight transportation and total delivery time over considered routes. The received results allow choosing the most favorable route for which the indicator of the system's efficiency has the optimal value (de Jong and Ben-Akiva, 2007). The remainder of the paper focuses on calculating the logistics cost function. The researchers describe that the model can be used if the following data is known:

- Data on individual shipments: sector of sender and receiver, origin and destination, the value of the goods.
- Data on where the freight terminals, consolidation and distribution centers and ports are located.
- Data on transport and logistics costs.

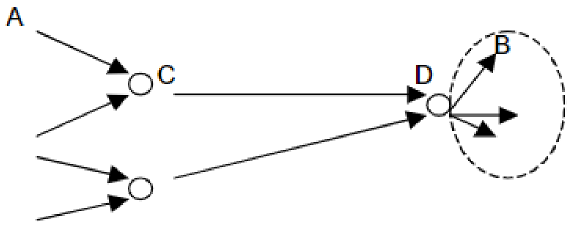

Figure 14: The shipment of goods from location A to B is consolidated at C and distributed at D (de Jong and Ben-Akiva, 2007).

3.3.3 Revenue management in transportation and logistics

In general, revenue management is concerned with demand-management decisions and can be of three basic types: structural decisions, pricing decisions and quantity decisions (Van Riessen et al., 2021). Moreover, revenue management refers to the strategies and tactics that companies use to scientifically manage demand for their products and services (Snoeck et al., 2020). Bilegan et al. (2022) did research in intermodal barge transportation. The objective of the research was to study the integration of revenue management considerations into service network design models targeting the tactical planning of intermodal consolidation-based freight transportation carriers. The authors proposed a scheduled service network design revenue management (SSND-RM) method, which targets the challenging issue of the interactions between the planning of the carrier's services and operations, on the one hand, and the revenue-management strategy it could implement, on the other hand. Combining revenue management in the context of intermodal barge transportation is interesting for our research. In the revenue management part, customer demands set are taken into account, as regular customer demands, partial-sport customer demands and full-spot customer demands. The limitation of the research is the fact that it is applied on a tactical level, by making use of schedules.

Beresford et al. (2021) performed a critical review of a holistic model used for assessing multimodal transport systems. They defined freight transport as the fundamental aspect of balancing time and space and reducing unit costs. The longer the transport distance, the more complex the solutions become, and trading protocols involving cargo owners, facilitators, and transporters need to be regularly reviewed in order to adjust to technological developments and global trading dynamics. The multimodal transport/cost/time model that has been analyzed is constructed by the United Nations Development Programme. The authors defined that over medium to long hauls modal combinations can be varied and complex. In these cases, elements such as cost, convenience, capacity, reliability, and practicality are considered together in a series of trade-offs; the door-to-door benefits of road haulage are thus compared with the qualities of a range of possible multimodal transport solutions. The traditional underlying principles for determining the roles of transport modes are the balance of fixed and variable costs, modal characteristics, and economies of scale. The authors stated that for making a cost/time distance model, the aim is to create a supply chain, which balances cost and customer satisfaction during the transportation process within a global market. The customer's willingness to pay is a good indicator for doing so. The model presented in the paper can be used as an analytical tool of transport operations. Second, it can inform transport and logistics operators regarding tactics for choosing, for example, least risk or maximum gain logistics solutions. Finally, the model enables policymakers to develop strategies.

3.3.4 Logit models

Monios and Bergqvist (2017) described modeling of intermodal systems and operations research in intermodal transport. Monios and Bergqvist (2017) explained that the common method for the modal split in intermodal transportation is the logit model. Logit models are based on a random utility function that shows how much a certain alternative is worth to a decision-maker. The model consists of a number of exhaustive and mutually exclusive options, that is the decision-maker must choose only one of the options. Each option has a certain utility value, which is a number representing how valuable the option is for the decision-maker. The decision maker is assumed to choose the option with the highest utility value. In real life, it is impossible to perfectly predict the decision maker's choice as it is impossible to perfectly measure the preferences of the decision maker and all possible attributes of the option. The unobservable components are included as random components in the model to represent the measurement errors. Equation (1) represents the mathematical formulation of the utility function in which $U_{t,q}$ is the utility of an alternative t to an individual q. It consists of a deterministic component V and a random component ε. By using this, the likelihood that a certain option is selected can be calculated.

$$U_{t,q} = V_{t,q} + \varepsilon_{t,q} \tag{1}$$

Sometimes a more realistic representation of the modal choice is to make the choice in steps. A logit model that allows for this is called a nested logit model, where choices with the same attributes are put in a 'nest'. An example of this can be seen in Figure 15. Al-Salih and Esztergár-Kiss (2021) applied linked mode choice with travel behavior by using a logit model based on the utility function. The authors used the same utility function as described in Equation (1), and described the function of the deterministic component V as follows:

$$V_{s,i} = \beta_1 S_{i,1} + \beta_2 S_{i,2} + ... + \beta_k S_{i,k} \tag{2}$$

where:
V_{si} = the value of the utility function of mode choice by the customer,
S_{ik} = the mode choice i by customer, which includes the modal choices

β_k = the coefficient of the independent variable or variables associated with the alternatives that describe individual characteristics in addition to trip characteristics.

The authors also described the difference between multinomial logit models (MNL) and nested logit models, as described by Monios and Bergqvist (2017) and shown in Figure 15. The mathematical structure known as the MNL gives the choice probabilities of each alternative as a function of the systematic portion of the utility of all the alternatives. The general equation for the probability of choosing an alternative 'i' from a set of J alternatives is shown in Equation (3).

$$Pr_i = \frac{exp(V_{in})}{\sum_{i=1}^{J} exp(V_{in})} \tag{3}$$

where:
Pr_i = probability of utility for a mode choice (n) by the customer choosing alternative (i)
V_{in} = the utility systematic component for a mode choice (n) by the customer choosing alternative (i)
V_J = is the systematic component of the utility of the set alternative (j)

The nested logit model is a generalization of the multinomial logit model and it characterizes a partial relaxation of the independence of irrelevant alternatives property of the MNL model. In this case, the probability function is different and is described in Equation 4.

$$Pr_i = \frac{e^{\beta} S_{j,i}}{\sum_{i=1}^{J} e^{\beta} S_{J,i}} \tag{4}$$

where:
Pr_i = probability that customer i chooses alternative j
β' = vector of all estimable coefficients for alternative j
$S_{J,i}$ = vector of all explanatory variables for customer i

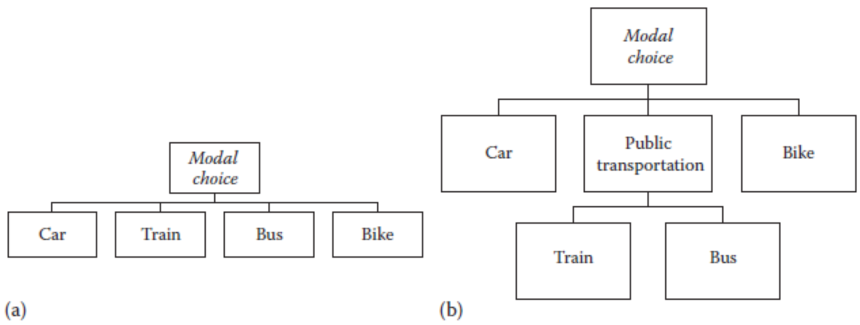

Figure 15: Logit models. (a) Multinomial logit model. (b) Nested logit model (Monios and Bergqvist, 2017).

3.4 Conclusions on literature

In this chapter, we researched the literature to get a good understanding of intermodal transport networks, and especially how to map the network. First, we found insights into intermodal transportation by describing the advantages and disadvantages, including environmental sustainability and how to calculate sustainability performance. Given the commonly used GLEC method, we decided to calculate sustainability performance in $kgCO_2e/TEU$ by using the framework. Second, the theory about intermodal logistics is given to understand end-to-end logistics better. We conclude that the theory is very limited, and therefore the focus is more on the transportation network instead of end-to-end logistics. Therefore, third, intermodal transport systems are described. We found that there are three levels and that they should be mapped. To do so, we selected elements of the LAMBIT model to map the geographic competitive region of Bolk. As the LAMBIT model does this by using a geographic information system, we selected to do so as well.

In the literature, we have seen just limited applicable methods for optimizing Bolk's competitive region. We decided to use insights from the probabilistic port hinterland model by Wang et al. (2016) for the optimization model. The probability theory about accepting a port's offer can be applied to the concept of the research. The logistic chain model by de Jong and Ben-Akiva (2007) looked promising in the concept of end-to-end logistics, but is mostly focused on calculating the total delivery time over considered routes. Because our research is on a strategic level, detailed calculations about delivery time are not necessary, that is more the case for operational models.

Since we want to maximize Bolk's competitive position, we can fluctuate in the prices offered to a customer. Insights into the revenue management model by Bilegan et al. (2022) applied in the context of freight transportation can be applied to our research as well. The optimization model concentrates on maximizing revenue. Revenue is only created by customers that choose the services of the company. We selected to take the maximized revenue by customers that accept Bolk's offer as an objective based on the research on Bilegan et al. (2022).

Lastly, details for modeling intermodal systems are described by explaining the model of Al-Salih and Esztergár-Kiss (2021). The theory applied in the logit model looks appropriate to be applied in the research since it takes the probability of accepting into account. In order to do so, Al-Salih and Esztergár-Kiss (2021) explained that data about customer behavior is required in order to calculate the right value of the utility function. Unfortunately, this data is not known and is complex to obtain since it requires the individual behavior of a large set of companies. Nevertheless, we decided to approach the different modal choices as approached in the multinomial logit model by Al-Salih and Esztergár-Kiss (2021), as shown in Figure 15.

To summarize, we conclude that the best solution approach for the case at Bolk will be formulating an optimization model based on the described concepts from the probabilistic port hinterland model, taking into account revenue management, using a multiple-criteria analysis approach and insights from the multinomial logit model.

4 Bolk's competitive position

In this section, Bolk's competitive position is mapped, based on the existing intermodal transport network and fixed parameters. By doing so, the following research question is answered in this chapter.

How can Bolk's competitive position be geographically mapped?

This is done by answering the following sub-questions:

- How can the basic model be formulated?
- What input data is required and available?
- What conclusions can be made from the mapping?

As concluded in Chapter 3, insights from literature are taken into account as a basis for this chapter. Parameters that are taken into account in order to map the competitive position are based on practical insights and theoretical concepts from Bergqvist and Egels-Zandén (2012). These are price, emissions and time. The LAMBIT model designed by Meers and Macharis (2014) is taken as a basis for mapping the different transportation solutions. First, the general model is given and explained in Section 4.1. The input data required for the model in the situation of Bolk is described in Section 4.2. How the model is used is provided in Section 4.3. Last, the conclusion of the chapter is given in Section 4.5.

4.1 Model

In this section, the model is explained. We start in Section 4.1.1 with a model outline, in which the purpose and steps of the model are described. The assumptions made for formulating the model are explained in Section 4.1.2. Section 4.1.3, 4.1.4, 4.1.5, and 4.1.6 explain respectively the parts of the model: sets, parameters, variables, constraints, and objectives. The explanation of the model in more detail is provided in Section 4.1.7.

4.1.1 Model outline

The model is based on elements used by Meers and Macharis (2014). The elements which are taken into account are ports, barge, and rail terminals. By using the model, different transportation options in the region can be compared. For making a comparison between transport options, the road network, rail network, inland waterways and final haulage network are used in the model, according to the LAMBIT model designed by Meers and Macharis (2014).

The aim of the model is to be able to compare the transport by Bolk for each customer with the best alternative, and in case Bolk is not the best option to be able to compare the best option with Bolk. It is therefore called a comparison model. It is simplified, with limited constraints. In the next chapter, a more extensive optimization model is provided, based on the insights of this chapter. In the model, zip codes are defined as potential customers. Moreover, sets, parameters, variables, and multiple objectives are defined, based on constraints. We made the decision to focus on the comparison based on price of transportation, emissions caught by the transport option, and transit time. This is done, because these are the main parameters that can be measured by Bolk and for the competitors by making assumptions. The model is described in the remaining sections of this chapter and is based on transporting a TEU from a seaport to the final customer.

The model is applied for each customer. In other words, for each customer, the defined transport solutions are calculated and compared with Bolk's option. The model is formulated.

4.1.2 Assumptions

Several assumptions are made in the implementation of this basic calculation model in order to map the geographic competitive position of the company:

- Around the region of Bolk, zip codes of the corresponding places are defined as potential customers in the model.
- The model is based on one TEU transported from a deepsea port to the end customer. Volume and weight are not taken into account in the model, to reduce the complexity of the model.
- Time of transshipment at a terminal has not been taken into account. This data is unknown.
- The size of an inland terminal is not taken into account, so all the terminals are assumed to be equal in size.

- The availability of the terminals have not been taken into account since this competitive information is not known.
- The transit time starts the moment a container is moved from a seaport to the end-customer. In the case of the ports of Hamburg and Bremen, most of the time the vessel bringing the containers has first arrived in the port of Rotterdam. This extra transit time between Rotterdam to Bremen/Hamburg has not been taken into account in the model, due to complexity.
- It is assumed that all competitive terminals do have the same price and emissions for each transport option compared to other terminals. So the price per kilometer per container for barge transport for one terminal is equal to another terminal.
- Reliability of a transport mode is not taken into account. Due to unknown data.

4.1.3 Sets

The following sets are defined.

$\mathcal{C}$	Set of all customers
$\mathcal{P}$	Set of all ports
$\mathcal{B}$	Set of all barge terminals
$\mathcal{R}$	Set of all rail terminals
$\mathcal{M}$	Set of all modalities

4.1.4 Parameters

In the comparison model, costs, emissions distances and time are defined as parameters.

Price

P_t	Price truck per km in euros
P_b	Price barge per km in euros
P_r	Price rail per km in euros
P_{Start}	Price basic fare using road transport

Emissions

E_t	Emissions truck per km in kg CO_2
E_b	Emissions barge per km in kg CO_2
E_r	Emissions rail per km in kg CO_2
E_{trans}	Emissions transshipment at inland terminal in kg CO_2

Distances

$D_{p,c}$	Distance port p to customer c in km
$D_{r,c}$	Distance rail terminal r to customer c in km
$D_{b,c}$	Distance barge terminal b to customer c in km
$D_{p,r}$	Distance port p to rail terminal r in km
$D_{p,b}$	Distance port p to barge terminal b in km

Time

$T_{p,b}$	Time port p to barge terminal b in minutes
$T_{p,r}$	Time port p to rail terminal r in minutes
T_{Truck}	Time truck per km in minutes

4.1.5 Variables and constraint

Since this basic start model is a simple comparison model, the model will not determine a decision variable based on the objective and multiple constraints. The model determines the best transportation option for each of the potential customers, based on the defined objective, by comparing different transportation options. To keep a formal formulation of this comparison model, we defined a variable and a constraint, which are requirements for making the comparison. $M_{c,m}$, formulated in Equation (5), represents a binary variable whether a customer will use a modality or not. It will use the modality if it is the best option. This is explained in the next section. Besides that, corresponding to this variable one constraint is formulated, as can be seen in Equation (6). This constraint makes sure that each customer chooses one modality, so either truck, barge, or rail transport.

$$M_{c,m} = \begin{cases} 1, & \text{if customer } c \text{ uses modality } m,\ c \in \mathcal{C},\ m \in \mathcal{M} \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

$$\sum_{m \in \mathcal{M}} M_{c,m} = 1 \quad \forall\, c \in \mathcal{C} \tag{6}$$

4.1.6 Objective

The objective is for each customer to calculate the transportation option with the minimum price paid by the customer, emissions caused by transportation, or transit time. It is decided to take these objectives separately in this first simplified model. By doing this, insights are created for the company on the competitive position for each of the objectives separately. Price is expressed in euros, emissions in kg CO_2, and time in minutes. In all three objectives, the goal is to minimize. Equation (7) expresses the minimization of the price, Equation (8) emissions, and Equation (9) the transit time.

$$Min\ Price\Big(\underbrace{M_{c,t} \cdot (D_{p,c} \cdot P_t + P_{Start})}_{\text{(Road)}} + \underbrace{M_{c,b} \cdot (D_{p,b} \cdot P_b + D_{b,c} \cdot P_t)}_{\text{(Barge)}} + \underbrace{M_{c,r} \cdot (D_{p,r} \cdot P_r + D_{r,c} \cdot P_t)}_{\text{(Rail)}}\Big)\ \forall\, c \in \mathcal{C} \tag{7}$$

$$Min\ Emissions\Big(\underbrace{M_{c,t} \cdot (D_{p,c} \cdot E_t)}_{\text{(Road)}} + \underbrace{M_{c,b} \cdot (D_{p,b} \cdot E_b + D_{b,c} \cdot E_t)}_{\text{(Barge)}} + \underbrace{M_{c,r} \cdot (D_{p,r} \cdot E_r + D_{r,c} \cdot E_t)}_{\text{(Rail)}}\Big)\ \forall\, c \in \mathcal{C} \tag{8}$$

$$Min\ Transit\ Time\Big(\underbrace{M_{c,t} \cdot (D_{p,c} \cdot T_t)}_{\text{(Road)}} + \underbrace{M_{c,b} \cdot (T_{p,b} + D_{b,c} \cdot T_t)}_{\text{(Barge)}} + \underbrace{M_{c,r} \cdot (T_{p,r} + D_{r,c} \cdot T_t)}_{\text{(Rail)}}\Big)\ \forall\, c \in \mathcal{C} \tag{9}$$

4.1.7 Explanation of the model

The above-described model is a simplified comparison model in which for each customer the best transport option is selected. The user of the model can define what the best option is by themselves. This can be based on price, emissions, or transit times. The decision variable is the modality used for each customer. As explained, the options are road, barge, or rail transport. The option of Bolk is within barge transport via the barge terminals Almelo or Hengelo. If barge or rail transport is selected, the transportation from the deep-sea port to the inland terminal is done by either barge or train and from the inland terminal to the customer is done by truck. This can be seen in Formulas (7), in which the price for each modality is calculated. In the formula, the price for road, barge, and rail transport can be seen, as indicated by the under brackets. For road transport $M_{c,t}$ is only multiplied by the distances. In the case of other modalities, first, the distance between a port to an inland terminal is multiplied by the price factor of the modality. Second, the last-mile distance by truck is multiplied by the price factor for road transport. This same construction is used for calculating the emissions and transit time, by using respectively the emission and time factors. By using the binary variable $M_{c,m}$, price, emissions, and transit time are multiplied by zero in case a modality is not used.

The model is used for each customer. The result is a selected modality for the customer with corresponding costs, emissions, or transit time. $M_{c,m}$ equals one if a modality has the lowest outcome compared to the other modalities. So in the case of the price, if for a certain customer road transport will cost 500 euros, barge transport 450 and rail transport 480, $M_{c,Road} = 0$, $M_{c,Barge} = 1$, and $M_{c,Rail} = 0$. The model is solved by calculating the options for each customer in *python*. In case one of the modalities has the lowest KPI, a value of one is assigned to the modality.

4.2 Input data

As input data for the model, ports, barge terminals, train terminals, and a set of customers' locations are selected. Moreover, values to the parameters are assigned. In this section, the selected input data is explained. For the model, locations of deep-sea ports, inland waterway terminals, and inland rail terminals are required. The locations are explained in Section 4.2.1.

4.2.1 Locations

In this section, the selected ports, barge terminals, rail terminals and set of customers are explained. In total nine barge terminals, two rail terminals, and three deep-sea ports are selected to take into account in the model. An overview is created with the geographic location of the terminals, and is shown in Figure 16.

Figure 16: Selected ports (Black), barge terminals (Purple), Bolk Terminals (Blue) and rail terminals (Pink)

Ports
Four deep-sea ports are selected: Rotterdam (NL), Antwerp (BE), Bremen and Hamburg (GER). These are the four main ports around northwest Europe and the terminals in which containers from the whole world can arrive.

Barge terminals
Nine inland container terminals where barges can arrive are selected. These terminals are located in the following places: Almelo, Hengelo, Meppel, Emmerich, Doesburg, Nijmegen, Groningen, Kampen, and Dörpen. These terminals are around Bolk's facilities in the north and east part of the Netherlands, and across the border with Germany, as can be seen in Figure 7 in Section 2.2.1. All the barge terminals are connected via inland waterways to the port of Rotterdam. The port of Antwerp can also be reached by the inland terminals, but the connection will also be via the port of Rotterdam. Therefore the direct connection of Antwerp to the inland terminals is not taken into consideration.

Rail terminals
Two rail terminals are selected to be taken into account in the model: Duisburg and Osnabrück. Both terminals are located in Germany and are closest to Bolk's facilities, compared to other rail terminals. The ports of Rotterdam and Hamburg have direct train connections to Duisburg. The port of Hamburg and Bremen have direct connections to both Duisburg and Osnabrück.

Customers
Zip codes of the Dutch provinces 'Gelderland', 'Overijssel', and 'Drenthe' are taken in the model. Moreover, zip codes ('Kreiscode' in German) are taken from the following 'Kreise' (sub-province in Germany): Borken, Coesfeld, Kleve, Recklinghausen, Steinfurt, Warendorf, Wesel, Stadt Münster, Emsland, Grafschaft Bentheim and Osnabrück. The selected region can be seen in Figure 17. In total 1276 zip codes are taken into account in

the model.

Figure 17: Selected zip codes around Bolk's facilities, Dutch zip codes (Grey), German (White).

4.2.2 Routes

In this section, the routes are described. Routes are made using the three modalities, truck, barge, and train. A truck can go directly from the deep-sea port to the end customer. A barge and a train need an inland container terminal to make a transshipment to road transport in order to reach the customer.

Truck
Six routes are defined from a deep-sea port to the customer:

Rotterdam	- Customer
Antwerp	- Customer
Hamburg	- Customer
Bremen	- Customer

Barge
Nine route options are defined for transport via inland waterways. The transport from the inland barge terminal to the end customer is done by truck.

Rotterdam	- Almelo	- Customer
Rotterdam	- Hengelo	- Customer
Rotterdam	- Meppel	- Customer
Rotterdam	- Emmerich	- Customer
Rotterdam	- Doesburg	- Customer
Rotterdam	- Nijmegen	- Customer
Rotterdam	- Kampen	- Customer
Rotterdam	- Groningen	- Customer
Bremen	- Dörpen	- Customer

Train
Four routes are defined for transport via rail. Rail terminals Osnabrück and Duisburg are selected, based on these terminals the following routes can be made from port to customer:

Rotterdam	- Duisburg	- Customer
Hamburg	- Osnabrück	- Customer
Hamburg	- Duisburg	- Customer
Bremen	- Duisburg	- Customer
Bremen	- Osnabrück	- Customer
Antwerp	- Duisburg	- Customer

4.2.3 Distances

Distances for each route are calculated. In transportation-related discussions, it is important to account for distances that encompass road, waterway, and rail networks, rather than relying on straight-line distances. For all the road options, distances are calculated by using *Bing maps*. An application programming interface (API) key has been implemented in *Python* to calculate all the different routes via road. The shortest distance is saved as the distance between points A to B. By using the API code, the accessibility of a customer by highway and normal roads can be taken into account. This provides a realistic view of the distance from A to B. For both inland waterway transport and rail transport distances are taken from *Routescanner* (Routescanner, 2023). This application calculates distances for waterway and rail transport, and with permission from that company, distances are used in this thesis. The distances can be seen in Table 1.

Table 1: Distances from ports to inland terminals

Port	Inland terminal	Distance (km)
Rotterdam	Almelo [Barge]	212
Rotterdam	Hengelo [Barge]	217
Rotterdam	Meppel [Barge]	197
Rotterdam	Emmerich [Barge]	144
Rotterdam	Doesburg [Barge]	141
Rotterdam	Nijmegen [Barge]	110
Rotterdam	Kampen [Barge]	173
Rotterdam	Groningen Westerbroek [Barge]	318
Bremen	Dörpen [Barge]	177
Rotterdam	Duisburg [Train]	216
Hamburg	Osnabrück [Train]	223
Hamburg	Duisburg [Train]	336
Antwerp	Duisburg [Train]	245

4.2.4 Emissions

For each transportation option, emissions are taken into account. As described the emissions are expressed as $kgCO_2e/TEU$. Since all modalities should be compared with each other in a fair way, general emission ratios are taken into account in the model. The values are calculated by *Routescanner* using the GLEC model (Routescanner, 2023)(GLEC, 2019). It can be seen that the emissions caused by a transshipment are quite high. This is because huge cranes are used at inland terminals, to be able to tranship a container from a vessel or train to a truck. Most of the times, these cranes run on diesel.

- E_b: 260 $gCO_2e/TEU\ per\ km$
- E_r: 170 $gCO_2e/TEU\ per\ km$
- E_t: 750 $gCO_2e/TEU\ per\ km$
- E_{trans}: 38 $kgCO_2e/TEU$

4.2.5 Transit times

Transit times for each route are calculated. Transit times for barge and train transportation are depended on available ships and trains on the route. Using public data from *Routescanner* transit times between the ports and terminals are shown in Table 2. For road and last-mile transport, an average speed of 65 km/h is used. This number is determined by expert opinion within Bolk Transport.

Table 2: Transit times from ports to inland terminals

Port	Inland Terminal	Transit time (hours)
Rotterdam	Almelo [Barge]	20
Rotterdam	Hengelo [Barge]	20
Rotterdam	Meppel [Barge]	15
Rotterdam	Emmerich [Barge]	15
Rotterdam	Doesburg [Barge]	15
Rotterdam	Nijmegen [Barge]	12
Rotterdam	Kampen [Barge]	15
Rotterdam	Groningen Westerbroek [Barge]	32
Bremen	Dörpen [Barge]	24
Rotterdam	Duisburg [Train]	4
Hamburg	Osnabrück [Train]	18*
Hamburg	Duisburg [Train]	5
Antwerp	Duisburg [Train]	4

* Transit times between Hamburg and Osnabrück vary a lot. The most common time is around 18 hours, although a relatively short distance.

4.2.6 Price parameters

Price parameters were difficult to estimate since exact price indications from competitors are unknown. Therefore together with stakeholders it is determined to use general prices, based on the price indication of Bolk. For rail transport, the price indication was very hard, since it varies a lot. After different meetings with stakeholders, rail terminals, and rail operators, it is assumed that rail transport has the same price as barge transport. In Table 3, the price indicated for each of the modalities can be seen. In the table, it can be seen that there is a basic fare for using road transport. This value is assigned to create a more realistic view of road transport. In case only a price parameter is used, the model will assign a very low price for a customer who is located close to a terminal, while in practice the price is higher, since the truck driver needs to be paid and there is some time involved in handling the container at the customer's location. Therefore, a basic fare for road transport is used in the model.

Table 3: Price parameters used for each modality (values are manipulated due to confidential issues)

Transport mode	Price
Road	€6.80/Km
Barge	€5.57/Km
Rail	€5.57/Km
Basic fare road transport	€324

4.3 Comparing Bolk's option

Together with the stakeholders, it is decided to integrate the model using the programming language *Python*. As described, in total around 1276 zip codes are used around the region of the facilities of Bolk. For each of the zip codes (further referred to as customer), the best truck, barge, and train options are calculated based on the defined objective. To calculate the best option for each of the modalities, for each customer all the possible transport options are compared for certain modalities. In case of a customer searching for the best road transport option, price, emissions, and time are calculated for transporting one TEU from the port of Rotterdam, Antwerp, Bremen and Hamburg to the customer. For the lowest objective score, the corresponding route is stored. After that, the three modalities are compared to each other and the best modality for the customer is selected. To map Bolk's competitive position, the best modality option per customer is compared to Bolk's option. As previously explained, Bolk's option is container transport from Rotterdam to either Almelo or Hengelo and last-mile delivery by truck. In the model this represents $M_{c,Almelo}$ and $M_{c,Hengelo}$. Bolk's option is compared to the best competing transport via a competitor's terminal or directly from a seaport.

A score is assigned by using Formula (10). In case Bolk option is not the best, the equation will give a negative score. This means that another route, not via Bolk, is better. In case the best transportation option for a customer is Bolk, Formula (11) is used. In the formula, the best transport alternative is compared to the option of Bolk. In this case, all the customers will have a score compared to Bolk's option.

$$Comparison\ score = \frac{Best\ option - Bolk\ option}{Bolk\ option} * 100\% \qquad (10)$$

$$Comparison\ score = \frac{Best\ alternative - Bolk\ option}{Bolk\ option} * 100\% \tag{11}$$

4.3.1 Mapping

According to Meers and Macharis (2014), GIS software should be used in order to map results. For each of the zip codes a score has been assigned. The zip codes with the corresponding score are mapped using GIS software applied in the program *Tableau*. Together with the stakeholders it is determined to use *Tableau*, since it shows clearly the map with corresponding scores. Examples of the layout of the mapping are shown in Figure 16 and 17.

4.4 Results

In this section, the results of the comparison model are described. First, the mapping based on transit time is explained in Section 4.4.1. Second, price in 4.4.2 and emissions in 4.4.3. Moreover, an overview is created of the different zones of each modality, this is further explained in Section 4.4.4.

*In this public version, confidential visualizations are left out, and text is adapted to still understand the approach and results.

4.4.1 Transit Time

The first map, based on transit time is shown in Figure 18. Speaking about transit times and intermodal transportation, in most situations the conclusion can be made that transport by road will always be the fastest transport option. Rail becomes a fast mode of transportation only when the distances to be covered extend over longer stretches. In the defined scope in this research, that is not the case, resulting in the fact that road transport will always be the fastest. Four different regions can be seen in Figure 18. The white region represents the shortest transit time by truck from a deep-sea port to the end customer. The most dark red region is the area in which the transit time is the highest. This is also the region in which Bolk's terminals are located. The conclusion can be made that the most dark red region is also the most interesting for using intermodal transportation solutions since direct trucking will take a long time to reach the port.

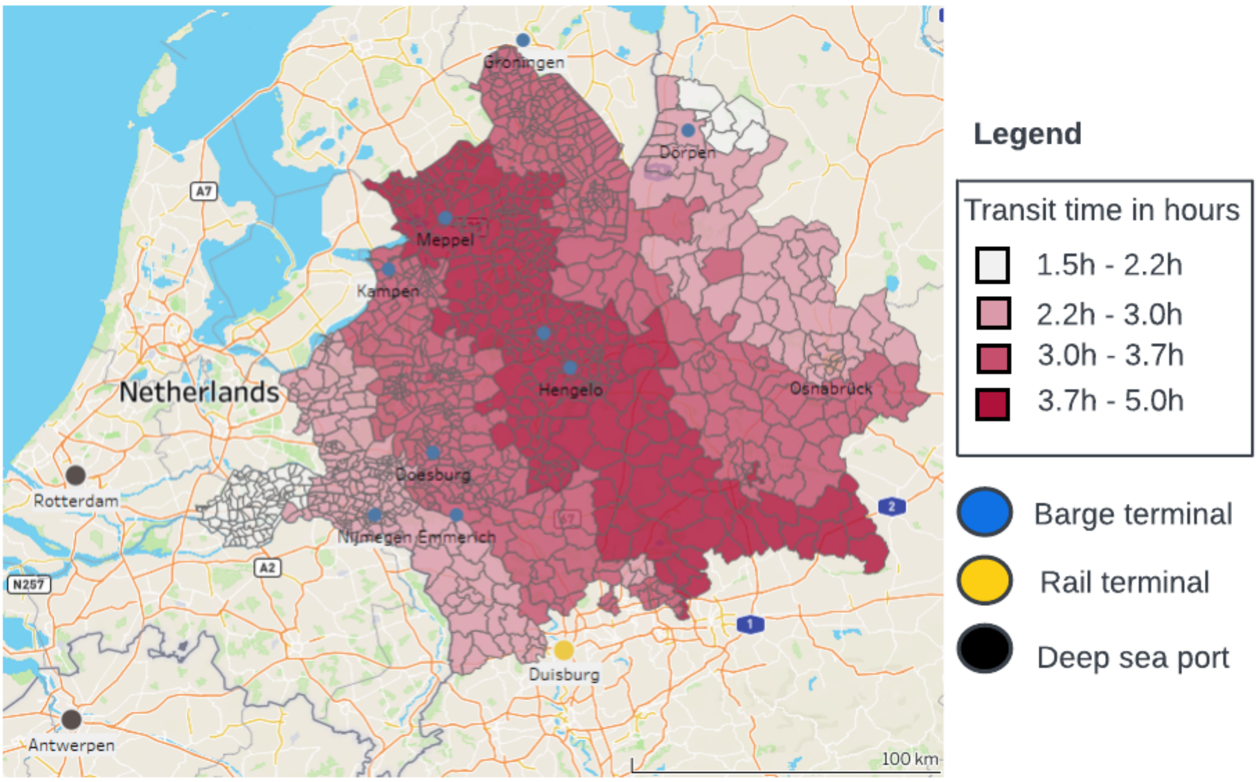

Figure 18: Transit times by road transport. Red represents the longest transit time based, and white is the shortest.

4.4.2 Price

A second map is created based on price. Due to confidential issues, the visualization has been left out of this public version of the thesis. We explain how the maps are created and what the corresponding results are.

A geographic map is created. The map has exactly the same structure as the map based on transit time, as shown in Figure 18. This means in the map the ports, barge terminals, and rail terminals are highlighted. Moreover, in Figure 18, it can be seen that each selected zip code has a color, based on the transit time. In the case of price, this is done as well. The color differentiation is based on the comparison score. Four different color categories are used. In case a customer has a comparison score between zero and 25%, the corresponding zip code is marked green, meaning Bolk is the best option. For a score between -20% and zero, it is marked pink. A score between -45% and -20% and between -45% or lower are marked respectively red and dark red. Scores below zero mean Bolk is not the best option and in other words, other transportation options by using competitors' terminals are more interesting. Table 4 shows the distribution of the different comparison score categories. Based on this table, we conclude that in 8.66% of the zip codes from the selected region, Bolk is the best option based on price.

Based on price, the competitive region of Bolk is around the terminals in Almelo and Hengelo and goes more to the east side of the terminals, which are customers located mostly in Germany. This can be explained. On the west side of Bolk, more barge terminals are located, and moreover, it is closer to the port of Rotterdam. Therefore going west will increase competition for Bolk. Less competitive terminals are located north and east, therefore the shape of the competitive region is more on this side. The region between the red and green is an interesting region in which Bolk is slightly less interesting compared to other transport options. This region is interesting for the optimization part of this research since in this model parameters are fixed.

Table 4: Distribution of the different comparison score categories out of the model based on price.

Comparison score	Percentage of selected zip codes
0 - 25%	8.66%
-20 - 0%	16.93%
-45 - -20%	52.65%
<-45%	21.76%

4.4.3 Emissions

The construction of the map based on emissions is the same as in the price model. In the case of emissions, the differences between terminals vary more than in the case of price. To visualize this, different categories are defined for the colors. zip codes with a comparison score between 35% and 70% has a dark green color. Zero between 35% has a green color. Last, a score between -35% and zero and a score between -70% and -35% have respectively a color of pink and red. The distribution of the different comparison score categories is shown in Table 5. In the table, we conclude that Bolk is the best option is the case of 15.37% (4.06% + 11.31%) from the selected region. From the confidential map, we conclude that the region is slightly different compared to the price one, Bolk's competitive position is stronger and larger. This can be explained. As mentioned earlier in this research, transportation by barge is the most sustainable way after rail transportation in terms of CO_2 emissions. In the price map, more competition comes from inland terminals to the west. From these competitors, smaller barge distances need to be covered, and a larger distance for the last-mile delivery by truck. Based on price, this can be a cheaper option, but if a customer targets more on emissions than the larger last-mile delivery by truck is not that interesting anymore. Resulting in a larger competitive position for Bolk.

Table 5: Distribution of the different comparison score categories out of the model based on emissions.

Comparison score	Percentage of selected zip codes
35% - 70%	4.06%
0 - 35%	11.31%
-35% - 0%	50.23%
-70% - -35%	34.40%

4.4.4 Modalities

As explained, three different modalities are compared, barge, rail, and road transport. The model provides the value of $M_{c,m}$ which equals one for a specific modality if that modality is the best option for a customer. By monitoring this value for each customer, a map is created with the best modality choice for a customer. The map is created using the same structure as previously explained in Section 4.4.2. The difference in this map is again the colors. Each modality has a separate color. For each customer, the corresponding zip code is marked with a color representing the modality. In the modalities map, four different colors are used. One color for rail, barge transport by Bolk, barge transport by a competitor, and road transport each. By doing this, the best modality for each customer can easily be seen. The distribution of the different modalities over the selected zip codes is shown in Table 7. These results are based on price. The same approach is applied to the model based on emissions. Results are shown in Table 6.

From the map, we conclude that Bolk's region is surrounded by primarily areas in which barge transportation is most environmentally beneficial, and partly in the east rail transportation via the German ports. Moreover, we conclude that in most of the selected regions, transportation by barge is the best option. Speaking about the competitive position, it can be concluded that Bolk is located in an area dominated by barge transportation and rail transport moving more to Germany. No visualization is created for transit time since the best modality based on time in the selected region is always transported by truck.

Table 6: Distribution of the different modalities out of the selected zip codes, based on emissions.

Modality	Percentage of selected zip codes
Truck	5.30%
Barge	38.70%
Train	37.80%
Bolk	18.20%

Table 7: Distribution of the different modalities out of the selected zip codes, based on price.

Modality	Percentage of selected zip codes
Truck	33.85%
Barge	57.10%
Train	0.08%
Bolk	8.97%

4.5 Conclusion

In this chapter, the research question: 'How can Bolk's competitive position geographically be mapped?' is answered. Based on the LAMBIT model and corresponding visualizations by Macharis (2000), the competitive position of the company is investigated. We formulated a comparison model, consisting of sets, parameters, variables, objectives, and constraints considering the KPIs price, emissions, and time separately. The model can be applied for each of the three defined KPIs, based on the preference of the company. The model is applied in Bolk's context. The input data consists of locations from seaports, inland terminals for barge and rail transport, and customers. Zip codes around Bolk's region are defined as customers. Between all the ports, terminals, and customers, distances are calculated using public information and an API from *Microsoft Bing maps*. Emissions and transit times are calculated for applying the model and price indications are made based on Bolk's information. For each customer, the best option for each transport mode is calculated. From these options, the best option is compared to Bolk and expressed in a comparison score. The scores are mapped in different figures, based on price, emissions, and transit time, using the software of *Tableau*.

Based on these insights, an optimization model is formulated to investigate how Bolk's competitive position can be maximized, based on existing infrastructure and network, and by combining KPIs and variable prices for each customer. This is explained in the next chapter.

5 Solution method

After the insights from Chapter 4, we formulate an optimization model to maximize Bolk's competitive position. Different from Chapter 4, the optimization model combines the parameters price, emissions, and time in one model. Moreover, the price by Bolk for a customer is not fixed anymore, but variable. By modeling this, we are able to determine for each customer whether Bolk is the best option, and what the corresponding optimal price for the customer is. By adding up the number of customers for which Bolk is the best option, we can determine Bolk's maximized competitive position. Moreover, by adding up the corresponding revenues, the total revenue created by the customer is known. This is all done by answering the following research question.

How can Bolk's competitive position be maximized?

Five sub-questions are answered, to provide insights for answering the research question.

- How can the optimization model be formulated?
- What is the type of model we use?
- Which pre-calculations need to be made for using the model?
- What conclusions can be made from the optimization model?

The chapter is built as follows. First, Section 5.1, provides the outline of the optimization model. Second, the formulation of the model is given in Section 5.2. Third, it is explained in Section 5.3 how the probability of accepting is used. Fourth, detailed information about the model is provided in Section 5.4. Last, the conclusion is provided in Section 5.5.

5.1 Model outline

In this section, the model outline is given. From the results of the comparison model described in Chapter 4, we concluded that an optimization model will create more insights into how the competitive position can be maximized, based on the current infrastructure and equipment of Bolk. We defined two objectives for maximizing the competitive position. First, maximizing the number of customers. Second, a maximization of the revenue created by the customers that choose Bolk's services. The purpose of this is explained later in this chapter.

In Figure 19, a simplified overview of the model is shown. The figure shows which steps need to be taken for each customer to be able to determine the selection of transport mode, from Bolk's perspective. Different variables are defined. The model provides the values of these variables. First of all, a variable determining whether Bolk's option is the best or not. The choice of a customer is determined by the defined KPIs, price, emissions, and time, applied in a combined score. It is assumed that emissions and time are fixed parameters. Therefore, the second variable is Bolk's internal price. This internal price consists by itself of barge transport and last-mile transportation by truck. The model provides an optimal price for barge and truck transport for each customer, independent of each other.

The two objectives are needed, because if the model only focuses on maximizing the number of customers choosing Bolk, it tries to assign a minimum price possible for each customer, resulting in limited earnings for the company. The price for a customer is determined by using the steps as shown in Figure 19. We measure the total amount of customers by adding up the customers for which Bolk is the best option. Moreover, the total revenue created by these customers is measured as well. It can be seen in the figure, that the model consists of two parts, a deterministic and a stochastic one. The deterministic part consists of the following steps. Based on the geographic position of the customer, all the distances between ports, terminals, and the customer are determined as done in Chapter 4. Based on this input, a score for the modalities truck, barge, and train are calculated. Based on these scores, the model determines the optimal price for each customer independently. After this, the stochastic part starts. Bolk's score is compared to the best alternative. By using the probability of accepting the offer by a customer, it is determined whether a customer accepts Bolk's offer as the best offer. In the remainder of this chapter, it is explained in more detail.

To summarize, the model finds the optimal price for each customer individually and determines whether Bolk's option is the best for a customer. It optimizes each customer independently from the other. By adding up and visualizing the total customers and total revenue created by these customers, Bolk's maximized competitive region is determined.

Figure 19: Simplified overview of the model

5.1.1 Pre-processing

In this section, it is explained which calculations and information are needed before executing the optimization model. As explained in the previous section, the KPIs time, price, and emissions are measured for each customer. Based on the insights of Al-Salih and Esztergár-Kiss (2021), a utility score $V_{c,m}$ is calculated for each customer for the modalities rail, truck, and barge (by Bolk's competitors). This score is needed to determine the optimal utility score for Bolk by determining the price based on the objectives. The score for each modality is calculated in four steps: Calculating the total price, total emissions, total time, and finally the total score. The calculation for price, emissions, and time is done in the same way as done in Chapter 4. Detailed calculations and the full description of the parameters are listed in Appendix A.

Last, the utility score is calculated. Each customer will have different assigned weights to the key performance indicators. The weights used for price, emissions and time are noticed respectively as α_c, β_c, and γ_c. The summation of the weights is equal to one. The score is calculated by using Formula (12). In the formula, it can be seen that the TotalPrice, TotalEmissions, and TotalTime are divided by constant parameters, namely MaxTotalPrice, MaxTotalEmissions, and MaxTotalTime. This is needed to create a reliable utility score. The constant parameters are the maximum values possible for price, emissions, and time by using the defined input data in our research. By doing so, the parameters are normalized, meaning that we are able to eliminate the units Euro, CO_2, and minutes. Moreover, a unitless value is created, which means that the utility of each modality can be compared in a fair way.

$$V_{c,m} = \alpha_c \cdot \frac{TotalPrice_{c,m}}{MaxTotalPrice} + \beta_c \cdot \frac{TotalEmissions_{c,m}}{MaxTotalEmissions} + \gamma_c \cdot \frac{TotalTime_{c,m}}{MaxTotalTime} \quad \forall\, c \in \mathcal{C}, m \in \{Rail, Truck, Barge\} \tag{12}$$

5.2 Model formulation

For each customer, the utility score for the transport options truck, rail, and barge is known. The next step is to figure out what the optimal utility score for a customer is by using transport by Bolk. Using this score, the maximized region can be determined, based on the two objectives. In this section, we explain how we formulated the model. The model consists of the same sets as used in Chapter 4. In this section, we only introduce new parameters and variables to be able to formulate the optimization model.

5.2.1 Parameters

α_c	Weight for costs for customer c
β_c	Weight for emissions for customer c
γ_c	Weight for time for customer c
$MinP_{BolkBarge}$	Minimum Price of using Bolk for barge transport per km in euros
$MaxP_{BolkBarge}$	Maximum Price of using Bolk for barge transport per km in euros
$MinP_{BolkTruck}$	Minimum Price of using Bolk for road transport per km in euros
$MaxP_{BolkTruck}$	Maximum Price of using Bolk for road transport per km in euros
$MaxTotalPrice$	Maximum Possible Price to pay for a customer
$TotalEmissions_{c,Bolk}$	Total emissions for customer c for using Bolk in kg CO_2
$MaxTotalEmissions$	Maximum possible Emissions for a customer in kg CO_2
$TotalTime_{c,Bolk}$	Total time for customer c using Bolk in minutes
$MaxTotalTime$	Maximum possible Total Time for a customer in minutes
$MinV_c$	Minimum Value of the utility function by customer c between barge, truck, and rail transport
$E_{BolkBarge}$	Emission rate barge per km in kg CO_2
$E_{BolkTruck}$	Emission rate for truck per km in kg CO_2
$BigM$	Large number

5.2.2 Variables

X_c	Binary Variable indicating if the utility score of Bolk is less than the best alternative for a customer $X_c \in \{0,1\}$
Z_c	Binary support variable, $Z_c \in \{0,1\}$
$P_{BolkBarge,c}$	Price for customer c of using Bolk for barge transport per km in euros
$P_{BolkTruck,c}$	Price for customer c of using Bolk for road transport per km in euros
$TotalPrice_{c,Bolk}$	Total Price for customer c for using transport by Bolk

5.2.3 Objective

Equation (13) represents the objective of maximizing the number of customers using Bolk. The second objective is formulated in Equation (14), which represents the sum of revenue created by each customer individually.

$$Max \sum_{c=1}^{C} X_c \tag{13}$$

$$Max \sum_{c=1}^{C} X_c \cdot TotalPrice_{c,Bolk} \tag{14}$$

5.2.4 Constraints

In this section, the constraints of the model are explained. First, Constraint (15) makes sure that for each customer a selection is made. In case $X_c = 1$, Bolk is the best transport option for a customer. Second, Constraints (16) and (17) are related to each other. If Bolk's utility score V_{Bolk} is less than the minimum utility score of the alternative transport options; $MinV_{c,m}$, it means that for a customer, Bolk option is the best, resulting in $X_c = 1$. Constraints (16) and (17) are therefore constructed as an if-then constraint, using the support variable Z_c and a Big M number: If $V_{c,Bolk} - MinV_c \leq 0$ then $X_c = 1$, otherwise $X_c = 0$.

$$X_c \leq 1 \ \forall \ c \in \mathcal{C} \tag{15}$$

$$X_c \leq BigM \cdot Z_c \ \forall \ c \in \mathcal{C} \tag{16}$$

$$V_{c,Bolk} - MinV_c \leq BigM \cdot (1 - Z_c) \ \forall \ c \in \mathcal{C} \tag{17}$$

For each customer, the value of the utility function for Bolk is calculated. This is done by using Equation (18). Within the formula, the total price for Bolk is used. This value is calculated by using Equations (19).

$$V_{c,Bolk} = \alpha_c \cdot \frac{TotalPrice_{c,Bolk}}{MaxTotalPrice} + \beta_c \cdot \frac{TotalEmissions_{c,Bolk}}{MaxTotalEmissions} + \gamma_c \cdot \frac{TotalTime_{c,Bolk}}{MaxTotalTime} \ \forall \ c \in \mathcal{C} \tag{18}$$

$$TotalPrice_{c,Bolk} = D_{p,b} \cdot P_{BolkBarge_c} + D_{b,c} \cdot P_{BolkTruck_c} + P_{Start} \ \forall \ c \in \mathcal{C} \tag{19}$$

The price for Bolk is variable but should be between minimum and maximum values. Limits are defined, otherwise, Bolk will either be too expensive for customers or Bolk will not gain any profit if the price is beneath a certain level. Constraints (20) and (21) make sure that the model selects a price between the defined boundaries.

$$MinP_{BolkBarge} \leq P_{BolkBarge_c} \leq MaxP_{BolkBarge} \ \forall \ c \in \mathcal{C} \tag{20}$$

$$MinP_{BolkTruck} \leq P_{BolkTruck_c} \leq MaxP_{BolkTruck} \ \forall \ c \in \mathcal{C} \tag{21}$$

Last, the sign constraints are formulated. Constraints (22) and (23) are formulated in order to make sure that both variables are binary. Constraints (24), and (25) make sure that the continuous variables are not negative.

$$X_c \in \{0, 1\} \ \forall \ c \in \mathcal{C} \tag{22}$$

$$Z_c \in \{0, 1\} \ \forall \ c \in \mathcal{C} \tag{23}$$

$$P_{BolkTruck_c} \geq 0 \ \forall \ c \in \mathcal{C} \tag{24}$$

$$P_{BolkBarge_c} \geq 0 \ \forall \ c \in \mathcal{C} \tag{25}$$

5.3 Probability of accepting

Unfortunately, in our research, customer behavior is unknown. We assumed zip codes as customers, to obtain the behavior of individual customers in each of the regions is not reachable. To still simulate a situation in which we can obtain information on whether a customer would choose Bolk's offer or not, we can again calculate a comparison score, representing the difference in offers in percentage.

$$ComparisonScore_c = \frac{MinV_{c,m} - V_{c,Bolk}}{V_{c,Bolk}} \cdot 100\% \tag{26}$$

Equation (26) is used in order to do so. For each customer, a score is calculated. Using this score, we can simulate the probability of accepting the offer by dividing the different scores into categories. Based on expert opinion, the scores are categorized, which are visualized in Figure 20. In case the comparison score is 20% or more, we assumed that a customer will always choose Bolk, so a probability of 1 is assigned to the customer, as can be seen in the Figure. In total six categories are defined, varying a probability between zero and one. Using this information, we can visualize per customer the probability of accepting and mapping to obtain strategic information. These visualizations are given in the next chapter.

One additional step can be made, by making use of a uniform distribution in order to simulate an outcome that will be different each time running the model. First, for each customer, a random value between zero and one is drawn. Next, the values out of Figure 20 can be used again to determine whether a customer selects the offer or not. To illustrate, if the comparison score falls between 5% and 20%, a customer chooses the offer when the random value exceeds 0.25 (1- 0.75). Let's consider another example where the comparison score is -4%. In this situation, the customer will still select Bolk as long as the random value is greater than 0.6 (1 - 0.4). By performing this multiple times, insights are created where potential customers can be located.

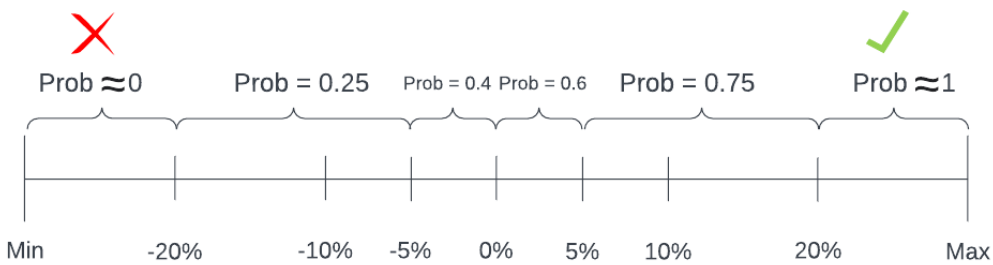

Figure 20: Accepting probability overview

5.4 Model details

In this section, details about the model are explained. First, the type of model is explained. Second, how uncertainty is involved in the model is provided.

5.4.1 Type of model

The model contains two types of decision variables. X_c and Z_c are binary variables where the price for barge and truck transport by Bolk are continuous variables within a predefined range. In the objective, the decision variables are multiplied by each other, making the model quadratic. There are no constraints in which both the binary variables and the continuous variables are multiplied by each other, so the model cannot be seen as a quadratically constrained program. Since the binary variables are integers, combined with the continuous variables, the model can then be defined as a **mixed integer quadratic program** (MIQP). An MIQP can be solved in different ways. In this research, we selected *Gurobi*, implemented in *Python*, as the optimization-solving tool. The model determines an optimal price for each customer independently, resulting in quick solving time using *Gurobi*. This makes it applicable to Bolk, to make use of the model in different situations.

5.4.2 Practical applicability

In this research, uncertainty is involved. As a result of this, the complexity of the model can be high. In order to be able to solve the model, we have made some decisions about which uncertainties we are taking into account. First of all, each customer's behavior is different, and as explained in Section 2.3.4, each customer can define differently which KPI is most important for selecting a transportation option. To reduce this complexity, we assigned pre-defined weights to the KPIs price, time, and emissions to the set of customers. In the experiments, we performed multiple analyses on the values of these weights. The second uncertainty is the fact whether a customer accepts the offer of Bolk or not. To simulate this behavior, in the model a probability of accepting is used, which is determined by the utility values. This uncertainty is taken into account, as explained, after executing the deterministic model.

For practical situations, we added the accepting probability after solving the model in a deterministic way. This has several reasons. First, the model determines the exact optimized price, after that, it determines whether a customer accepts the offer or not. By performing the model in this order, we can assign information to Bolk about what the final price offered to the customer can be. Next, we are able to provide information about the region in which customers are located that in the end will accept the offer. Second, Bolk stated as a requirement that they can see the difference between Bolk's offer and the one of the competitor as a percentage of each other, in the same way, it is done in Chapter 4. In order to calculate this, a division is made, which makes the model hard to solve because of the fact that the decision variable will be positioned in a denominator. By executing the accepting probability after the optimization model, both the model can be solved and insights can be created about the accepting customers.

5.5 Conclusion

In this chapter, the research question '*How can Bolk's competitive position be maximized*' is answered. In order to maximize the competitive position, an optimization model is formulated. By making use of the geographic position of a customer, a weighted score can be calculated for each of the modalities, taking into account the KPIs price, time, and emissions, and assigning weights to these KPIs. Based on the score, the optimization model can determine the price for a customer. This is based on two objectives, maximizing the number of customers choosing Bolk and maximizing the created revenue by these customers. A mixed integer quadratic program is formulated. Uncertainty is involved by using a probability of acceptance. This is applied after the deterministic optimization, such that we can still compare the optimized offer by Bolk with the competitors as a percentage while being able to solve the model. In the end, the model determines if for a customer Bolk is the best option, based on an optimal price for that specific customer. Moreover, the model provides practical insights, which the company can use in different situations. In the next chapter, an analysis of the model is done and experiments are performed.

6 Experiments

In this chapter, we focus on setting up, performing, and explaining different experiments. These experiments are necessary to test the model under different scenarios. In consultation with the stakeholders within the company, we defined the experiments to see what the maximized competitive position of the company is under different real-life scenarios that can occur. In order to do so, the following research question is answered.

'What experiments can be employed to investigate the performance of the model, and what are the corresponding outcomes or findings of these experiments?'

The question is answered by discussing the following sub-questions:

- How is the model performing under a base instance?
- Which scenarios are interesting to be investigated, and what are the corresponding outcomes?
- How can the outcome of the model be verified and validated?

The chapter is built as follows. In Section 6.1, we explain what the results of the model are under a base instance. Next, we define different scenarios to be tested. This is explained in Section 6.2. Third, in Section 6.3, we provide an overview of how the model is validated using historical data. Last, we state our conclusions from this chapter in Section 6.4.

6.1 Base instance

The base instance is based on input data provided by Bolk and explained in Section 6.1.1. Second, the performance of the model is explained in Section 6.1.2. Third, Section 6.1.3 provides outcomes of the model under extreme values. Last, a sensitivity analysis is executed and described in Section 6.1.4.

6.1.1 Input data

In this section, it is explained which input data is used for applying the model. The data used is the same as elaborately explained in Section 4.2. However, some parameters are different. In the optimization model, internal data from Bolk is used. This especially applies to the emissions created by Bolk's trucks. Together with the expert on emissions within Bolk, the internal emission rate for road transport by Bolk's truck is determined. From all the trips done by Bolk container transport, the average fuel consumption per kilometer is determined. Moreover, the emission factor from the corresponding fuel is used to calculate the total emission. This is done by using Equation (27).

$$Emission\ truck\ Bolk = Distance * Fuel\ Consumption\ per\ km * Emission\ factor \quad (27)$$

Normalizing factors

As shortly explained in Section 5.1.1, parameters MaxTotalPrice, MaxTotalEmissions, and MaxTotalTime are used to normalize the utility score. These are the maximum values used for the whole dataset, so not different for each customer. As input for the model, three values are used. First, the MaxTotalPrice is defined as the maximum price that could be paid by a customer in the selected region used in the model. Using our input data in the model, the highest price would be paid for ordering a container from the port of Hamburg, transported by train to Duisburg, and finally delivered by truck in Noordenveld (The Netherlands), representing a price of €1793. Second, in the case of emissions, the highest emission for transporting a container is assigned for a container transported by truck from the port of Hamburg to ZaltBommel (The Netherlands), involving 354 kg CO_2. Last, the maximum time is involved in delivering a container by barge from Rotterdam to Groningen, followed by last-mile transportation to Straelen (Germany). All these three routes are not realistic to be planned by a customer, because of the large price, emissions, and time, but are needed in order to normalize the utility function.

Customer profile

As described 5.4.2, we reduced the complexity due to uncertainty by making use of a pre-defined profile for a customer. This profile consists of the weights for the parameters price, time, and emissions, as used in Formula (18). For the base instance, the following weights are used: 0.6 for price, 0.3 for emissions, and 0.1 for time. These values are defined by expert opinion. In the experiments, we tested the effects on different weights.

6.1.2 Results on base instance

In this section, the output of the model for running the base instance is given. The outcome of the objectives is important to evaluate the model. For conclusions and interpretations of the outcomes, the corresponding visualizations are more important, because we are in that case able to see what the region is. The outcome of the model is an optimized price for each of the customers for which Bolk is the best. Adding up the total customers and corresponding revenue is 162 and €88058. In the remainder of this chapter, we refer to the summation of the outcome of all individual customers.

The stochastic model is run 100 times, the results are shown in Table 8. The average outcome is around 180 customers. The minimum, maximum, and standard deviation between the values of the 100 runs are measured and shown in the table to see the difference in the performance of the runs.

The table illustrates that the stochastic model yields higher results compared to the deterministic model. This discrepancy can be explained by referring to Table 9, which examines a total of 1282 zip codes. Following the deterministic model, these zip codes are classified into various probability categories, as explained in Section 5.3 as shown in Figure 20. Table 9 displays the count of zip codes per category. Notably, for the 0.25 and 0.4 categories, there exists a possibility of accepting Bolk's offer, despite not being the optimal score. Conversely, the 0.6 and 0.75 category presents a chance of rejecting Bolk's offer, despite being the best score. The reason behind the higher outcome in the stochastic model lies in the fact that the 0.25 and 0.4 categories collectively account for 22.39% (19.5% + 2.89%), while the 0.6 and 0.75 categories make up 12.64% (10.76% + 1.87%) of the overall customer base. Consequently, the likelihood of accepting customers is greater in the stochastic model, resulting in a higher number of customers.

Table 8: Results of the stochastic model

	Average	Min	Max	Standard deviation
#Customers	180.58	160.00	204.00	10.01
Revenue (€)	96598.14	86028.31	109038.15	5330.11

Table 9: Distribution of the outcome of the model

Probability category	Number of zip codes	% of total investigated region
0	833	64.98%
0.25	250	19.50%
0.4	37	2.89%
0.6	138	10.76%
0.75	24	1.87%
1	0	0.00%
Total	1282	100%

*In this public version, confidential visualizations are left out, and text is adapted to still understand the approach and results.

For the stakeholders, a value of 162 customers does not create significant insights. Therefore, visualizations are made, which take the geographic location of the customers into account. The visualizations are created in the same way as done in Chapter 4, by transferring the output created in *Python* to *Tableau*, which is using GIS software for creating maps. Moreover, each zip code is marked with a color based on the comparison score again. Table 10 shows the distribution of the comparison score categories in the visualization, based on running the deterministic settings. A customer with a comparison score between zero and 25% has its corresponding zip code marked green on the map. A score between -20% and zero is marked pink. Between -45% and -2-% and between -65% and -45% are marked respectively red and dark red. As explained, a positive score means that Bolk is the best option. From the table, we conclude that in 11.86% of the investigated region, Bolk is the best option. This region is centralized around Bolk's terminals in Hengelo and Almelo.

Table 10: Distribution of the different modalities out of the selected zip codes, based on emissions.

Comparison score	Percentage of selected zip codes
0% - 25%	11.86%
-20% - 0%	21.22%
-45% - -20%	49.61%
-65% - -45%	17.32%

Another visualization is created in which the different categories of the accepting probability, as explained in Section 5.3, are shown. In the visualization, colors are used as well. Each probability category has its own color on the map. A customer with an accepting probability of 0.75 is marked dark green on the map. An accepting probability of 0.6, 0.4, 0.25, and 0.0 are marked respectively with green, white, orange, and red on the map. The distribution of the different accepting probabilities out of the selected zip codes is shown in Table 11.

Table 11: Distribution of the different modalities out of the selected zip codes, based on emissions.

Probability category	Percentage of total selected zip codes
0	64.98%
0.25	19.50%
0.4	2.89%
0.6	10.76%
0.75	1.87%

For each of the customers within Bolk's region, an optimized price is determined. Based on the distances, the corresponding revenue per customer is calculated. Figure 21 shows the differences in revenue from the customers in Bolk's region. Nine intervals are created. From the histogram, we conclude that most customers within Bolk's region generate revenue between €535 and €557.

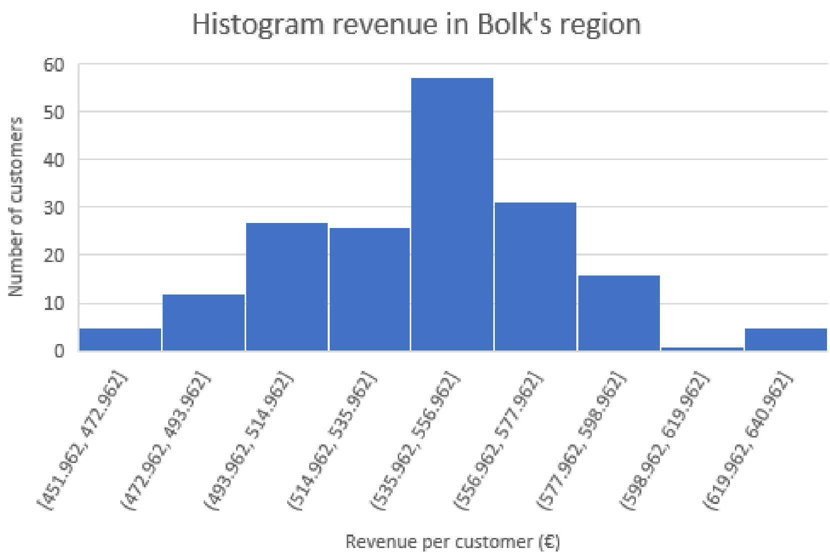

Figure 21: Histogram visualizing the number of customers per revenue interval.

Insights from the vizualizations
From tables 10 and 11 and their corresponding confidential visualizations we conclude several things. Bolk's region is around the terminals in Almelo and Hengelo and is slightly more positioned on the east side of these terminals, like an oval. We conclude that within Bolk's region, the strongest customers are located just around the terminals in Almelo and Hengelo. This is logical since the last-mile transport by truck is minimum, resulting in a lower price, emissions, and transit time. Moreover, we conclude that on the north and south side of the region, customers are located for which Bolk's offer is slightly less interesting than the competitive one. These customers fall in the 0.4 probability category.

Pricing differences
From Figure 21 and its corresponding confidential map, we obtain insights about the differences in revenue per

customer. The customers with the highest revenue are located on the east side of the terminal in Hengelo, representing the darkest green regions in the figure. These customers are located mostly in Germany. It is concluded that the lowest revenue is created in regions located on the west side of the maximized competitive position. This is explained by referring to the competitive barge terminals located more on the west side of Bolk's terminals. From the map, we conclude that the difference between the lowest and highest revenue created by a customer is around €150. A note should be made, that we are talking about revenue instead of profit. The longer the distances, the higher the price, and therefore the revenue.

6.1.3 Extreme values of the Pareto Front

In this section, we explain how we found the extreme values of the Pareto front graph, showing the performance of the two objectives. This is useful to measure the relationship between the two objectives and to create insights for Bolk on the effect on the region if the model is tested with extreme values. The extreme values are determined by testing the model under extreme scenarios by changing the boundaries in which the model can determine the optimal price. The boundaries are formulated in Constraints (20) and (21) in Section 5.2.4.

Six different options for the values of $MinBarge_{Bolk}$, $MaxBarge_{Bolk}$, $MinTruck_{Bolk}$, and $MaxTruck_{Bolk}$ are tested. In Table 12, the values are shown. The first three tests are focused on finding the extreme values by setting the prices to the **minimum**. In the first test, both the price for the barge and truck is set to the minimum value (taking the minimum and maximum values the same). For the second test, we set the price for barge fixed to the minimum and the truck price between the boundaries as defined in the base instance. The model can only fluctuate in truck pricing in this case. The third test is done the other way around, setting truck prices as a minimum and fluctuating with the barge prices.

The last three tests are focused on finding the extreme values based on **maximum** prices. This is done by first setting the price for both barge and truck to the maximum. Second, fixing the barge price to the maximum and fluctuating with the truck price. Last, fixing the truck price to the maximum and fluctuating with the barge price. For all the tests, the amount of customers and the corresponding revenue is measured. This is done for both the deterministic and stochastic models. Output is stored and the average value for both objectives is stored in the table.

Taking the minimum values, the maximized region is 162 customers for the deterministic model and between 183 and 199 for the stochastic model. We see that fluctuating with the minimum price for barge and truck will have no impact on the number of customers on the deterministic model and a minor impact on the stochastic model. Testing the maximum values, more impact on the fluctuations can be seen. The most impact can be seen by fluctuating with the barge price, increasing the number of customers from 69 to 143 in the deterministic model and 92 to 151 in the stochastic model. This is useful information, since we know that the objectives are more sensitive to barge price differentiation. This is reasonable since the barge price will cover most of the total price for customers around Bolk's terminals.

Table 12: Outcome of testing the model under extreme values. The prices are in euros.

MinBargeBolk	MaxBargeBolk	MinTruckBolk	MaxTruckBolk	Deterministic #customers	Deterministic Revenue	Stochastic #customers	Stochastic revenue
1.5	1.5	1.8	1.8	162	74142	199	96017
1.5	1.5	1.8	2.5	162	76120	194	95254
1.5	2.0	1.8	1.8	162	87395	183	97496
2.0	2.0	2.5	2.5	69	38460	92	53808
2.0	2.0	1.8	2.5	85	47675	108	62909
1.5	2.0	2.5	2.5	143	78437	151	84313

6.1.4 Sensititvity analysis input data

In this section, we explain how we performed a sensitivity analysis on the model. The goal of this is to test the results of the model by changing different parameters which influence the outcome of the model. The utility score is calculated by normalizing the KPIs price, time, and emissions. The impact of lower and higher values of the denominators in Formula (28) is tested by decreasing and increasing it. Since the stochastic model continues with the basis of the deterministic model, the utility function is tested for the deterministic model. The results are shown in Appendix B.

First, the *MaxTotalPrice* is tested. Testing values between €500-2500 do not give significant differences in both objectives. The same holds for the *MaxTotalEmissions*, testing values between 500 and 2500 Kg CO_2, resulting in minor differences in both objectives. In the case of *MaxTotalTime* it is different. Values between 1000 and 5000 minutes are tested, resulting in higher fluctuations in the output of the two objectives. The amount of customers varies between 151 and 196 resulting in a revenue between €58172 and €107498. We conclude that for the utility calculation, *MaxTotalTime* is influencing the outcome of the formula the most. A note should be made, the different weights for the different KPIs do influence the outcome of the utility even more. By changing these factors, for example for increasing the weight over time, the model will find the maximized region focused more on transit time. The effects of changes in the weights and KPIs are tested in the next section, in which different scenarios are worked out.

$$V_{c,Bolk} = \alpha_c \cdot \frac{TotalPrice_{c,Bolk}}{MaxTotalPrice} + \beta_c \cdot \frac{TotalEmissions_{c,Bolk}}{MaxTotalEmissions} + \gamma_c \cdot \frac{TotalTime_{c,Bolk}}{MaxTotalTime} \ \forall\ c \tag{28}$$

6.2 Scenarios

*In this public version, confidential visualizations are left out, and text is adapted to still understand the approach and results.

In this section, scenarios are defined and the results of them are explained. The scenarios are based on real-life situations that occurred in the past, or can occur in the future and are defined by stakeholders in the research. First, Section 6.2.1 explains the outcome of the first scenario, focusing on the price fluctuations of Bolk. Second, Section 6.2.2 describes the experiment in which the model is tested with an extra competitor. Third, Section 6.2.3 provides an experiment based on fluctuations in rail transport. Last, Section 6.2.4 explains the last experiment which is emissions focused. The tested values are shown in Table 13.

6.2.1 Scenario 1: Price fluctuations Bolk

Table 13: Number of customers for each tested value of $MinP_{BolkBarge}$

$MinP_{BolkBarge}$	Amount of customers	Change in region	Change in revenue
1.0	279	55.00%	38.55%
1.1	258	43.33%	31.66%
1.2	232	29.00%	21.00%
1.3	210	17.00%	11.60%
1.4	195	8.33%	5.70%
1.5	180	0.00%	0.00%
1.6	163	-9.44%	-7.95%
1.7	154	-17.78%	-14.82%
1.8	135	-25.00%	-20.93%
1.9	121	-32.78%	-28.33%
2.0	108	-40.00%	-34.90%

In the first scenario, different tests are formulated in which price fluctuations can occur. Two sub-scenarios are executed. One focuses on a low water scenario, the second on the possibility to take three layers of containers on a barge.

$$MinP_{BolkBarge} \leq\ P_{BolkBarge_c} \leq\ MaxP_{BolkBarge}\ \forall\ c \in \mathcal{C} \tag{29}$$

Scenario 1a: Low water scenario

As described in Section 2.4.1, during summer it can occur that the water levels in the 'Twentekanaal' are lowering due to warm weather, resulting in the fact that barges that are fully loaded with containers cannot go through the canal anymore. Barges with fewer containers can only be transported through the canal in this case. The moment fewer containers are transported, the price per transported container will increase. In order to measure the result, experiment 1a is performed in which the value of $MinP_{BolkBarge}$ in Equation (29) is increased from €1.5 to € 2.0 per km. The number of customers is measured, by running the stochastic model. The objective for each value of $MinP_{BolkBarge}$ is shown in Table 13. For each value of $MinP_{BolkBarge}$ the model ran 100 times. The average value of the objective is written down in the table. Moreover, the change in the region is written in the third column, which represents Bolk's region, in other words, customers have a comparison score above zero. Due to confidential issues, corresponding maps are left out. The maps are created the same way as explained in Chapter 4, by assigning the same colors to the comparison score categories. From table 13 we conclude that by increasing the value for the constraint, so an increased price for barge transportation, Bolk's competitive region is lowering. From the confidential maps, we conclude that Bolk's region in this case is centralized just around the terminals in Hengelo and Almelo.

Scenario 1b: 3-layers containers

Scenario 1b is related to a price reduction. At the moment of executing this research, maintenance at the Twentekanaal is conducted for the expansion of the canal (van Infrastructuur en Waterstaat, 2023). After the maintenance, bigger barges can go through the canal. These barges can transport three instead of two layers of containers on their ship. Because more containers are transported, the average price per container transported from the seaport to the region of Twente can be reduced. In order to measure the result, Scenario 1b is performed in which the value of $MinP_{BolkBarge}$ is decreased from € 1.5 to €1.0 per km. The results of the experiments are measured in the same way as Scenario 1a and can are also shown in Table 13. The number of customers is increasing from 180 to 280, an increase of 55.56%. From confidential figures, we noticed that the region is mainly growing to the southeast region of Bolk's terminals. This is exactly the region between the rail terminals Osnabrück and Duisburg. We conclude while decreasing the constraint, the region will grow to the area between the competitive rail terminals in Germany.

6.2.2 Scenario 2: A new competitor

In this scenario, the focus is on a change in the selected competitors. In the defined region in which competitors are taken into account, a new competitor will position itself in 2023, opening an inland barge terminal in Deventer, the Netherlands (terminal Deventer, 2023). In this scenario, the effect of this is tested by assuming that the new build barge terminal is already operating. The location of the terminal towards the other barge terminals is shown in Figure 22. The terminal is added to the input data of the model and tested using five different settings by changing the customer's weights to the KPIs and testing it with the stochastic model. The different tests are shown in Table 14.

In order to draw conclusions, the same tests are executed with the original situation. For each of the tests, the stochastic model ran 100 times, the average values of the number of customers are shown in the table. We conclude that by opening a terminal in Deventer, Bolk's competitive region will decrease the most if a customer is more emissions focused. This can be explained because from the visualizations we can conclude that the decrease in the number of customers is due to a loss on the west side of the region. In this region, less distance on the barge is involved when choosing Deventer instead of Bolk. In case a customer is more price focused, the loss in the region is limited, up to approximately 5.7%. From the confidential visualization and the results shown in the Table, we conclude that from the terminal in Deventer, a small loss in the west side of Bolk's region will be made, which can be increased if customers are more emission focused, due to fewer barging distance using Deventer.

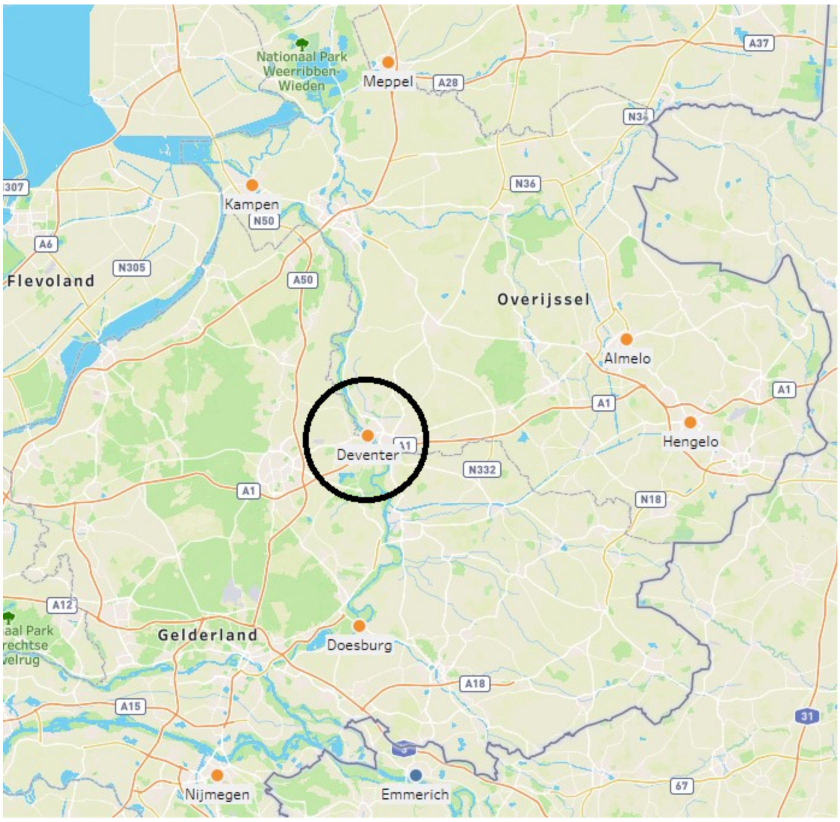

Figure 22: The location of the new terminal in Deventer, positioned in the black circle.

Table 14: Output scenario 2

Settings weights [Price, Emissions, Time]	#customers with Deventer	#customers without Deventer	Decrease in region
[0.6, 0.3, 0.1]	168.7	178.95	-5.73%
[1, 0, 0]	241.05	255.5	-5.66%
[0, 1, 0]	177.75	213.45	-16.72%
[0.5, 0.5, 0]	197.35	226.05	-12.70%
[0.3, 0.6, 0.1]	172.15	188.75	-8.79%

6.2.3 Scenario 3: Fluctuations in rail transport

Rail transport in practice is complex. First, trains need to be available in order to transport the containers. Second, on the rail itself, passenger transport has priority over cargo transport, resulting in longer transit times. Also, delays in passenger transport can as well cause delays in cargo transport. In general, it is known, train transport is profitable over longer distances compared to trucks. Because rail transport is the most sustainable way of transporting, governments want to stimulate rail transport more and more by offering subsidies. In this scenario, we concentrate on different fluctuations in rail transportation. In the case of Bolk, the competitive rail terminals are located in Germany.

Scenario 3a: Less transport via Osnabrück
On the east side of Bolk's region, the rail terminal in Osnabrück is located. CTT's director mentioned in an interview that companies do not always choose rail transportation via Osnabrück because of practical reasons such as availability and delays. Due to complexity, these factors are not taken into account in the model. The aim of scenario 3a is to measure the effects on Bolk's region in case the terminal in Osnabrück is not available. Therefore we ran the model without taking into account the terminal. The stochastic model is run 100 times, the results are shown in Table 15. We tested it under different customer profiles to measure mainly the effects on price and emissions.

From the results shown in the table and the corresponding visualizations, we conclude that for an average customer, not taking into account Osnabrück will have a minor impact: 1.00% change in Bolk's region. From the other tests, we conclude that without taking into account Osnabrück, Bolk's maximized region will slightly increase more to the east part of the region. Focussing on emissions, the biggest increase in region will be made; 14.71%. One can notice on the maps that without Osnabrück, Bolk will not cover the region around the location of the rail terminal. From the analysis, we see that in this case, direct trucking from the German ports of Hamburg and Bremen is the best option. This is also why, the biggest increase in region is made if the customer is more emission focussed. Since barge transport is more environmentally friendly compared to direct trucking.

Table 15: Output Scenario 3a

Settings weights [Price, Emissions, Time]	#Customers with Osnabrück	#Customers without Osnabrück	Increase in region
[0.6, 0.3, 0.1]	180,00	181.80	1.00%
[1.0, 0.0, 0.0]	256.67	257.46	0.31%
[0.0, 1.0, 0.0]	212.54	243.80	14.71%
[0.5, 0.5, 0.0]	221.69	241.17	8.79%
[0.3, 0.6, 0.1]	188.21	192.80	2.44%

Scenario 3b: Subsidy for rail transport
The second sub-scenario related to rail transport is based on the fact that governments are providing subsidies for rail transport in order to decrease costs. Since transport by rail is the most sustainable transport option, governments want to stimulate this by giving subsidies in order to reduce the costs of using rail transport, and therefore the price to be paid. The price of transport by rail is therefore decreased step-by-step to measure the results on Bolk's region. The stochastic model ran for a value from € 3.3 to € 2.9 per km per TEU, taking into account the average customer profile. Results are shown in Table 16. We conclude from this experiment that Bolk's region will approximately stay the same size. The region around the rail terminals in Osnabrück and Duisburg will increase, but this will not affect the green region of the company.

Table 16: Output scenario 3b (Values are manipulated due to confidential issues)

Price Rail per km	3.3	3.2	3.1	3.0	2.9
#Customers	179.79	179.80	177.37	175.54	176.45

6.2.4 Scenario 4: Emissions focused

Nowadays, companies increase their focus on emissions within their supply chain. New developments are going on for cleaner barges and trucks. Scenario four is therefore focused on emissions. The effects on different emissions at Bolk and their competitors are measured by performing sub-experiments.

Scenario 4a: Competitors with low emissions
In this experiment, we test the effect on Bolk's region in case competitors will decrease their barge and truck emissions. The barge and truck emissions in the model are decreased for both 10% and 20% compared to the original settings. Eight tests are executed to measure the effect on Bolk's region, taking into account the average customer profile. The results are shown in Table 17. From the experiment, we conclude that Bolk's region is most sensitive to changes in barge emissions by competitors. Take for instance test two, in which a 20% decrease in barge emissions is tested, resulting in a decrease of 20.37% of the region.

Table 17: Output scenario 4a: Decreasing competitors' emissions

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Barge	-10%	-20%	0	0	-10%	-20%	-10%	-20%
Truck	0	0	-10%	-20%	-10%	-10%	-20%	-20%
#Customers	146	129	156	152	143	124	138	120
Decrease in region	-9,88%	-20,37%	-3,70%	-6,17%	-11,73%	-23,46%	-14,81%	-25,93%

Scenario 4b: Bolk lowering emissions
In this scenario, we test the effect on Bolk's region in case Bolk is able to decrease its internal emissions. As done in the previous scenario as well, we lower the emission rate of barge and truck transport by 10% and 20%. Results are shown in Table 18. Same as for the last scenario, most effect on the region is made by lowering the barge emissions since it will cover most of the transport emission by a customer in the region. As shown in test two, by lowering the barge emissions by 20%, an increase of 11% can be made in the region. From this scenario, we conclude for increasing the region, by decreasing emissions, Bolk should focus on lowering their barge emissions in the transport chain. A note should be made that in this scenario, we did not include any possible increase in transport prices as a result of decreased emissions. More sustainable barges can for example be more expensive, due to high investment costs. Since we do not have sufficient insights into these possible price increases, we did not include them in the scenario.

Table 18: Output scenario 4b: decreasing Bolk's emissions

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8
Barge	-10%	-20%	0	0	-10%	-20%	-10%	-20%
Truck	0	0	-10%	-20%	-10%	-10%	-20%	-20%
#Customers	171	180	166	170	174	187	180	196
Increase in region	5,56%	11,11%	2,47%	4,94%	7,41%	15,43%	11,11%	20,99%

6.3 Validation and verification

*In this public version, confidential visualizations are left out, and text is adapted to still understand the approach and results.

In this section, it is explained how the outcomes of the model are validated are verified. We first start with verification. This is done by checking the outcome of the model for one individual customer. We selected customer 'Hardenberg' to be investigated. According to the model, the optimal price for Bolk is €1.79 per km for transport by Barge and €1.80 per km for road transport, and therefore a customer within Bolk's region. These values are within the defined price constraints. To verify if this outcome is valid, we calculated all the steps by hand in order to compare. We tested if Bolk's utility score is less than the best alternative. In this case, the potential customer is in Bolk's maximized region. In Appendix C, an extensive overview of all the calculations is provided. Out of these calculations, it can be seen that Bolk's utility score is slightly less than the best alternative in the case of this specific customer.

Second, the outcome of the model is validated. It is hard to validate the performance of the model, due to lack of data. There is no data about the performance and region of the competitors. In order to still validate the outcome of the model, the results are presented to experts within Bolk and compared to historical customer data. First, the comparison with the historical data is explained. From CTT, we obtained customer data from 2022 representing data about customers who booked a container from Rotterdam, via barge by CTT and last-mile transportation by Bolk. These are intermodal customers, not end-to-end logistics customers. In the data, the locations of the customers with corresponding amounts of containers can be read. We added to the data the corresponding zip codes, to compare it with the output of the model. This is done in two ways. First, the customer locations in Bolk's region are compared. In 2022, CTT had 119 zip codes in which customers are located. These are locations in which one or more containers are delivered, as also locations in which only a few containers are delivered in the whole year. Of the 130 locations, 31 are positioned in Bolk's region, which is only 26%. The customers are located all around the investigated region in the Netherlands and Germany. The low percentage is explained as follows. Looking at the volume per customer, it can be seen that most of the customers located out of Bolk's region have a low volume of containers per year. To be more precise, 54791 containers were transported via the terminals of CTT in 2022, of which 41902 containers were delivered inside Bolk's region. This is 76.5%. In other words, the 31 customers (26% of the CTT's total customers) inside Bolk's region are responsible for 76.5% of the volume.

The validation results are presented to several directors of Bolk and other stakeholders in the research. The competitive region is in line with the expectations of the directors. Practical issues are the reason why most of CTT customers are out of Bolk's region (not looking at volumes). As explained, most of these customers have a low volume of purchases from Bolk. In case a competitive terminal is not available, companies book a container via Bolk as the best alternative. Moreover, to spread the risks of booking containers all via one terminal, some companies also book containers via other terminals, such as Hengelo and Almelo. Another reason has to do with the import and export chain. Shipping companies are the owner of the container and want to reduce the time a container is empty. Therefore, it is more beneficial if a container can be transported from a seaport to the customer and from there the other way around back to the port. The directors mentioned that therefore companies outside the region select Bolk because containers need to return back to Rotterdam instead of a German port for example.

6.4 Conclusions

In this chapter, we aimed to answer the question '*What experiments can be employed to investigate the performance of the model, and what are the corresponding outcomes or findings of these experiments?*'. To do so, we first ran the model for the base instance. From this, we found that the maximized region is 162 customers in the case of the deterministic model, and an average of 181 customers for the stochastic model. The extreme values of the model, given the base instance, are found and tell us what the most extreme objectives are. From the sensitivity analysis, we conclude that the utility function is most sensitive to the time objective, compared to price and emissions.

We defined four experiments, based on real-life situations that occurred in the past or can occur in the future. From the first experiment, which focussed on price fluctuations at Bolk, we conclude the following things. First, in case low water levels occur in the 'Twentekanaal', resulting in a price increase, Bolk's region can decrease up to 38% for a 33% price increase and will as a result centralizes just around the terminals in Almelo and Hengelo. Second, in case barges with 3-layers of containers are able to go through the 'Twentekanaal', resulting in a price decrease, Bolk's region can grow up to 55.56% for a price decrease of 33%. We can therefore conclude that Bolk's region is more sensitive to a price decrease than to a price increase. In the second experiment, we tested the effects of a new competitor located in Deventer. From this experiment, we conclude a small loss in the west side of Bolk's region will be made, which can be increased if customers are more emission focussed, due to fewer barging distances to be made via Deventer. The third experiment tested fluctuations in rail transport. From this experiment, we conclude that less transport via Osnabrück will increase Bolk's region to the east part. Moreover, a subsidy for rail transport, resulting in a price decrease for transport by rail, will not affect Bolk's region. In the last experiment, we focused on emissions. We conclude that Bolk's region is most sensitive to changes in barge emissions by competitors. Therefore we conclude as well that for an increase in the region, Bolk should lower the emissions by barge.

We verified and validated the model. The verification is done by recalculating the optimal outcome for a specific customer. The optimal prices for this customer satisfy the formulas and constraints. We validated the model by comparing the results with CTT's customer dataset of 2022. If we only look at the locations of the customers, we conclude that only 26% of the customers are positioned in Bolk's region. Taking into account the corresponding volumes of the customer, it creates a more realistic view. Doing this, we conclude that 76,5% of the volume is generated by customers inside Bolk's region.

7 Implementation and evaluation

In this chapter, we describe the implementation of the solution method and how it can be evaluated over time. We do this by answering the following research question.

How can the solution method be implemented and evaluated?

Four sub-questions are answered, to provide insights for answering the research question.

- How can the model be implemented in a practical way for Bolk?
- How can the model be used by BBI?
- How can the model be implemented for other companies?
- How can the model be evaluated over time?

The chapter is built as follows. First, the implementation plan is described in Section 7.1. Second, in Section 7.2 it is explained how the solution method can be evaluated over time. Last, the conclusion is given in Section 7.3.

7.1 Implementation

In order to implement the solution method, we first shortly recap the action and core problem to understand the need for implementation. In Chapter 1, we formulated the action problem as follows:

'No customers that make use of Bolk's end-to-end logistics'

There was a gap between the norm and reality. In order to tackle this, the core problem, 'unknown what end-to-end logistics can provide for Bolk's geographic competitive position', is solved. The gap can be bridged by using the solution model and corresponding insights. In this section, we provide an implementation plan for Bolk Business Improvement, which is a brief description of the necessary activities. The aim is to actively search for end-to-end logistics customers, using the insights of this research.

This chapter is structured as follows. First, we describe in Section 7.1.1 how BBI can implement the solution method to actively search for E2E logistics customers, we do this from a strategic perspective. Second, a tool is developed, and it can be used internally is explained in 7.1.2. Last, how the solution method can be applied for other companies as well is provided in Section 7.1.3.

7.1.1 Strategic implementation

We solved the core problem to be able to solve the action problem as well. The target is simply formulated, finding customers for the combined Bolk's services, further addressed as the end-to-end (E2E) logistics solutions. With the findings from the solution method, Bolk's maximized geographic competitive position is known, meaning that in this area Bolk is the best logistics option. Knowing this, BBI can apply two strategies.

First, from CTT's historical customer dataset, we saw that approximately 77% of the yearly volume is transported within the competitive position of Bolk. To recap again, these are companies that choose only for transportation solutions by CTT and Bolk. From the insights of the model, we see which customers are located in the region. BBI can approach these companies and try to convince them to choose logistics services as well, by offering them E2E logistics.

The second approach involves actively targeting companies located in Bolk's maximized region, excluding cities where existing CTT customers are located because targeting these companies is part of the first strategy. By doing so, new E2E logistics customers might be found. In order to implement this strategy, we analyzed the outcomes of the solution method, for running it under the base instance. We tracked all the zip codes with the corresponding probability of acceptance. We created a list, consisting of cities located inside Bolk's region within the acceptance probability categories of 0.4 and higher. The list is shown in Figure 23 in Appendix D. Using the outcomes of the solution method, for each of these cities, the optimized price is determined.

For companies located in these zip codes, BBI can use the model to create additional insights. In this research, the model is run for an average customer profile. The model can be adjusted to match the customers values. In case the company is located inside Bolk's region, BBI can show the visualization to the company, in order to convince them for choosing Bolk. Moreover, from the optimization model, BBI can see what the optimal price is for this specific company. The weights of the customer can simply be implemented by changing the input parameters of the KPI weights in the model.

7.1.2 Internal use: Tool implementation

In order to actively search for customers, a tool is created to help companies understand the possibility for end-to-end logistics and intermodal transportation. The model is built in *PowerBI*, consisting of two dashboards. Overview of the two dashboards are shown in Appendix E, respectively in Figure 26 and 27. The basis of the dashboards is the deterministic model, with fixed parameters. The wish of the stakeholders was a dashboard in which easily the value of the parameters can be changed. The input data is used, and the same calculations as done in *Python* are used in *PowerBI*. Since, the program does not allow quick optimizations, such as done with *Gurobi*, the model is run with fixed parameters. BBI can still use the output of the optimization model as input for the tool. This is explained by describing the two dashboards.

The first dashboard is an overview of Bolk's competitive position. This is constructed in the same way as done in *Tableau*. In the dashboard, two maps are shown, one from the selected zip codes from the Netherlands, the other one from Germany. Beneath the two visualizations, all the important parameters of the model are displayed. Making use of measures in *PowerBI*, the values of the parameters are directly connected to the calculations. In other words, changing the value in the dashboard will make sure all calculations are done again and the visualizations will be updated automatically. BBI can therefore easily see what the new region is.

The second dashboard is customer focused. Multiple KPIs are shown to create insights for a company about the different transport and logistics possibilities. In the dashboard, the user can enter a specific zip code. All the output is based on the selected zip code. The scores of the four modalities, barge transport by Bolk, rail transport, direct trucking, and barge transport, are shown as a value. Moreover, they are positioned in a graph to visualize the differences between them. The comparison score as well as the distance to Bolk's closest warehouse are shown as well. Beneath the KPIs, all the parameters are listed. Based on the company's preferences the outcome of the model can be adjusted, for example, if a company is more focused on emissions. BBI can use this tool in case they want to convince a company to choose Bolk's end-to-end logistics services and help them think about the different options. Moreover, BBI knows the optimized price for the specific zip code, and can easily enter that price in the tool.

7.1.3 External use

As stated in Section 1.4.5, one of BBI's requirements was that the model can applied in other areas or for other companies as well. As explained, BBI is a consulting company, offering solutions for both Bolk as well as for external companies. Therefore, there is a wish to implement the solution method to make sure BBI is able to potentially use it for other companies as well. One assumption needs to be made in order to apply it to the same end-to-end logistics issue. The warehouse is directly located next to the container terminal, resulting in a negligible distance from the terminal to the corresponding warehouse. Eight steps are defined and provided in detail in Appendix F. In the same appendix, an overview is given with technical details of the solution method. This is useful to fully implement it externally.

7.2 Evaluation

When implementing a solution, it is important to evaluate it over the long term. After implementation, BBI is in the lead for evaluation. We describe four important evaluations. First how the input data can be evaluated, and next, three evaluations are defined based on insights from Heerkens and Winden (2017).

7.2.1 Input evaluation

Using the right and reliable input data is necessary in order to draw the right conclusions. Therefore, regularly the input data should be checked, if it still can be used. The input data should be changed in case of the following situations:

- New competitors enter the market by opening new terminals (e.g. such as done in Section 6.2.2). In this case, the location of the terminal should be added, including corresponding distances, to the input data of the terminals, and the model should be run again in order to draw the right conclusions.
- Terminals are closed or not available. In this case, the terminal should be deleted from the input data, and the model should be run again.
- Price changes. In case the prices of modalities are increased, these should be adapted to the new standards.

7.2.2 Summative evaluation

Checking whether the goals have been met is defined as summative evaluation (Heerkens and Winden, 2017). The goal is to have E2E logistics customers. This can easily be checked, whether this is the case or not. Also, it should be analyzed if part of the goals are met, in case new customers do not fully select the E2E but for example just the transportation or logistics part.

7.2.3 Formative evaluation

Finding out the causes of the effects, for example, checking whether the implementation went according to plan is defined as formative evaluation (Heerkens and Winden, 2017). BBI should investigate what the causes are and whether the goals are met or not. In case BBI will have E2E logistics customers, they should investigate what the reasons of the companies are for selecting Bolk as the best option. Have the outcomes of the model been used for approaching this customer and convincing it? These are questions that need to be asked. In case BBI is not able to find companies for E2E logistics, the causes of this need to be written down in order to evaluate it.

7.2.4 Improvements

The last step is the improvement step. As the evaluation ends, the feedback process begins. From the results of the formative evaluation, a list should be created with focus points in order to improve the solution method. If BBI experiences at some point a discrepancy between the norm and reality, new research should be defined in order to solve this gap.

7.3 Conclusion

In this chapter, we discussed how the solution method can be implemented and evaluated at Bolk Business Improvement, as well as for other companies. The need for implementation is addressed by referring to the core and action problems. The core problem is solved, implementation is needed to solve the action problem. Strategic implementation is provided. A list is created with locations in which potential customers might be located. This list can be used to actively search for E2E logistics customers. Technical details are explained on how to use make use of the solution method from a technical perspective. Moreover, the model can be used for external companies as well, by following the provided steps. Last, the solution method can be evaluated by making use of input evaluation, summative evaluation, formative evaluation, and improvements.

8 Conclusions, recommendations, and future research

Within this thesis, an optimization model has been formulated and executed to identify how Bolk's geographic competitive position can be maximized, based on end-to-end logistics. This is done by analyzing the current situation and performing a literature study. Using the insights from theory to formulate a basic comparison model. Next, going one step further by formulating an optimization model and testing it under different experiments. Last, write down an implementation and evaluation plan in order to reach the end goals. In this last chapter, we discuss the last research question:

'What recommendations and conclusions can be made from conducting the thesis at Bolk Business Improvement?'

This is done by answering the following sub-questions:

- What are the main conclusions from conducting the thesis?
- What are the main recommendations for conducting the thesis?
- What are the theoretical and practical contributions of the research?
- Which limitation can be formulated related to the research?
- In which area is further research needed?

Section 8.1 provides the conclusions. The recommendations are given in Section 8.2. The theoretical and practical contributions are explained in Section 8.3. Last, the limitations and suggestions for future research are provided in Section 8.4.

8.1 Conclusions

We defined Bolk's end-to-end logistics as the combined services of barge transport by CTT, logistics solutions by Bolk Logistics, and container transport by Bolk container transport, all supervised by Bolk Business Improvement. To find E2E logistics customers, we tackled the problem from a strategic perspective by investigating what Bolk's maximized competitive position is to find information in which region potential customers are located. Context analysis is performed to understand the current intermodal transport network around Bolk's facilities as well as to understand the pros and cons of different modalities. Out of the literature review, insights from the LAMBIT model (Macharis, 2000), probabilistic port hinterland model (Wang et al., 2016) and revenue management (Bilegan et al., 2022) are selected to formulate the model to maximize Bolk's competitive position. As a start, a simple comparison model is formulated to figure out Bolk's competitive position based on time, price, and emissions, taken separately from each other. After that, an optimization model is formulated, in which Bolk's competitive position is maximized, by determining the optimal price for each customer, taking into account time, price, and emissions combined. Experiments are executed to measure the effect on the region under different scenarios.

After this research, we conclude that we solved the core problem: 'Unknown what end-to-end logistics can provide for Bolk's geographic competitive position'. An implementation and evaluation plan has been formulated to bridge the gap between the core problem and the action problem: 'No customers that make use of Bolk's end-to-end logistics'. Out of this research, we listed the following conclusions for BBI:

1. Using the optimization model, we are able to determine Bolk's maximized region, resulting in visualized maximized region. Moreover, the optimized price for each potential customer is determined based on the model.
2. For actively searching for end-to-end logistics customers, Bolk can make use of the compiled list of locations, as shown in Figure 23.
3. In the event of a low-water scenario, Bolk's region has the potential to shrink by as much as 40%, caused by a corresponding price reduction of 33.3%.
4. In case CTT is able to transport by barge with three layers of containers, Bolk's region has the potential to increase up to 55% for a price decrease of 33.3%.
5. Reduction in Bolk's region in case of an operating barge terminal in Deventer will be minor; 5.73%. This percentage can increase to 16.7%, dependent on how much a customer is focussed on emissions. The loss is on the southeast side of Bolk's facilities.

6. The rail terminal in Osnabrück has a minor impact on Bolk's competitive position.
7. Subsidies for rail transport in order to decrease the price of rail transport have approximately no impact on Bolk's region.
8. Based on time, Bolk's is positioned in an area in which the transit time by truck is the highest, due to the position between the Dutch and German ports. Making it interesting for alternatives for road transport, as shown in Figure 18.
9. Looking at the different modalities, Bolk's region based on price is mostly surrounded by barge transport by competitors, and rail transport on the east side, as shown.

8.2 Recommendations

Based on the performed research and stated conclusions, we set up a list with recommendations for Bolk Business Improvements.

1. Use the optimization model for determining the optimal price for a customer, as a decision-helping tool. To actively help a company select the right transport and logistics solution, it is recommended to make use of the tool.
2. To execute E2E logistics with proper preparation, we recommend formulating a tactical and operation plan for E2E logistics, starting with tactical. The focus should lie on communication between BBI, CTT, Bolk Logistics, and Bolk container transport. Moreover, in the plan also the alignment between the technical details of the different IT systems should be described. The daily tasks should be explained in the operation plan. BBI should take the lead.
3. To expand the competitive region, we recommend Bolk focus on reducing emissions by barge transport. A decrease of 20% emissions by barge can cause an increase of 11% in Bolk's region. To further enhance the region, we secondly recommend focusing on reducing truck emissions for reducing the total CO_2 caused by the E2E logistics.
4. We recommend using the list with locations in which potential customers might be located for actively searching for E2E logistics customers.
5. Focus on international-oriented companies, since Twente is more attractive on the international market compared to national companies.
6. If E2E logistics is applied, we recommend sending one invoice to the customer, made by BBI. By doing so it will be easier for the customer, instead of paying four different invoices to each of the separate Bolk companies.
7. We recommend Bolk to calculate its internal emissions according to the GLEC Model. By doing so, the emissions per customer can be communicated according to an international standard.

8.3 Contribution

In this section, the theoretical and practical contribution of the research is described.

8.3.1 Theoretical contribution

In this research, we conducted a literature study on intermodal transport networks, and especially how to map the network. Moreover, theoretical insights about the probabilistic port hinterland model (Wang et al., 2016), revenue management in intermodal transportation (Bilegan et al., 2022), and multinomial logit model (Al-Salih and Esztergár-Kiss, 2021) are taken into account by formulating the optimization model. The utilization of GIS to map transportation solutions, based on insights from the LAMBIT model, is recognized in the literature as a valuable contribution to strategic decision-making (Macharis, 2000). Moreover, revenue management models enable policymakers to develop strategies. As explained in Chapter 3, limited literature is available describing end-to-end logistics.

Our contribution lies in transferring the end-to-end logistics issue to strategic research, making use of both insights from the LAMBIT model and GIS as well as revenue management in intermodal transportation. By doing so, we created an optimization model that is able to calculate the price for a customer and provide strategic insights into the different intermodal transportation options. Combining these elements is not addressed in the literature.

8.3.2 Practical contribution

This research is performed at Bolk Business Improvement, in cooperation with the different companies of the Bolk Group. The practical contribution to the company is the model for determining the optimal price per potential customer. Moreover, multiple geographic maps of Bolk's competitive position are delivered. On top of that, by using the model with specific customer weights, the maps can be changed for specific companies. Since BBI does also perform consultancy assignments, the practical contribution is as well that the model can be applied to other companies as well. Moreover, the created tool can be used to actively guide companies in selecting the right transport and logistics solution. Last, we have proven that we transferred the theoretical insight out of the LAMBIT and the probabilistic port hinterland models into a practical model which can be used by BBI in the field, and can be used to convince a potential customer to select Bolk to perform their logistics and transportation operations.

8.4 Limitations and future research

This master's thesis deals with different complex issues. In order to limit the complexity, a scope, and assumptions were needed. The research has multiple limitations but also potential for future research. The following limitations are formulated:

- As described in Section 2.3.4, multiple different variables are involved in the modal choice. Due to the complexity, we had to make assumptions to leave out different variables, as written down in Section 4.1.2. Monios and Bergqvist (2017) mentioned as well that strategic models are less detailed but more complex due to the unstructured problem and wide scope. Future research can be done in formulating a model which takes into account more variables, such as volume, availability, and reliability. Moreover, the type of product to be transported is not taken into account in this research. Future research could be made in investigating what the best suitable type of product is for end-to-end logistics in the case of Bolk.

- This research is performed from a strategic perspective. In practice, executing E2E logistics can be very complex, because besides the different companies in the Bolk group, also other companies/organizations need to be involved, such as customs, freight forwarders, and shipping companies. Future research is needed to investigate how E2E logistics can be applied from a tactical and operational perspective on a day-to-day basis.

- In the model, input data for the competitors are all equal, due to lack of data about the competitors. In practice, this will not be the same. Future research can be done in adapting the model such that all competitors can have different input data.

- We wanted to stay in line with the insights from the optimization models described by Wang et al. (2016) and Monios and Bergqvist (2017), making use of the probability of utility for a mode choice. Due to a lack of customer behavior, assumptions needed to be made. This is a main limitation. Future research can be done on customer behavior, by performing interviews and conducting surveys to different companies about their modal selection and adapting this in the model by assigning a distribution.

- In the stochastic part of the model, a probability category is defined in which the probability is zero. Looking at CTT's customer data, customers can be discovered who are located in the zero probability area, although they have chosen CTT in the past. It is a limitation that the probabilities are not connected to CTT's customer data in this case.

- The stochastic part of the model is run after the deterministic part. A limitation of the research is the fact that this is not combined into one model, in which the model determines the optimal price taking into account the probabilities at first.

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A Model details

In this appendix, the parameters used in Section 5.1.1 are provided. Moreover, the pre-calculations are given as well.

Parameters

$D_{p,c}$	Distance from port p to customer c in kilometers
$D_{p,b}$	Distance from port p to barge terminal b in kilometers
$D_{b,c}$	Distance from barge terminal b to customer c in kilometers
$D_{p,r}$	Distance from port p to rail terminal r in kilometers
$D_{r,c}$	Distance from rail terminal r to customer c in kilometers
α_c	Weight for costs for customer c
β_c	Weight for emissions for customer c
γ_c	Weight for time for customer c
E_t	Emission rate truck per km in kg CO_2
E_b	Emission rate barge per km in kg CO_2
E_r	Emission rate rail per km in kg CO_2
E_{trans}	Emission rate for transshipment in kg CO_2
$T_{p,b}$	Time from port p to barge terminal b in minutes
$T_{p,r}$	Time from port p to rail terminal r in minutes
T_t	Time truck per km in minutes
P_t	Price truck per km in euros
P_b	Price barge per km in euros
P_r	Price rail per km in euros
P_{Start}	Price basic fare using road transport
$TotalPrice_{c,m}$	Total price for customer c for using modality m in euros
$TotalEmissions_{c,m}$	Total emissions for customer c for using modality m in euros
$TotalTime_{c,m}$	Total transit time for customer c for using modality m in euros
$MaxTotalPrice$	Maximum Possible Price to pay for a customer
$MaxTotalEmissions$	Maximum possible Emissions for a customer in kg CO_2
$MaxTotalTime$	Maximum possible Total Time for a customer in minutes
$V_{c,m}$	Value of the utility function of modal choice m by customer c

First, the price for each modality except Bolk is calculated. The total price for using road transport is calculated by multiplying the distance from a seaport to the end customer times the price factor for road transport, as can be seen in Formula (30). For the modalities of inland waterway and rail transport, the price is slightly different calculated. First, the price is determined for transporting a container from the seaport to the inland terminal by multiplying the distance times the price factor for the modality. The last-mile transport from the terminal to the end customer is done by truck and therefore the price is determined by multiplying the distance times the price factor for road transport. Moreover, using a truck, an additional basic fare need to be paid. This is formulated in Equation (30). The equations for barge transport are expressed in Formula (31) and rail transport in Equation (32).

$$TotalPrice_{c,truck} = D_{p,c} \cdot P_t + P_{start} \quad \forall c \in \mathcal{C} \tag{30}$$

$$TotalPrice_{c,barge} = D_{p,b} \cdot P_b + D_{b,c} \cdot P_t + P_{start} \quad \forall c \in \mathcal{C} \tag{31}$$

$$TotalPrice_{c,Train} = D_{p,r} \cdot P_r + D_{r,c} \cdot P_t + P_{start} \quad \forall c \in \mathcal{C} \tag{32}$$

Second, the emissions are calculated. The total emissions for each modality are calculated in the same way as the total price, but using the emission factor for each modality instead of the price factor. The formulas for road, barge, and rail transport can be seen respectively in Equations (33), (34), and (35).

$$TotalEmissions_{c,truck} = D_{p,c} \cdot E_t \quad \forall c \in \mathcal{C} \tag{33}$$

$$TotalEmissions_{c,barge} = D_{p,b} \cdot E_b + D_{b,c} \cdot E_t + E_{trans} \quad \forall c \in \mathcal{C} \tag{34}$$

$$TotalEmissions_{c,Train} = D_{p,r} \cdot E_r + D_{r,c} \cdot E_t + E_{trans} \quad \forall c \in \mathcal{C} \tag{35}$$

Third, the transit time is calculated. The transit time for each modality is as well calculated using the same construction as for the price calculation, but using distance multiplied by the time factor per kilometer, resulting in a total time in minutes. The formulas for road, barge, and rail transport can be seen respectively in Equations (36), (37), and (38).

$$TotalTime_{c,truck} = D_{p,c} \cdot T_t \quad \forall c \in \mathcal{C} \tag{36}$$

$$TotalTime_{c,barge} = D_{p,b} \cdot T_{p,b} + D_{b,c} \cdot T_t \quad \forall c \in \mathcal{C} \tag{37}$$

$$TotalTime_{c,Train} = D_{p,r} \cdot T_r + D_{r,c} \cdot T_t \quad \forall c \in \mathcal{C} \tag{38}$$

B Sensitivity analysis

Table 19: Outcome of the sensitivity analysis on MaxTotalPrice

MaxTotalPrice	#customers	Revenue
500	187	99730
1000	171	92055
1500	164	88929
1793	162	88057
2000	159	86651
2500	153	83721

Table 20: Outcome of the sensitivity analysis on MaxTotalEmissions

MaxTotalEmissions	#customers	Revenue
500	187	99730
1000	171	92055
1500	164	88929
1793	162	88057
2000	159	86651
2500	153	83721

Table 21: Outcome of the sensitivity analysis on MaxTotalTime

MaxTotalTime	#customers	Revenue
1000	84	41321
1800	148	79705
2000	155	83878
2222	162	88057
2400	163	88970
3000	170	93288
5000	173	97328

C Calculation validation

In this section in the appendix, we provide a calculation verification of the optimization model, by calculating the steps the model takes in order to determine the optimal price for a customer. In this calculation example, we selected customer 'Hardenberg' to be investigated. Based on shortest distances, in the case of Hardenberg, the best port for direct trucking is Bremen. The shortest option for barge not done by Bolk is via Rotterdam to Meppel. Train transport from Bremen to Osnabrück is the best option by rail. For these three options, the utility scores are calculated to determine $MinV_{Hardenberg,m}$. Using the following input data, the utility scores are calculated.

Input data

$D_{Bremen,Hardenberg}$	223.545 km
$D_{Rotterdam,Kampen}$	173 km
$D_{Kampen,Hardenberg}$	66.987
$D_{Bremen,Osnabrck}$	197 km
$D_{Osnabrck,Hardenberg}$	117.455 km
α_c	0.6
β_c	0.3
γ_c	0.1
E_t	0.75 kg CO_2
E_b	0.260 kg CO_2
E_r	0.170 kg CO_2
E_{trans}	38 kg CO_2
$T_{Rotterdam,Kampen}$	900 min
$T_{Bremen,Osnabrck}$	1080 min
T_t	1.083 min per km
P_t	€ 2.10
P_b	€ 1.72
P_r	€ 2.0
P_{Start}	€ 100

For each of the modalities, the total price, total emissions, and total time is calculated in order to calculate the utility scores. This is done by using the following calculations.

$$TotalPrice_{Hardenberg,truck} = D_{Bremen,Hardenberg} \cdot P_t + P_{start} = 223.55 \cdot 2.10 + 100 = 569.44$$

$$TotalPrice_{Hardenberg,Kampen} = D_{Rotterdam,Kampen} \cdot P_b + D_{Kampen,Hardenberg} \cdot P_t + P_{start} =$$
$$173 \cdot 1.72 + 66.99 \cdot 2.10 + 100 = 538.23$$

$$TotalPrice_{Hardenberg,Train} = D_{Bremen,Osnabrck} \cdot P_r + D_{Osnabrck,Hardenberg} \cdot P_t + P_{start} =$$
$$197 \cdot 2.0 + 117.45 \cdot 2.10 + 100 = 740.66$$

$$TotalEmissions_{Hardenberg,truck} = D_{Bremen,Hardenberg} \cdot E_t = 223.55 \cdot 0.75 = 167.66$$

$$TotalEmissions_{Hardenberg,barge} = D_{Rotterdam,Kampen} \cdot E_b + D_{Kampen,Hardenberg} \cdot E_t + E_{trans} =$$
$$173 \cdot 0.260 + 66.987 \cdot 0.75 + 38 = 133.15$$

$$TotalEmissions_{Hardenberg,Train} = D_{Bremen,Onsabrck} \cdot E_r + D_{Osnabrck,Hardenberg} \cdot E_t + E_{trans} =$$
$$197 \cdot 0.170 + 117.45 \cdot 0.75 + 38 = 159.58$$

$$TotalTime_{Hardenberg,truck} = D_{Bremen,Hardenberg} \cdot T_t = 223.55 \cdot 1.083 = 242.10$$

$$TotalTime_{Hardenberg,barge} = T_{Rotterdam,Kampen} + D_{Kampen,Hardenberg} \cdot T_t = 1200 + 1.083 \cdot 117.46 = 1272.55$$

$$TotalTime_{Hardenberg,Train} = T_{Bremen,Osnabrck} + D_{Osnabrck,Hardenberg} \cdot T_t = 1080 + 1.083 \cdot 117.46$$

$$V_{Hardenberg,truck} = \alpha_c \cdot \frac{TotalPrice_{Hardenberg,truck}}{MaxTotalPrice} + \beta_c \cdot \frac{TotalEmissions_{Hardenberg,truck}}{MaxTotalEmissions} +$$

$$\gamma_c \cdot \frac{TotalTime_{Hardenberg,truck}}{MaxTotalTime} = 0.6 \cdot \frac{569.44}{1793.48} + 0.3 \cdot \frac{167.66}{354.07} + 0.1 \cdot \frac{242.10}{2222.16} = 0.34$$

$$V_{Hardenberg,Barge} = \alpha_c \cdot \frac{TotalPrice_{Hardenberg,Barge}}{MaxTotalPrice} + \beta_c \cdot \frac{TotalEmissions_{Hardenberg,Barge}}{MaxTotalEmissions} +$$

$$\gamma_c \cdot \frac{TotalTime_{Hardenberg,Barge}}{MaxTotalTime} = 0.6 \cdot \frac{538.23}{1793.48} + 0.3 \cdot \frac{133.15}{354.07} + 0.1 \cdot \frac{1272.55}{2222.16} = 0.35$$

$$V_{Hardenberg,Rail} = \alpha_c \cdot \frac{TotalPrice_{Hardenberg,Rail}}{MaxTotalPrice} + \beta_c \cdot \frac{TotalEmissions_{Hardenberg,Rail}}{MaxTotalEmissions} +$$

$$\gamma_c \cdot \frac{TotalTime_{Hardenberg,Rail}}{MaxTotalTime} = 0.6 \cdot \frac{740.66}{1793.48} + 0.3 \cdot \frac{159.58}{354.07} + 0.1 \cdot \frac{1207.20}{2222.16} = 0.44$$

$$MinV_{Hardenberg} = 0.34 \quad (Truck\ transport)$$

In the case of Hardenberg, the best score out of barge, truck, and rail is transportation by truck. Now, we can determine the optimal price for transport by Bolk. In the case of Hardenberg, using the barge terminal in Almelo is more beneficial than Hengelo. The total emissions and time for transport from Rotterdam to Almelo by Barge and Almelo to Hardenberg by truck are calculated:

$$TotalEmissions_{Hardenberg,Bolk} = D_{Rotterdam,Almelo} \cdot E_b + D_{Almelo,Hardenberg} \cdot E_t + E_{trans} =$$

$$212 \cdot 0.260 + 33.60 \cdot 0.75 + 38 = 115.32$$

$$TotalTime_{Hardenberg,Bolk} = T_{Rotterdam,Almelo} + D_{Almelo,Hardenberg} \cdot T_t = 1200 + 33.60 \cdot 1.083 = 1234.68$$

The final step is to verify the outcome of the model in the case of Hardenberg. The formula for the utility function of Bolk is formulated as follows:

$$V_{Hardenberg,bolk} = 0.6 \cdot \frac{TotalPrice_{Hardenberg,bolk}}{1793.48} + 0.3 \cdot \frac{115.32}{354.07} + 0.1 \cdot \frac{1234.68}{2222.16}$$

According to the model, $P_{BolkBarge_Hardenberg} = 1.79$ and $P_{BolkTruck_Hardenberg} = 1.8$ resulting in the following $TotalPrice_{Hardenberg,Bolk}$ and utility score:

$$TotalPrice_{Hardenberg,Bolk} = 212 \cdot 1.79 + 33.60 \cdot 1.8 + 100 = 540.48$$

$$V_{Hardenberg,Bolk} = 0.6 \cdot \frac{540.48}{1793.48} + 0.3 \cdot \frac{115.32}{354.07} + 0.1 \cdot \frac{1234.68}{2222.16} = 0.34$$

We can verify the outcome of the model since both values are equal. The model has increased the price for barge transport by Bolk such that the utility score of Bolk is equal in value with the $MinV_{Hardenberg}$. Due to rounding of the numbers, the values are equal. Looking at the exact outcomes of the model, we see that $V_{Hardenberg,Bolk}$ is slightly less than the competitor ($5.15e^{-12}$). The prices are between the defined boundaries and therefore we conclude that the outcome of the model in the case of Hardenberg is verified.

D Implementation

Zipcode	Country	City
48341	Germany	Altenberge
48727	Germany	Billerbeck
48488	Germany	Emsbüren
48465	Germany	Engden, Isterberg, Schüttorf u.a.
49828	Germany	Esche
48329	Germany	Havixbeck
48612	Germany	Horstmar
49847	Germany	Itterbeck/Wielen
48366	Germany	Laer
48739	Germany	Legden
48629	Germany	Metelen
49824	Germany	Ringe, Laar, Emlichheim
48720	Germany	Rosendahl
48499	Germany	Salzbergen
48624	Germany	Schöppingen
48703	Germany	Stadtlohn
49843	Germany	Uelsen, Halle, Gölenkamp, Getelo
48691	Germany	Vreden
49849	Germany	Wilsum
7157	Netherlands	Berkelland
8153	Netherlands	Dalfsen
7635	Netherlands	Dinkelland
7775	Netherlands	Hardenberg
7687	Netherlands	Hellendoorn
7496	Netherlands	Hof van Twente
7731	Netherlands	Ommen
7461	Netherlands	Rijssen-Holten
7675	Netherlands	Twenterand

Figure 23: Cities in which potential customers might be located, based on the output of the optimization model.

```
#API function to calculate the distances
def findTravelDistance(From, To):
    str_req = 'http://dev.virtualearth.net/REST/V1/Routes/Driving?o=xml&wp.0={}&wp.1={}&key=Aos9msiDIuvYiffuHh7wsfWWkH5fDO0BtX24c008aHm_71DJBsrCh9yVFVicTcym'.format(From, To)
    req = requests.get(str_req)
    if req.status_code == 200:
        xml_document = xmltodict.parse(req.text)
        return xml_document['Response']['ResourceSets']['ResourceSet']['Resources']['Route']['TravelDistance']
```

Figure 24: Python code of the API calculation function

PercentageNL.txt Zipcode (PercentageNL.txt)	PercentageNL.txt Country (PercentageNL.txt)	PercentageNL.txt Score (PercentageNL.txt)
07741	Netherlands	-5,6046
07761	Netherlands	-11,6616
07776	Netherlands	-4,4685
07846	Netherlands	-14,4075
07872	Netherlands	-21,8221
08028	Netherlands	-16,9004
08262	Netherlands	-31,5272
08346	Netherlands	-24,4124
08437	Netherlands	-20,9856

Figure 25: Overview of how the data is stored in *Tableau*, using the combination of zip code and country.

E Implemented tool

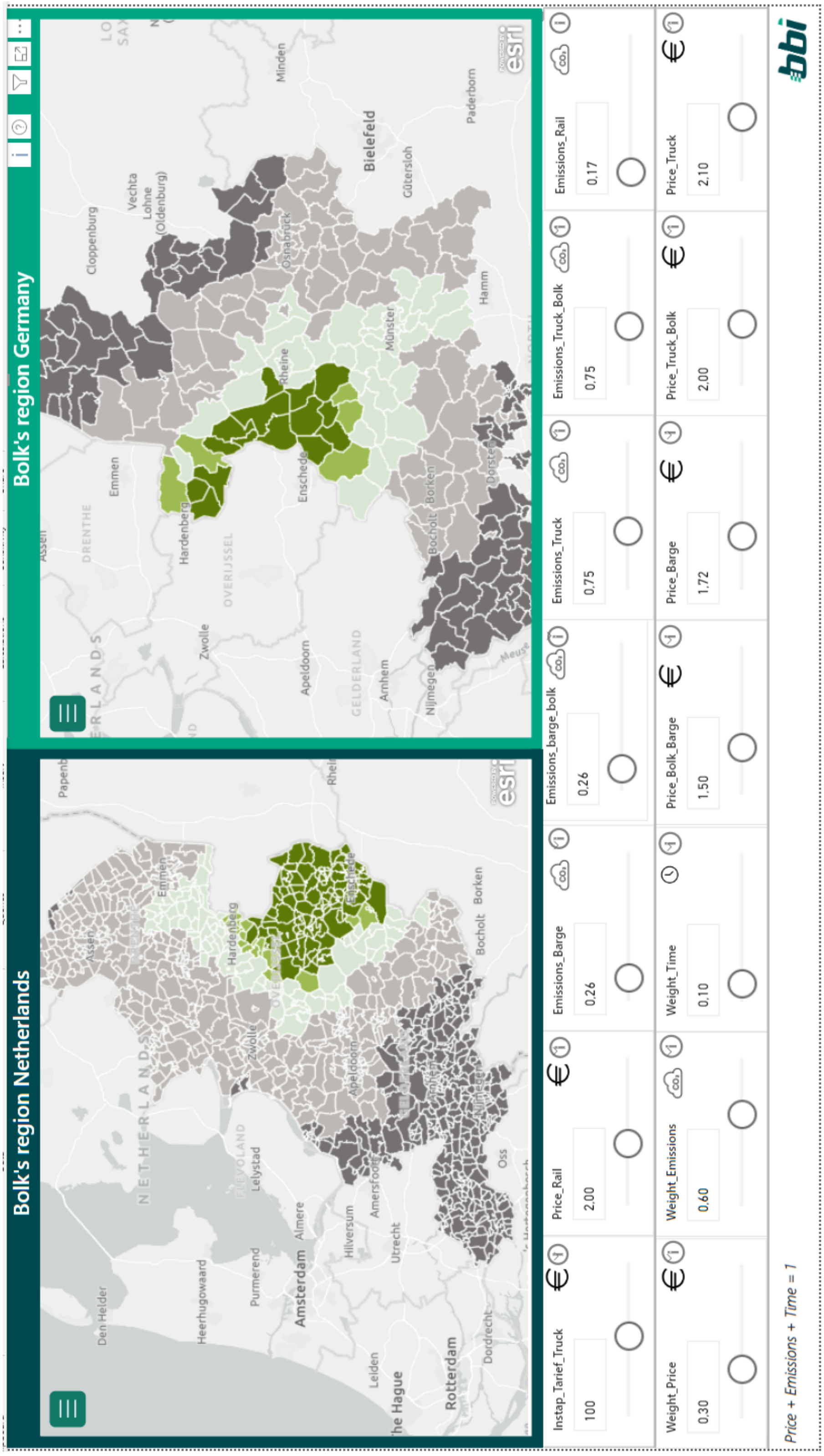

Figure 26: Overview of the first dashboard of the implemented tool, in which the competitive position can be seen.

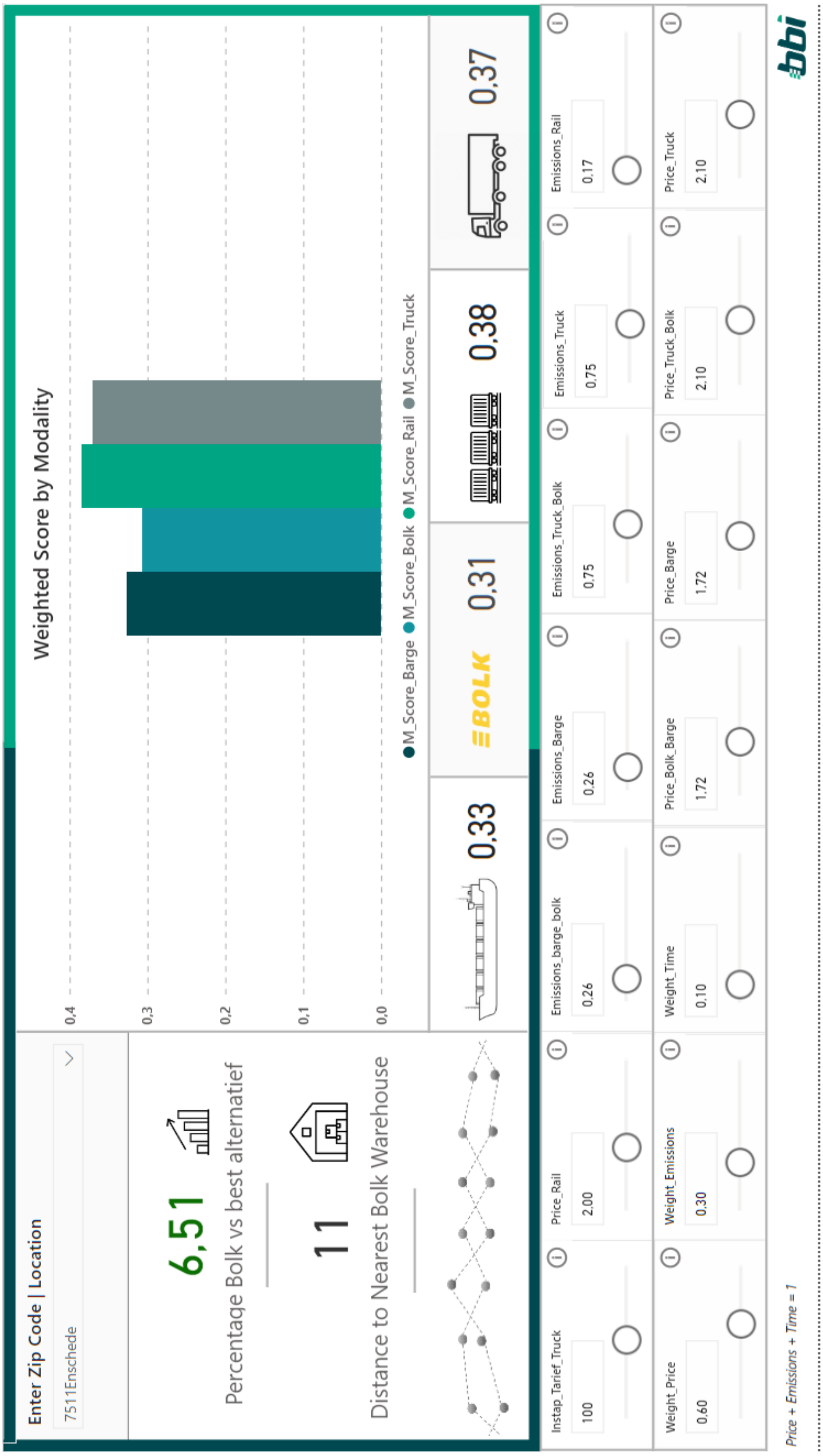

Figure 27: Overview of the second dashboard of the implemented tool. An overview of the different transport options per zip code.

F Detailed explanation implementation

Technical details
In this section, technical details of how the solution method can be used are explained.

API distance calculations
In *Python*, an API distance function is programmed. The used code is shown in Appendix D, Figure 24. In the function, the parameters 'From' and 'To' can be found. For calculating the road distance between two points, these two parameters need to be used. Both a zip code (without letters) and a city name can be used in order to calculate the distance. An example of the function to calculate the distance between Enschede and Hengelo is: *findTravelDistance('Enschede', 'Hengelo')* resulting in a distance of 9.38 km. A note should be made about *Python*. In case there is no license for using the program, an alternative computer programming language needs to be used for calculating the distances.

Model
The optimization model is also programmed in *Python*. The structure of the code consists of five parts. First, input data is loaded from CSV files into the script. In case data need to be changed, it can be done by changing parameters in the CSV files. Second, the pre-calculating is done. In this research, for around 1280 zip codes the pre-calculating is done. For each zip code, the scores for truck, barge, and rail are calculated. Moreover, in preparation for the optimization part, it is also determined for each zip code what the best Bolk terminal is, either Hengelo or Almelo. The results are saved as input for the optimization model. The third step is the optimization part. For executing this, the *gurobipy* package is used. Fourth, using the data from the optimization part, the stochastic part is programmed. By using the *random.uniform* function, random numbers from a uniform distribution are generated. Last, output data is stored in csv files and loaded in *Tableau* for the visualizations. In order to do so, for each customer the zip code, corresponding country, and final comparison score need to be saved.

Visualizations
Tableau is reading the combination of the zip code and the country to identify the right corresponding zip code in the map. Therefore it is needed for each customer to know the zip code, country, and score. An overview of how the data is stored in *Tableau* is shown in Appendix D, Figure 25. By loading in the locations of the ports, barge, and rail terminals, and the output data of the model, the map can be created. A note should be made about *Tableau*. In case there is no license for using the program, alternative data visualization programs need to be used for creating the map.

External use details
In this section, how the solution method can be implemented at other companies is explained in detail.

1. Define company to be investigated
Define the company to be investigated. It should be a logistics company connected to an intermodal terminal. This can be either a rail or an inland barge terminal.

2. Define scope
Define the scope, in other words, the area to be investigated. The following actions need to be done in order to define the scope.

- List the deep sea ports to be taken into account.
- List the barge terminals to be taken into account.
- List the rail terminals to be taken into account.
- List the provinces to be taken into account.

Moreover, it is important to define the KPIs that need to be investigated. Is the company interested in the geographic competitive position based on time, price, emissions, or combined? On top of that, it should be determined if the investigated company also wants to find out in which areas a price differentiation can be made. In that case, the optimization model can be used.

3. Zip codes
Zip codes are important to be able to calculate distances between locations and in order to visualize the outcomes. Therefore zip codes need to be written down for all the ports, barge, and rail terminals. Moreover, from the selected provinces, the corresponding zip codes need to be downloaded.

4. Search intermodal distances
The intermodal distances need to be written down. These are the distances of the routes which can be transported by train or barge. Different websites on the internet provide this information.

5. Calculate road distances
An important step is to calculate the road distances. The API tool, programmed in *Python* is developed in order to calculate the distances. This tool should be used for the following situations.

- Deep seaport - customer
- Barge terminal - customer
- Rail terminal - customer

6. Pre-calculating
The next step is pre-calculating. Using *Python*, the best transport options for each zip code can be calculated, based on price, time, emissions, or combined. In case the company wants to take all the KPIs involved, the customer weights should be defined, by defining an average customer profile (e.g. 0.6 weight to price, 0.3 to emissions, and 0.1 to time). In this case, the utility score for each modality can be calculated, which is the basis for the model. On top of that, the best utility score can be determined, to be used as input for the optimization model. The following input parameters need to be defined in order to execute the pre-calculating.

- Emission rate per km in kg CO_2 for a truck, barge and train.
- Emission rate per km in kg CO_2 for a transshipment.
- Price rate per km in euros for a truck, barge, and train.
- Basic fare price for using road transport.

7. Run the model
After all the pre-calculating, input data is generated to be used in the model. Before using the optimization model, first, the minimum and maximum prices for barge and truck transport need to be determined (barge prices need to be swapped for rail in case a rail terminal is investigated). In case the company only wants to focus on one of the KPIs, the customer weights can simply be adjusted. For example, if the company only wants to focus on price, the weights for emissions and time are set to zero. Moreover, if the company does not want to investigate its price differentiation, the internal price can simply be set to be fixed and the corresponding utility score for the company can be calculated. The next step is to run the model, which will determine the optimal price and the areas in which the company will have the best score.

8. Data visualization
The last step is data visualization. The output of the model will be a comparison score for each of the investigated zip codes. The zip codes can be mapped using GIS software, which is implemented in for example visualization tool as *Tableau*.