Optimizing Shipment Consolidation for a Logistic Hub at E. van Wijk Forwarding

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Preface

Dear reader,

This report is about my research project as the final part of the Industrial Engineering and Management programme at the University of Twente, Enschede. This research was conducted at E. van Wijk Forwarding in Almelo, the Netherlands. The goal of the thesis is to evaluate the effect of a shipment consolidation strategy at a logistic hub at E. van Wijk Forwarding.

I would like to thank my external supervisor, Sara and Gerwin, for giving me the opportunity to conduct such an interesting assignment at their company. They were ever willing to help me with the research and bounce ideas to further develop the project. Furthermore, I want to express my gratitude toward Henk Jan from E. van Wijk Forwarding, who was always available to answer my questions and provided me with all of the necessary data and information.

Special thanks to my university supervisors, Dr. Amin Asadi and Dr. Lin Xie, for their valuable and insightful feedback. Their ideas allowed me to further progress with my research and inspired me to develop new solutions. Their feedback and discussions helped me immensely and allowed me to develop myself towards becoming an independent researcher. I am thankful for sharing their expertise but furthermore being great mentors throughput the graduation process. Your time and support are highly appreciated.

Thank you all so much for helping me conduct my bachelor's thesis. This project was not only really interesting but I believe it can have real implications for E. van Wijk Forwarding. I really enjoyed working on this assignment and I hope you find it insightful!

Nisho Tanev

Enschede, July 2023

Management summary

This research is conducted at E. van Wijk Forwarding in Almelo, the Netherlands. EvW Forwarding is a forwarding company in the business-to-business market. The company acts as the intermediary between customers and transportation companies. They help customers transport given goods from *A* to *B,* without actually executing the transportation, which is fulfilled by their partners. This research focuses on the operations department of the company which organises the transportation planning.

EvW Forwarding has identified a change in the customers' needs, as they require a complete service and an end-to-end solution. However, the company's limited control over its business operations does not allow them to meet these customers' demands. Reasons such as a limited customs department, no consolidation of goods and inability to track shipments, incite the company to implement a centralised logistic hub to gain greater control over their supply chain. Though, EvW Forwarding does not know how to optimally operate and benefit from such a hub. Therefore, this is the main research question, which is answered through the CRISP-DM methodology.

Based on the analysis of the current situation, consolidation of goods is chosen as the main focus for the research. The literature review reveals several different consolidation strategies, but shipment consolidation is the most relevant as the company wants to utilise their current warehouse as a central hub for combining shipments. This consolidation type aims at combining multiple shipments in order to minimize the total number of containers needed. To implement this strategy, we develop a bin packing problem with a time-quantity shipment-release policy. The various ways of solving this problem include multiple exact algorithms and heuristics. The latter proves to be the more suitable approach, due to the limited accessibility of commercial solvers that can provide optimal solutions to EvW Forwarding.

The objective function of our model is to minimise the total number of containers needed. The specifics of EvW Forwarding's case demand the introduction of additional constraints on shipment-release policies and complying with a zero-delay requirement. Based on the performance of different algorithms, an offline First Fit Decreasing algorithm is chosen for solving the heuristic, considering its performance and E. van Wijk Forwarding's requirements.

The model and the consolidation procedure are implemented in MS Excel VBA. The performance of the heuristic is a crucial aspect of the validity of the output. Therefore, the heuristic's performance is evaluated based on the lower bound restriction, discussed in the literature review. The results of the heuristic are assessed based on a set of key performance indicators related to transportation, time and costs. These include the total number of containers used, total costs and the average truckloads.

The consolidation procedure reveals significant improvements in the key performance indicators. The model reduces the total number of containers needed by 49.25% and the total costs by 5.14%. Furthermore, the model performs substantially better in the new as there is a 47.28% increase in average truckload and 97.03% increase in average truckload utilisation rate. Additionally, the average costs per pallet per container decrease by 39.24%.

Therefore, the model proves the value of the implementation a logistic hub with a consolidation procedure, as there are significant benefits for EvW Forwarding. These benefits go beyond pure numbers in terms of reduced costs and increased truckload, but create added value for the company and increase its competitiveness in the market by offering a more complete service. This analysis implies that a shipment consolidation strategy is a logical way of operating a logistic hub as it improves the set of key performance indicators.

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List of abbreviations

EvW:	E. van Wijk Forwarding
FTL:	Full truckload
LTL:	Less than truckload
KPI:	Key performance indicator
CRISP-DM:	Cross Industry Standard Process for Data Mining
NL:	The Netherlands
PL:	Poland
3PL:	Third-Party Logistics Provider
LDM:	Loading meters
BPP:	Bin packing problem
BPM:	Business Process Modelling
SLR:	Systematic Literature Review

1. Introduction

The purpose of this chapter is to give a brief introduction of the company and the challenges they are currently facing. Moreover, this chapter will provide relevant information, regarding the scope of the project and the design of the research questions.

Company Description

E. van Wijk Forwarding (EvW) is a forwarding company that is part of the E. van Wijk group. The group consists of three separate branches, namely E. van Wijk Logistics, E. van Wijk Forwarding and E. van Wijk Real Estate (E. van Wijk, 2023). This bachelor's thesis is conducted at E. van Wijk Forwarding (EvW). The company is a forwarding service provider in the business-to-business market (B2B). A forwarder acts as the intermediary between the customer and a carrier to organise all logistical processes (Twentepoort Logistiek, 2023). EvW compromises of six forwarding companies that have different specialities. They serve different parts of Europe and Asia and focus on the transportation of a variety of specialised goods. The companies offer multiple solutions such as road and railway shipments, express deliveries and specialized goods deliveries. The diversity and the different focus of the companies allow EvW to offer various logistics solutions to its' customers (Himex Logistics, 2023).

EvW operates out of XL Businesspark Almelo. XL Businesspark Almelo is a large sustainable business park in the Twente region, the Netherlands. The park offers multimodal access to the region of Twente through road, rail and water connections. The park's ideal location offers great opportunities for international logistics and transportation activities (Port of Twente, 2023).

The main role of EvW and its' different companies is organising the transport between point *A* and point *B* in the most cost-efficient and fast way. Their daily operations consist of contacting customers and partners for grouping shipments together, preparing customs transportation documents and managing the processes and activities in the warehouse. The transportation itself is not done by EvW but they rather use their vast network of partners to reach certain destinations. EvW does not have its own fleet of vehicles, hence why they only act as the intermediary and connect both parties and organise the full service.

My role as a researcher within the company is to conduct a study and evaluate different concepts to see how they would affect the profitability, sustainability, and business opportunities of EvW.

Problem Identification

The first step of a proper research is problem identification and understanding the underlying issue in the current situation. The goal of this phase is to find the core problem by identifying several issues and linking them together in cause-and-effect relationships.

Context

With more than 12 000 haulage companies, the logistic market in NL is really competitive. It is reported that almost a quarter of the international cargo transport within Europe is coming from Dutch companies (Dutch Industry, 2023). Most of the logistic companies offer similar solutions, hence, it is really hard to stand out in the market and gain a competitive advantage.

Upon joining the company, the objective was to gain a comprehensive understanding of the various processes within the different departments. To accomplish this, I actively engaged in meetings with colleagues, managers, and supervisors from the company. These interactions provided me with valuable insights into the overall operations of the company and helped me identify key focus areas of my research.

Recently, the company did a "Strengths, Weaknesses, Opportunities, and Threats" (SWOT) analysis, which allowed them to understand their strengths and weaknesses. The analysis showed that EvW has a competitive advantage due to the different companies it operates and their own specialities, such as a focus on pharma and healthcare products, chemicals, construction equipment, automotive and general goods. The companies within EvW are able to provide different services across Europe and transport specific goods that require additional requirements such as heating and cooling cargo, unconventional sizes, fragile goods, etc. This furthermore gives them the flexibility to navigate the ever-changing market and adjust to unforeseen events. However, a weakness they managed to identify was the changing customers' demands. In the current state of logistics, customers demand a full, convenient, and efficient solution to their transportation needs, namely a full-service package. They want a one-stop place where they can meet all of their needs, instead of choosing different companies to provide each part of the solution in a supply chain. As the 27th Annual Third-Party Logistics Study (2023) reported, due to the current state of the market and the increasing consumer expectations, ongoing volatility, and the drive to increase efficiency and control costs, the relevancy of an end-to-end supply concept continues to advance. Furthermore, it emphasizes the quality of relationships between parties as a valuable component of the supply chain's success (3PL Study, 2023). This switch in the customers' behaviour has made a gap in the market and a business opportunity for expansion. EvW could identify the importance of this aspect in order to provide continuity for the company and remain competitive.

However, at the moment, EvW cannot exploit this opportunity. In order to be able to offer a full service, the company has to first have a better grasp of all supply chain operations. Currently, this overview is very limited and that restricts EvW's expansion possibilities. Therefore, the limited control over the supply chain is the main managerial dilemma. A problem cluster is utilized to further investigate the reasons why EvW has limited control over its transportation activities and the main relationships between the different factors.

Problem Cluster

In order to get to the core problem of the managerial issue, we first need to fully understand the action problem, namely the limited reach over the supply chain.

In the case of EvW, a limited reach reflects the inability to have full control over the way each order is fulfilled. This includes all the operational and transportation activities in the supply chain, the organisation of the shipment transportation routes, etc. Therefore, there are a couple of reasons why EvW has a limited control over the supply chain.

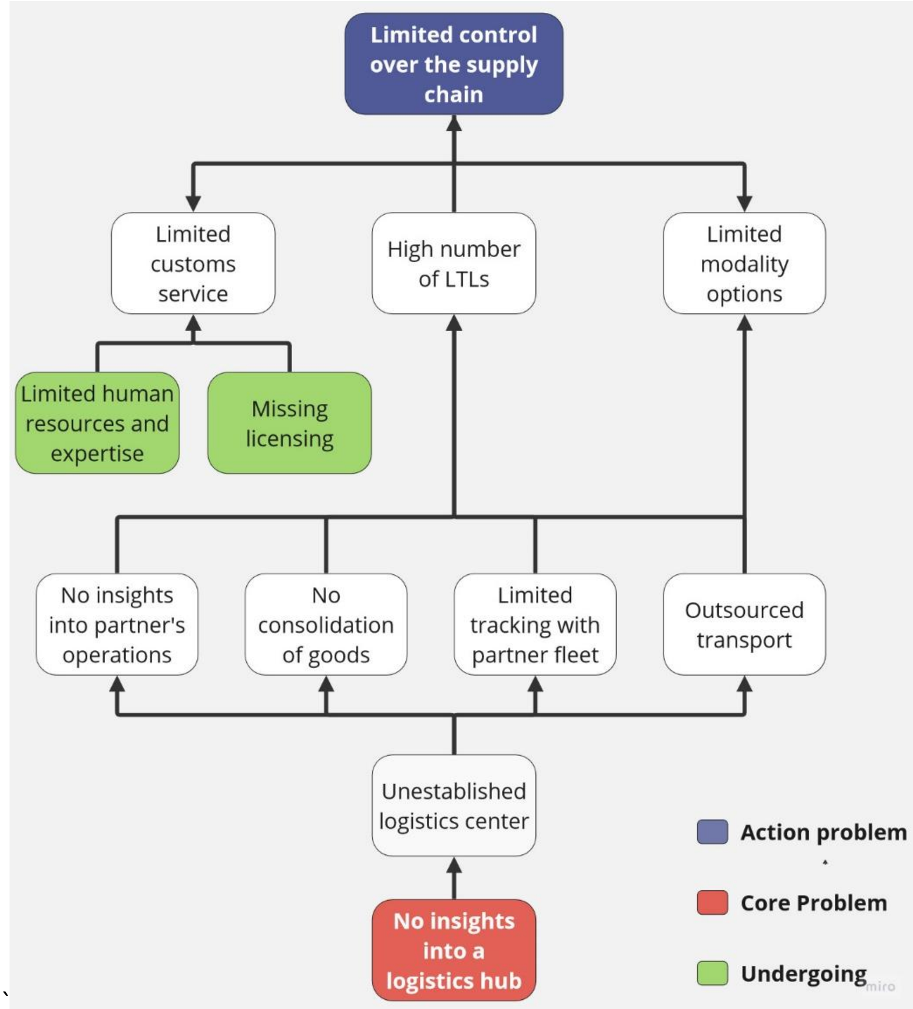

Figure 1: Problem Cluster

One of the reasons why EvW has limited control over the supply chain is the fact that they do not have a full customs service. Currently, they have a limited amount of people with expertise who can deal with such legal requirements. Moreover, the company is missing licensing in order to offer a full range of custom clearance options. There is no dedicated department to deal with such formalities due to the limited need. Nevertheless, EvW has been working on obtaining the required licensing and hiring experts in the field, which can allow them to expand. Even though this can be considered as a core problem, it is not the chosen one, as the company has already taken a step towards implementing it. They are currently in the process of obtaining the necessary licensing, however, it takes time, effort, and expertise.

Another reason why EvW has a limited reach is the limited amount of modalities they offer. The company has been trying to introduce different modalities, but currently road modality takes between 95-99% of all the logistics of the company, due to many limitations. One of them is the fact that EvW does not have its own fleet of vehicles, but rather they rely on partners as they outsource the actual transportation. Currently, they only act as the freight forwarding intermediary, which connects the partner and the customers. A freight forwarding intermediary is a company that is contracted by a shipper to be a liaison between the shipper and a motor carrier to facilitate the movement of their property from origin to destination by accessing its vast network of carrier relationships (Young, 2018). In order to become a full-service provider, a company needs to be able to offer many different modality options such as road, rail and water transportation (Rotra, 2023).

This means that a company should utilise all available resources to offer a full set of options that allows the transportation of goods in the most convenient and efficient way. Hence, a connection between ports, inland waterways, hubs, train stations and motorways ensures full modality choice. In the case of EvW, this would mean utilising the already existing sea connection through the Port of Twente as well as further inland or rail shipping, apart from the current road prevalence. EvW organises the logistical planning of the shipments, however, they do not control the actual transporting operations and conditions. The currently restricted reach and limited control over this part of the supply chain does not allow them to expand and offer more complete modality alternatives.

Moreover, due to the outsourcing of transportation activities, EvW cannot guarantee the efficiency and efficacy of the delivery process. This leads to a great number of LTLs (less than a truckload). The partner decides on how to transport the given goods and often they select the most cost-efficient way for them, which is not necessarily the most sustainable or logistically optimal.

In order to reduce the LTLs, EvW needs to have more knowledge about certain aspects of the logistical process, such as tracking partners' trucks and more information on their loads and routes. Right now, this information is limited, mainly due to the fact that the transportation activities of EvW are outsourced. This problem is further emphasized by the fact that there is no consolidation of goods, which causes irregular shipments and inefficiency in the truckloads. One can argue that not outsourcing can be a solution, however, this is not the case, as this is the business model of forwarding companies, including EvW. Therefore, this is not something that can be changed, but rather a solution needs to be found under this outsourcing business model.

The accumulation of these issues suggests a deeply rooted cause which can provide more insights into the problem definition. During the analysis of the above-mentioned problems, namely no consolidation of goods, no insights into transportation operations and limited tracking, we can see an underlying problem – no central hub for coordinating all the activities of EvW. The company is missing a logistic hub which allows for precise tracking of goods as well as expansion into different modalities, establishment of a customs department and more control over the transportation.

After understanding the problem and asking experts from the company, it was evident that they are missing knowledge about a logistic hub and its value. The current warehouse of EvW in Almelo is solely used for storage of goods without consolidation and distribution processes. It facilitates most of the logistic operations, but does not allow for flexibility or development. Therefore, it cannot be considered as a logistic hub and leads to operational limitations. EvW can benefit greatly from such an expansion, however, they do not know how beneficial a logistic hub can be for the company.

Core Problem

The analysis of the problem cluster clearly indicates that all the above-mentioned problems emerge from the fact that there is not an established logistic hub to operate the transportation. The reason for that is the lack of knowledge about the value of a central hub and the benefits associated with it. Therefore, the core problem is that EvW does not have insights into the implementation possibilities of a logistic hub.

Research Approach

Having decided on the core problem, the next step is to determine the main research question which guides the whole project. Furthermore, the research question is split into sub-research questions, which allow the research to follow a natural progression and have a step-by-step approach. The combination of sub-research questions and knowledge questions allows us to answer the main research question and gives us a direction for conducting the research.

Research Scope

An essential aspect of determining the research question is narrowing down the scope and clearly defining the level of detail within the project. To ensure the research is conducted efficiently and aligns with the appropriate level of expertise, it is essential to concentrate solely on specific aspects of the organization. By specifying the scope of the research, the project can be executed within the selected knowledge field and maintain focus on the relevant areas of investigation. My research is on the tactical level of decisions for the company. Tactical planning focuses on short-term decisions and department-specific projects in order to satisfy the strategic alignment of the whole company (Future Cio Club, 2022). In my project, the strategic decisions within EvW involve expanding the business opportunities and becoming a full-service provider to meet the customers' changing demands. However, in order to satisfy this goal, there are other mid-term projects that need to be accomplished such as the implementation of a logistic hub which can bring a lot of knowledge and a more clear vision for providing new service solutions, which is the tactical focus of this research. The main goal is to utilise the current resources, such as EvW's warehouse in XL Businesspark Almelo, to evaluate what is the effect of process changes in the operations department and the warehouse, such as the consolidation of shipments. The information and data from the operations department allow us to analyse the implementation possibilities and benefits of a logistic hub on the logistics of EvW and provide recommendations to the executive management.

Research Limitations

A crucial part of any research is understanding the project limitations. First of all, in order to limit the scope of the research, we solely analyze the transportation processes between NL and PL as this represents the greatest share of the operations at EvW. For 2020, the overall turnover from transportation between NL and PL was the biggest, with more than 20% out of all transactions at EvW. The model of the logistic hub only concerns the transportation between these two destinations. This allows for a more streamlined model and better analysis, given the available data. Focusing solely on this route allows us to evaluate the logistic hub and accordingly check whether it can be feasible for other routes as well.

Secondly, the focus of the research is not on the location of the warehouse, as this is already fixed, but rather on evaluating its' impact on the logistic operations at EvW. The company wants to utilise the already existing warehouse in XL Businesspark Almelo while implementing the additional processes required for a logistic hub and consolidation. The current warehouse is positioned at a strategic location between NL and the rest of Europe and is used as a gateway to most delivery locations of EvW.

Furthermore, the focus is on the processes outside of the logistic hub, not within. Our goal is to evaluate the effect of the logistic hub on the logistics of EvW, hence why we focus on the operations and processes between the different locations. Our focus is not on the processes in the warehouse or the changes required within the establishment. The logistic hub is treated like a singular block in the supply chain where shipments go through and can get processed, consolidated, tracked and documented accordingly.

Research Methodology

After evaluating different methodologies for conducting research, CRISP-DM seems to fit this research the best. The Cross Industry Standard for Data Mining (CRISP-DM) is a methodology that is suitable for data science processes. During this research, data is heavily involved, hence CRISP-DM is a good fit for this project. Other methodologies such as MPSM (Managerial Problem-Solving Method) are not as suitable due to their theoretical solution approach and lack of data usage. Furthermore, the steps in CRISP-DM exactly fit within the approach for evaluating the logistic hub. CRISP-DM is a natural choice whenever you are dealing with data science projects. Moreover, it has been highly regarded as a good methodology to understand both business and the customers' needs, prepare data, utilise various modelling techniques and evaluate the model's outcome (Hotz, 2023). CRISP-DM fits both this project's approach and the available data, therefore it is the selected methodology.

During this research, we are following the steps of CRISP-DM, which allow us to evaluate the logistics hub. The first step of the process is to understand the business of EvW. Mapping out the main processes and understanding the connections between them is essential for creating the appropriate model. Secondly, we look into the available data. This includes both understanding and preparing the data for further analysis. During this phase, we can further analyse the business, if there is missing data or uncertainties about the processes. Then, the next steps are to model the solution and evaluate the outcome. A part of the modelling phase is constantly consulting the data and updating the solution to ensure the validity of the model. The last step of CRISP-DM is deployment, where EvW's task is to refer to the conclusions and recommendations and potentially implement the new approach. Based on the CRISP-DM methodology, the main and sub-research questions of the research were formulated.

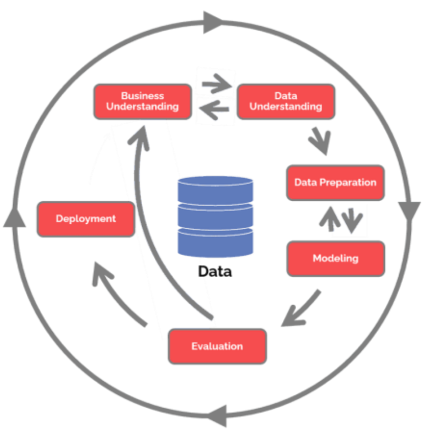

Figure 2: CRISP-DM Methodology

Main Research Question

Considering the problem cluster, the action and core problems and the scope limitations, we can formulate the main research question. This question should be the centre point of our research and should solve the core problem. Given that EvW does not have insights into the benefits of a logistic hub, a logical research question is: **How to optimally operate a logistic hub to improve a set of KPIs at EvW?** This question encompasses all the necessary aspects as well as gives answers to the core problem that can help the company to take decisions and assess the profitability of the improvements.

Sub-Research Questions

The main research question is a broad statement that guides the whole project, but it does not give a step-by-step approach. That is why we need to create sub-research questions which are more detailed and allow us to gather information and knowledge about the topic in order to reach a final conclusion.

1. ***What are the current and desired processes in operations at EvW?***

   The first part of the research is analysing the current processes within the operations department to get an overview of the potential bottlenecks and understand what are areas for improvement. This leads us to develop the process of the desired situation. An analysis of both situations allows us to create a more accurate implementation model to best fit EvW.

2. ***What are the most relevant shipment consolidation models for a logistic hub?***

   There are multiple ways to implement a logistic hub and the associated processes. We look into the literature to find the most relevant models that fit both the current situation at the company as well as the available data to provide an adequate model to evaluate the implementation of a logistic hub. The literature gives us an overview of the relevant approaches to evaluating a logistic hub.

3. ***What data is available that is relevant for analysing the operations and processes at EvW?***

   The operations department collects all the data for the shipments and orders. This data can be used to get information about the processes and check which records might be useful for evaluating the situation in the warehouse. Furthermore, the data is narrowed down and only relevant input for the given case is selected for further analysis.

4. ***Which model is most suitable for operating a logistic hub?***

   In this question, we select and evaluate the available models for operating a logistic hub. There are different types of models based on the main purpose of the hub. After an analysis of the available options, we can select the model that best fits the project and takes into consideration all aspects and available information.

5. ***What is the performance of the model based on a set of KPIs?***

   Having selected the appropriate model and the relevant KPIs, we can build a tool for the model in order to assess the performance and compare the results with the current situation. The model is evaluated based on the KPIs and further on financial and sustainability aspects. Afterwards, we analyse the results to form conclusions.

Research Design

The table below represents the research design of the project. It contains the characteristics of all sub-research questions based on the selected methodology. Furthermore, it includes the necessary data gathering and processing methods as well as the planned activities for each knowledge problem. It also mentions the research population and respective strategy.

	Research type	*CRISP-DM phase*	*Research population*	*Research strategy*	*Data gathering*	*Activity plan*
1	Descriptive	Business understanding	EvW management	Qualitative	Interviews, observations	1. BPM diagram 2. Analysis 3. KPIs
2	Descriptive	-	Literature	Qualitative	Literature	1. Research and SLR 2. Overview and comparison 3. Analyse relevancy and choice
3	Descriptive	Data understanding	Dataset and software	Quantitative	Interviews, observation and data	1. Data collection 2. Data preparation 3. Data analysis 4. Data selection 5. Data evaluation
4	Explanatory	Modelling	Literature and EvW management	Qualitative	Literature, interviews and analysis	1. Model comparison 2. Analyse overview 3. Choose a model
5	Explanatory	Evaluation	Model and KPIs	Quantitative	Model outcome	1. Mathematical model 2. Model implementation 3. Analyse KPIs 4. Evaluation

Deliverables

This section contains the main deliverables and outcomes to be provided at the end of this graduation assignment.

2. A list of relevant KPIs for operating a logistic hub
3. A literature review of shipment consolidation models for operating a logistic hub
4. A modelling tool for operating a logistic hub
5. Performance analysis of the model based on the selected KPIs

2. Business Understanding

In this chapter, we analyse the current and desired situations at EvW. This chapter is related to the business understanding step of the CRISP-DM and answers the question **what are the current and desired processes in operations at EvW**. Furthermore, in this chapter, we develop the list of KPIs to asses the performance of the logistic hub.

Current Situation Analysis

In order to get a better understanding of the whole business and the process within EvW, we need to visualise the main operations. The focus of this research is on the processes and operations of the operations department. This is the department that creates the logistical and transportation planning, therefore they have all the required information. Figure 3 shows a flowchart of the current situation at EvW.

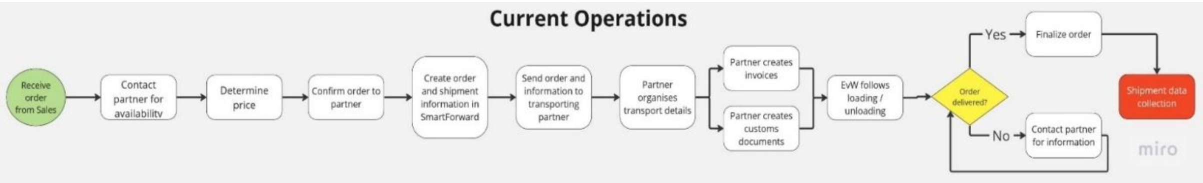

Figure 3: Flowchart of the current situation

The process starts from the moment that the sales department receives an order. After they confirm the order and coordinate the details, it gets transferred to operations. There, the operations department contacts a partner carrier to ask for availability and a final price. After this information is obtained and the final details to the customer are communicated, the order gets confirmed by all parties. This is where most of the impact from EvW finishes as they act like a middleman between the customer and the transporting company. EvW facilitates the process of the customers as it gives them the best option based on a large network of partners. However, EvW does not organise the transportation itself. After the order has been confirmed, the partner transporting company takes over the process and they organise the loading, unloading and delivery process. EvW can only follow this process through communication with the given partner but does not have any direct impact on the way the process is executed. For example, EvW does not know how full the truck is, what is the exact route or what documents are being prepared. This complicates the operations of EvW and does not allow for full clarity and transparency about the processes. During the process of transportation, EvW can ask about the current location and estimated arrival day, which can be communicated to the customer, but the reliability lies with the transporting company, therefore limiting EvW's influence. One of the last steps is to confirm whether the shipment has been delivered. After this is confirmed, the given order is finished and the data can be processed for further analysis.

Current Limitations

As we discussed before, the current situation is not optimal for EvW and this is especially true for a couple of reasons. One of the reasons for the suboptimal current situation is the lack of traceability and transparency within the processes. As explained above, the main process of transportation is executed by a partner of EvW, which limits the impact they have. When the partner organises all operations, it is difficult for EvW to have a meaningful influence on the processes. To give an example, the partner is given a location to load the shipment, however, EvW does not know at what time of the day, how safe the procedure is and whether there are any mistakes during the process. EvW acts as a middleman but does not actually execute the process. Another important aspect of the lack of traceability and transparency is the knowledge about the truckloads. In the current situation, EvW does not have much information about the truckloads of the partner during the delivery. This happens because EvW requests the delivery of a certain amount of pallets to the partner, for example five pallets, but they do not know how full the rest of the container is, as this is purely organised by the transporting partner. This can cause issues such as unsustainable transportation and a lack of responsibility for the logistical continuity. This is highly undesirable for EvW because of the high carbon footprint per pallet, which contradicts their goals.

Another limitation in the current situation is the lack of an overview of the customs and invoicing documentation. Both the customs and invoicing processes are done by the partner, which means that EvW cannot guarantee the given service but relies on the expertise of the partner. This can lead not only to mistakes and errors but a lack of different options. Having a more inhouse process ensures the full responsibility of EvW and the company can guarantee a plethora of different solutions when it comes to customs clearance of goods. In the current situation, this reach is limited, which accordingly restricts the number of potential customers for EvW and impedes business growth.

Lastly, the current situation forces EvW to have high transportation costs. The partner companies charge higher due to the unpredictive nature of the orders coming from EvW. The partner companies do not know how many orders and pallets they can expect which does not allow for an optimal planning. Having a more organised schedule allows for higher collaboration, which results in lower costs. Furthermore, it is really expensive for the partner if he has to load goods at a certain location and deliver only a small number of pallets. Therefore, he would like to earn more and subsequently the rate for EvW is higher. This hinders EvW’s growth and reduces profits. Having a more organised and structured approach when it comes to shipments with a small number of pallets, can benefit EvW and lead to a positive outcome.

Desired Situation Analysis

Given all of the identified limitations within the current situation, EvW wants to make a change. All of the problems appear from the lack of centralised processes. Limited tracking of shipments, customs complications, and higher transportation rates can all be solved with the introduction of a centralised location which implements these aspects. One of the obvious changes that can lead to resolving the following issues is the introduction of a logistic hub. The company has been considering such an implementation for some time already. Their idea is to use the already existing warehouse in XL Businesspark Almelo, but introduce new processes in order to create a logistic hub that can fix the current limitations. However, EvW does not know whether it is worthwhile to invest in such an implementation and wants to assess the value and benefits of it.

Logistic Hub Improvements

The introduction of a logistic hub can lead to significant improvements in different areas of the business of EvW.

Firstly, the logistic hub allows for implementing tracking of goods. This is possible because the shipments can go through the hub. This means that EvW can register the shipments accordingly and follow them in their systems. Furthermore, as they leave from the warehouse, with organised and secure transport, they can be tracked, which leads to a better overview of the delivery process. It is obvious that if the company has a point of contact with the goods and they go through the logistic hub, they are able to track them. This undoubtedly improves the current process and allows for further improvements. However, this is not a topic during this research as it cannot be measured. We assume that this is considered as a fact, given the management decides to implement a logistic hub.

Secondly, a logistic hub allows for an inhouse customs clearance department. Recently, the company has been investing in such a project. They have been hiring experts to fill the missing roles and they are in the process of getting the certifications needed. This allows EvW to offer a wider range of activities such as clearing specific types of goods. Moreover, such an expansion creates further business opportunities as EvW becomes a more attractive forwarding company for customers. The benefits of such an expansion are eminent as EvW simply can have more expertise, due to the new certifications, which can lead to more customers. This is considered as added expertise and can certainly bring additional business opportunities to the company. It is not a part of the research assignment as this project is currently ongoing at EvW and furthermore, it is not related to the research knowledge field.

Lastly, a logistic hub has an effect on the operations of the company. The logistic hub allows for consolidation of goods. Consolidation of goods is “a logistics process that consists of grouping shipments to bring down transportation costs and optimising the distribution of goods” (Mecalux, 2022). This means that the warehouse is not only going to be used for storing goods but would also serve as a terminal where shipments go through. This influences both the costs and the number of containers required to ship all goods. This is a significant improvement for EvW as it solves many of the current problems. Having a logistic hub that consolidates orders allows us to reduce the overall number of containers required and the respective costs. Therefore, based on the analysis of possible improvements of the logistic hub, the main focus of this research is going to be on the evaluation of the consolidation process, which can be clearly measured. The measurement can be achieved with an algorithm which compares the current and the desired situations based on a set of KPIs in order to check whether the logistic hub is worth implementing.

KPI Selection

In order to evaluate the effectiveness of the logistic hub, a set of KPIs is selected to measure the performance. These indicators help us compare both situations and allow us to verify whether the logistic hub can be beneficial for EvW. Below is the list of identified KPIs.

1. ***Transportation KPIs***
    - Number of containers used
    - Average truckload used
    - Average LTL truckload
    - Average truckload utilisation rate

- Average KMs per pallet per container
- Average KMs per pallet
- Total KMs travelled

2. ***Financial KPIs***
    - Total costs
    - Average costs per container
    - Average costs per pallet
    - Average costs per pallet per container
    - Average costs per KM
3. ***Time KPIs***
    - Average time in the hub before release
    - Average time between loading and final delivery

In my KPI selection, I consulted the management of EvW as well as relevant literature. The company already has a predetermined set of KPIs, which were used as a base. Furthermore, some literature, such as the paper by Pérez-Martínez et al. (2020), was used as an inspiration to further develop the final list.

Based on the list above and the identified improvement possibilities, we can accomplish the main goal of the research, namely evaluating a logistic hub with a consolidation procedure based on a set of KPIs.

Desired Processes

As discussed previously, a logistic hub can be highly beneficial and can allow for a significant change in the processes in the operations department at EvW. In this section, we discuss how the logistic hub and the consolidation process fit within the operations department. Figure 4 represents the desired situation for EvW.

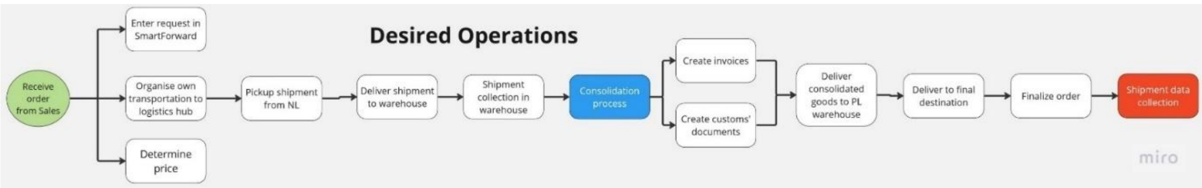

Figure 4: Flowchart of desired situation

The process starts similarly to the current one with the sales team receiving an order. Afterwards, they determine the price based on the transportation costs of the partner. After everything is confirmed, the transportation from the given address in NL to the logistic hub in Almelo is organised by the operations department. EvW Forwarding does not have its own fleet of vehicles, therefore they cannot execute the transportation. The company can use the vehicle fleet of EvW Logistics, the sister company of EvW Forwarding. EvW Logistics has its own vehicles as they are an actual logistics company that transports goods. Both companies work in a close partnership together and therefore can collaborate on this part of the process. EvW Logistics picks up the shipment and brings it to the warehouse on the given day. At XL Businesspark Almelo, the shipments are collected. Then, the consolidation process starts. This is the process of combining multiple small shipments into larger truckloads in order to reduce costs.

After the consolidation is done and the necessary documents are created, the shipment leaves NL for PL. This part of the route is executed by a transportation partner of EvW. This partner is a specialist in the given route and can be inquired for multiple shipments per week, which ensures the best rate and high collaboration between both parties. The shipment then arrives at the JAS FBG warehouse in Poznan, Poland, where it gets sorted and prepared for last-mile delivery within PL. JAS FBG is a logistics partner of EvW, that operates in PL. The company has a warehouse which can be used as the receiving point in PL before the final-mile delivery. EvW is already working closely with JAS FBG and the warehouse allows for connections to all parts of PL. The choice of the warehouse in Poznan was made because of its central location in PL and the facilitated access from NL. After the delivery process is completed, the order is finalised and the data is collected for further analysis.

Involved Stakeholders

When analysing the current and desired situations, it is important to identify the key stakeholders and their influence on the processes. These are the parties that have a significant influence on the implementation and process changes. Four key stakeholders have been identified.

1. **EvW Forwarding's operations department**

   This department deals with all the operations and organises the transportation activities. They are present in both the current and the desired situations and play a crucial role in the whole process. They are the main actor in the processes of EvW that concern this research.

2. **Partner transportation companies**

   EvW has connections with many partners that have their own fleet of transportation vehicles. Those are companies that have their own fleet of trucks and transport goods from *A* to *B.* They are crucial for EvW Forwarding, as the company does not have their own transportation vehicles, but they inquire partners to do this part of the process. These partners play a role in both the current and the desired situation as they transport the given orders form NL to PL. The extensive reliable network of partners for EvW is a great asset for future business growth.

3. **EvW Logistics**

   EvW Logistics is the sister company of EvW Forwarding and they are both part of the EvW Group. The difference between the two companies is that EvW Logistics has its own fleet of vehicles and executes transportation activities. EvW Logistics is part of the desired situation at the company as they are a key actor in transporting the goods within NL, namely from the origin destination to the warehouse in XL Businesspark Almelo. Using EvW logistics is the most reliable and cost-efficient way of transporting goods to the logistic hub.

4. **Customers**

   Customers are the centre of the business for EvW as they generate revenue for the company. They create the orders and dictate what should be delivered and where. The ultimate goal of EvW is to help the customers fulfil their targets and have a successful business partnership.

3. Theoretical Framework

A crucial part of conducting research is finding and discussing the available literature in order to get an overview of the relevant theories. Therefore, in this chapter, we answer the question of **what are the most relevant shipment consolidation models for a logistic hub**. This analysis allows us to gather information about the most appropriate models and use them in the development phase.

Third-Party Logistics Providers

EvW can be considered a Third-Party Logistics provider (3PL) as they do not have their own fleet of vehicles but they rather outsource the transportation activities and act as the link between customers and logistic companies. The 3PL service providers arrange all operations but do not execute them. Furthermore, they can offer a variety of services such as warehousing, invoicing, customs, etc (Weerakkody et al., 2021). Mutlu et al. (2010) mention that 3PL service providers have the possibility for consolidation, which lowers truckload rates and increases control over the deliveries, as the companies can benefit from economies of scale.

Modelling Approach

As discussed previously in the Desired Situation Analysis section, the main aspect of the project is to evaluate the performance of a logistic hub in comparison to the current situation in order to assess its worthiness. The logistic hub is an establishment, which can be used as a central point of the transportation system, where all shipments and goods are collected to be consolidated. The shipments go through this hub and it can be used as temporary storage until the consolidation process is finished (Liu et al., 2015). A logistic hub can serve many purposes but most notably it allows for tracking shipments, as they can go through the hub, customs documentation, as they can be declared at the hub, and consolidation of goods.

The main focus of this research is going to be on the consolidation of goods, as discussed in the Logistic Hub Improvements section. Consolidation has been an important part of logistics and transportation for many years. A survey by Jackson (1985) revealed that 100% of firms consider consolidation as important or very important to get an advantage in terms of costs. The same paper also suggests that costs decrease as shipment size increases, in other words, FTL is more economically efficient than LTL (Deng, 2013). Furthermore, other benefits of consolidation are the reduction of shipment damage, due to high truckload security, and the reliability in terms of transit time due to smaller variability. There are many reasons why a certain company would like to implement a consolidation policy, but the most important, according to most firms, is the reduction of costs, as shown by the survey of Jackson (1985).

Consolidation methods

The consolidation can be executed in many different ways but the literature has suggested three most common ways. They can be classified as terminal consolidation, vehicle consolidation and inventory consolidation. Terminal consolidation concerns the transportation of small goods to a central location where they should be consolidated. The main focus of this specification is the hub location and services. Vehicle consolidation is a strategy to create an efficient multi-stop route for a single vehicle in order to optimise the container capacity throughout the route. The main idea is to create a route that allows maximisation of the truckload in order to reach as many locations as possible and deliver all the goods with minimal vehicles. The main requirement for this model is operational routing and assignment problems. Lastly, inventory consolidation is a strategy where shipments are collected to wait for future deliveries. The idea is that by accumulating more shipments, there is a possibility for creating an FTL, rather than transporting multiple LTLs, which reduces costs and delivery times. The main aspects of inventory consolidation are packing the goods and the shipment-release policies. Shipment-release policies define when to dispatch a certain shipment to ensure it meets all the requirements, but at the same time benefits as much as possible from economies of scale (Deng, 2013; Ghiani et al., 2004; Higginson & Bookbinder, 1994).

The focus of this project is on inventory consolidation as this is the only strategy that is relevant for this case. As discussed in the Research Limitations section, the location of the hub is already fixed, hence this is not a point of consideration. Furthermore, the company does not have the possibility to change the location but rather would like to understand the possibilities with the existing one. Moreover, we are not trying to improve the routing of the transportation as this is not part of EvW's expertise and therefore there is no reason for evaluating it. EvW is a forwarding intermediary, hence they use partner vehicles to transport the shipments and do not influence the routing. The company wants to assess the implementation of a logistic hub. Therefore, EvW is interested in learning how to combine shipments to decrease the truckloads and minimize the number of containers used. This strategy is known as inventory shipment consolidation.

Inventory Shipment Consolidation

There are two major parts to introducing a consolidation strategy, namely optimally packing the goods and the shipment release policies.

Packing Items

Packing the goods consists of optimally putting together the different truckloads into a full container in order to reduce the total number of containers. In this case, optimal means having the least possible number of containers given a set of restrictions. This problem is part of the big fields of combinatorial optimization problems, which are relevant to this case. Our problem can be classified as a bin packing problem (BPP). The BPP is an optimization problem, where different size items must be packed into a number of containers with a fixed capacity. The goal of the problem is to minimize the number of containers used. The BPP is a variation of the famous Knapsack problem. In the knapsack problem, the number of bins is limited to one and the goal is to achieve the highest value based on the allocated items. On the contrary, the classical BPP can have both a finite and an infinite number of containers (Deng, 2013; Du & Pardalos, 2005; Martello & Toth, 1990). In our case, the BPP considers allocating all of the items into an infinite set of bins. In logistics, the bins of the BPP can be interpreted as truck containers to be transported. The number of containers is considered to be unlimited as EvW can inquire multiple partners to organise the transportation and there is always availability for additional containers.

The BPP can be classified into three variations based on the parameters of the items. The one-dimensional BPP (1D BPP) concerns only the weight or volume of the items without actual parameters like heigh, width, length, etc. This version is useful if the items are of identical size. Two-dimensional BPP (2D BPP) is a case where the items are categorized by length and width. This problem is more difficult as rectangular items need to be packed into a rectangular bin. The thirddimension BPP (3D BPP) deals with packing 3D items in a 3D bin (Deng, 2013; Ghiani et al., 2004). The last two versions are used for container packing with varying size items. In our case, this is not relevant as the items we have to allocate are identical size pallets and therefore can be considered as volume. Given that a general truck container can hold 33 pallets and all of our items are identical size pallets, we can use a 1D BPP to pack multiple items (pallets) in an infinite number of containers with a finite capacity (container = 33 pallets).

Shipment-Release Policy

The other important aspect of the consolidation strategy is the shipment-release policy. In our case, we cannot just pack everything simultaneously and then send it. The items are not available at the same time and some of the shipments may face unnecessary delays. This means that we need to introduce a shipment-release policy. Higginson & Bookbinder (1994) have made extensive research on different shipment-release policies. The three main policies are time, quantity and time-quantity shipment-release strategies. A time policy means that the consolidated shipment is released after a certain time has passed, similar to a scheduled delivery. A quantity policy is when the shipment is released after the given bin has reached maximum capacity. A time-quantity policy is when the shipment is released whenever one of the two policies is completed first, namely either the container has reached full capacity or a certain amount of time has elapsed (Chen et al., 2018; Higginson & Bookbinder, 1994; Mutlu et al., 2010).

In our case, the best option is to introduce a time-quantity shipment-release policy. This means that the given container is released either if it contains 33 pallets or a certain time limit is reached. This is the best policy given EvW's zero delay requirement. This means that the container has to be released according to its delivery time (time policy) and cannot simply wait until maximum capacity is reached, unless that occurs before the delivery date (quantity policy). Therefore, a time-quantity shipment-release policy is the best option for EvW.

After gathering all the necessary information and choosing the appropriate model, namely a 1D BPP with a time-quantity shipment-release policy, we can proceed to formulating the mathematical model.

Mathematical Model

The first step of solving the BPP is to create the appropriate mathematical model. The mathematical model consists of a definition of variables and parameters, the objective function and the necessary constraints. This model is largely based on the classical 1D BPP model from Martello and Toth (1990), however it includes additional shipment-release constraints. In this formulation, the objective function is to minimize the total number of bins used.

Sets

j: number of containers, $j \in \{1 \; to \; n\}$

i: set of shipments, $i \in \{1 \; to \; n\}$

Parameters

S_i: volume of shipment i, $S_i \in \{1\ to\ n\}$

BC: container capacity

BR_j: container release date for bin j, $BR_j \in \{1\ to\ n\}$

SD_i: shipment delivery date for shipment i, $SD_i \in \{1\ to\ n\}$

DT: required delivery time in days

Decision variables

$Y_j\ =\ 1\ if\ bin\ j\ is\ used, 0\ otherwise$

$X_{ij}\ =\ 1\ if\ item\ i\ is\ assigned\ to\ bin\ j, 0\ otherwise$

Objective function

$$Min\ Z = \sum_{j=1}^{n} Y_j$$

Constraints

$$\sum_{j=1}^{n} X_{ij} = 1, for\ i \in \{1, \dots, n\} \quad (1)$$

$$\sum_{i=1}^{n} S_i * X_{ij} \leq BC * Y_j,\ for\ j \in \{1, \dots, n\} \quad (2)$$

$$\mathrm{BR}_j * Y_j\ \leq \mathrm{SD}_i * \mathrm{X}_{ij} - \mathrm{DT} + \mathrm{DT} * (1 - X_{ij}), for\ i, j \in \{1, \dots, n\} \quad (3)$$

$$Y_j =\ 0\ or\ 1, for\ j \in \{1, \dots, n\} \quad (4)$$

$$X_{ij} =\ 0\ or\ 1, for\ i, j \in \{1, \dots, n\} \quad (5)$$

The first constraint ensures that each shipment gets assigned to only one container in order to avoid duplicates. As discussed previously in the Shipment-Release Policy section, our situation requires a time-quantity shipment-release policy, therefore we need both a time and quantity constraint. Constraint 2 ensures that the sum of the items in a given container does not exceed its' capacity as they have a limited size. Constraint 3 ensures that the release date of the bin is smaller than or equal to the shipment delivery date, based on the required travel time, in order to guarantee timely delivery. Constraints 4 and 5 express Y and X as binary variables.

The objective function of this model is to minimise the number of required containers, which is also the main KPI. The objective function is not dependent on costs as they are calculated for each bin after combining the items, therefore the costs do not influence the model. The purpose of the model is to minimise the number of containers, which can in turn reduce costs based on the financial parameters of the company.

Solution Methods

Having formulated the mathematical model and discussed all constraints, the next step is to determine the solution methods. There are two main algorithms to solve a BPP - exact solution methods and applying heuristic solution methods.

Exact Algorithms

Exact methods for solving the BPP allow us to find the optimal solution between all possibilities. Martello & Toth (1990) have developed one of the best exact algorithms for solving a BPP. Their model is based on a branch-and-bound algorithm with a first-fit decreasing approach. Their algorithm called MTP provides a good solution to the BPP. Later, Korf (2002) proposed a faster alternative called the Bin Completion model. This algorithm is largely based on the one from Martello and Toth, however its focus is on considering each bin at a turn rather than each item, as Martello and Toth did. This algorithm is still based on sorting the items in decreasing order based on volume and utilising a branching approach. Other exact methods have been developed by Fekete and Schepers and Hung and Brown (Korf, 2002; Martello & Toth, 1990). Nevertheless, there is a common theme in the above-mentioned exact algorithms, namely they are not suitable for large NP-hard problems like BPPs. The exact algorithms are usually very time-consuming due to their computational nature. In order to find the optimal solution, these algorithms need to calculate all possible solutions, which takes a great amount of time and computational power, therefore cannot be used for large problems.

In order to solve an exact algorithm, the company requires commercial solvers such as CPLEX or Gurobi, which are not accessible to the company as they are expensive and complex to operate. Therefore, we use heuristics to provide a near-optimal for the company's problem.

Heuristics

Heuristics is a problem-solving method of finding an approximate solution in a reasonable amount of time given large modelling constraints. For the BPP there are two types of heuristics – online and offline. The difference is based on the fact whether the items that need to be packed are available beforehand when the procedure starts. In online heuristics, items need to be assigned to a bin one by one in the order they arrive, hence a decision needs to be made immediately. There is no knowledge about future items or the existence of any. In comparison, an offline heuristic allows the items to be preprocessed, for example sorted, in order to achieve a better performance. For an offline heuristic, all of the items are visible from the beginning. This means that the list can be sorted in a certain order in terms of volume, which leads to greater performance. Johnson (1973) has proved that any offline algorithm that runs on a decreasingly sorted list, results in a better performance than online heuristics. The offline heuristics clearly have an advantage as they allow for modification of the list of items which leads to greater performance, however this is at the expense of increased solving time and modelling complexity (Ghiani et al., 2004; Saska, 2020).

Heuristics Algorithms

There are many available algorithms for solving the BPP, however the main solving method is the same in all of them: for each item in the list, the algorithm checks whether it fits into one of the currently open bins. If that is the case, then the given item is assigned to this bin. However, if it does not fit, a new bin is opened and the item is assigned to it. The different algorithms differentiate by the way they select the open bin for the new item. The most popular online algorithms are Next-fit (NF), First-fit (FF) and Best-fit (BF). The most simple algorithm is the NF. This algorithm always keeps only one bin open. When the new item cannot fit into this bin, the algorithm opens a new bin and closes the other one, so that only one bin stays open at all times. Another algorithm with better performance is FF. This algorithm keeps all the bins that have any available space open and tries to assign the given item to the first available container from the order. Only in cases when the item cannot fit in any of the open containers, then a new bin opens. The last algorithm is BF. This one is similar to FF in the sense that it keeps all bins open, however, BF tries to put the item in the bin with the maximum load that it fits in. Otherwise said, it puts the item into the bin with the least residual space and the main idea is to fill the bins as much as possible. For the offline heuristics, we can apply the same algorithm with certain adjustments, namely sorting the items in decreasing order of volume. The most famous offline algorithms are Next-fit-decreasing (NFD), First-fit-decreasing (FFD) and Best-fit-decreasing (BFD). The only difference in the offline heuristics is the fact that we first sort the items in decreasing order of volume and afterwards we apply one of the online algorithms, namely NF, FF or BF (Martello & Toth, 1990).

Performance Analysis

An important aspect of heuristics is comparing the performance of different algorithms. Martello and Toth (1990) have made extensive analyses of the performance of each algorithm.

Figure 5 represents a summary of the results of each algorithm based on the asymptotic worst-case performance ration. This ratio is calculated by the fraction of the number of bins that are used by this algorithm and the minimum number of bins required for this list of items. If we denote the number of bins for a certain algorithm as A(L) and the minimum number of bins as OPT(L), then the performance ratio is A(L)/OPT(L). Figure 5 contains the best performing online and offline bin packing algorithms, their complexity and the according results based on the given ratio. It reveals that all offline algorithms perform better than their online counterparts. Furthermore, the difference in performance is significant, with FFD and BFD having the same best performance. This means that both of them are valid options and ensure good performance. As we can see from Figure 5, both FFD and BFD have a worst-case performance ratio of 1.22. This means that, if applied correctly, an FFD algorithm ensures that its performance is at most 1.22 times worse than the optimal one.

Algorithm	Time complexity	r^{∞}	$r^{\infty}_{1/2}$	$r^{\infty}_{1/3}$	$r^{\infty}_{1/4}$
NF	$O(n)$	2.000	2.000	1.500	1.333 ...
FF	$O(n \log n)$	1.700	1.500	1.333 ...	1.250
BF	$O(n \log n)$	1.700	1.500	1.333 ...	1.250
NFD	$O(n \log n)$	1.691 ...	1.424 ...	1.302 ...	1.234 ...
FFD	$O(n \log n)$	1.222 ...	1.183 ...	1.183 ...	1.150
BFD	$O(n \log n)$	1.222 ...	1.183 ...	1.183 ...	1.150

Figure 5: Performance analysis of different algorithms (Martello & Toth, 1990)

Furthermore, Korf (2002) has shown the performance of heuristics in comparison to his exact algorithm. Figure 6 presents the optimality gap between Korf's exact algorithm and the FFD and BFD heuristics. The first column is the number of elements to pack. The second column is the average number of bins used in the optimal solution based on Korf's exact algorithm. The third column is the average of the wasted-space lower bound. Lastly, columns 4 and 5 show the percentage of problem instances in which the FFD and BFD heuristics return the optimal solution. Meaning that given a problem size of 90 items, the FFD solution is optimal in 94.69% of the experiments. This shows that the FFD heuristic performs well and gives a reasonable solution, comparable to an exact algorithm.

N	Optimal	L2 bound	% Optimal	
			FFD	BFD
5	3.215	3.208	100.000%	100.000%
10	5.966	5.937	99.515%	99.541%
15	8.659	8.609	99.004%	99.051%
20	11.321	11.252	98.570%	98.626%
25	13.966	13.878	98.157%	98.227%
30	16.593	16.489	97.790%	97.867%
35	19.212	19.092	97.478%	97.561%
40	21.823	21.689	97.153%	97.241%
45	24.427	24.278	96.848%	96.946%
50	27.026	26.864	96.553%	96.653%
55	29.620	29.445	96.304%	96.414%
60	32.210	32.023	96.036%	96.184%
65	34.796	34.598	95.780%	95.893%
70	37.378	37.167	95.556%	95.684%
75	39.957	39.736	95.322%	95.447%
80	42.534	42.302	95.112%	95.248%
85	45.108	44.866	94.854%	94.985%
90	47.680	47.428	94.694%	94.832%

Figure 6: Heuristics performance comparison (Korf, 2002)

Another aspect of the performance of the model is the possible minimum value. This is the so-called lower bound. This value is the minimum number of bins that need to be used in order to combine all items from a given list. This number can be calculated by dividing the total amount of volume for all shipments by the maximum container size (e.g. 33 pallets). In our case, the minimum number of bins is 829,42 (Full calculations are removed for confidentiality). This means that EvW requires at least 830 containers as it is the minimal number of containers needed for the given set of items (Ghiani et al., 2004; Martello & Toth, 1990; Saska, 2020).

Modelling Challenges of a Consolidation System

Modelling a consolidation strategy is not an easy task and has many challenges involved. The challenges are not only from a modelling perspective but also in terms of limitations and restrictions. Cetinkaya (2005) discusses many different challenges when modelling a consolidation policy, however not all of them are relevant to EvW's case.

According to Çetinkaya (2005), the first challenge is keeping a high-level customer service as the nature of consolidation may lead to delays. The suggestion is to implement a maximum allowed holding time, which in our case is going to be introduced. For EvW, this is the latest delivery date possible according to the customers' requirements, as the company does not want to have any delays, but rather pertain high customer service level.

Transportation costs should be considered as a challenge in a consolidation model, as the routing might change significantly and lead to higher costs. This is not going to be a problem for EvW, as they already work with reliable partners that provide them with a reasonable offer. Moreover, the specific route from Almelo to Poznan is being scheduled on a daily basis at EvW. Hence, the transportation costs do not change significantly from the current situation. Of course, having a more streamlined process and a more scheduled delivery allows for better rates from partners, but the price mostly stays the same (Çetinkaya, 2005).

When there is consolidation involved, the interdependence between that process and the shipment-release policies plays a crucial part. The implementation of different shipment-release policies is inseparable from the consolidation model and needs to be carefully chosen as discussed previously in this chapter (Çetinkaya, 2005; Higginson & Bookbinder, 1994).

Lastly, Cetinkaya mentions the cargo capacity as a possible challenge in a consolidation model. This is not a point of consideration for EvW. In our situation, there is a fixed cargo capacity, namely a container of 33 pallets, therefore this is not a particular challenge. In case there is a policy change in EvW, this aspect has to be reconsidered to ensure a relevant consolidation model (Çetinkaya, 2005).

4. Data Understanding

In order to evaluate the model, we need data as input. In this chapter, we answer the question of **what data is available that is relevant for analysing the operations and processes at EvW**, which allows us to further proceed with the model creation and evaluation.

Description of Data

The model is based on data from the operations department and the specific shipments. The dataset was acquired based on necessary details while complying with confidentiality requirements and internal privacy policies. Therefore, specific data values and confidential information has been removed to comply with privacy regulations.

The dataset contains all shipments from NL to PL for the two companies that operate on this route. The dataset contains the order number (9-digit unique number), details of the loading and unloading locations and dates, dimensions, price of sale and the associated costs, as shown in Figure 7 (Removed for confidentiality).

Data Exploration

The first six columns contain the order number, loading/ unloading places and the according dates. The columns include the locations of pickup in NL, the final destination in PL and the loading and delivery dates at each location.

The column “Dimensions” includes the number of pallets for each shipment and/or the dimensions of the goods. This is a really important characteristic as it is crucial for the BPP. This is going to act as the dimensions of the items to pack in a 33-pallet container. Initially, the data was not normalised and did not clearly mention the number of pallets in each order.

Columns eight and nine contain the price of sale and the order costs. The sale price represents the amount that the customer has to pay to EvW, while the order cost is the amount that EvW has to pay to the partner for the transportation. This data is useful for the financial analysis, especially the costs, as we want to compare the expenses of the current scenario compared to the case where EvW utilises a logistic hub.

Data Modifications

The column “Days between loading and unloading date” was not part of the initial dataset. It was created later to depict the difference between the loading and unloading day of every shipment. This gives us an idea about the transportation time and the estimated time at the warehouse. This is a crucial aspect of the modelling process and indicates how long a certain shipment can be stored to benefit from consolidation.

Another analysis was made about the unique loading and unloading days and the number of shipments per day. A UNIQUE function was used to identify the unique loading and unloading dates and then a COUNTIF function to count the number of shipments per day. Specific data analysis is removed for confidentiality.

Moreover, thanks to the geography features of MS Excel and the unloading place location, we were able to create a heatmap of all the places where shipments were delivered in PL. This allows us to understand where most of the shipments to PL are delivered. This can be used for further improvements or analysis of the most prominent locations. Figure 8 (Removed for confidentiality) contains an example of the map.

In order to be able to analyse the situation and create the model, we require the exact amount of pallets for each order. We use the column "Dimensions" to note the volume of each shipment. EvW is working with euro pallets as this is the standard within the company. Each container can fit 33 euro pallets. Some of the shipments already have the exact number of euro pallets. The others have the number of block pallets. These need to be transferred to euro pallets with the ratio of 1 block pallet = 1.25 euro pallets. Other shipments have the loading meters. These are also transferred to euro pallets, where 13.6 LDM = 33 euro pallets, or 0.4 LDM = 1 euro pallet. Furthermore, there are other special kinds of tools or boxes, however, all of them are transferred to euro pallets based on the LDM or size of the given shipments. This assumption has been coordinated with the operations department and they have confirmed its' validity. This means that the column **"Europallets"** contains the number of pallets for each order. At the same time, it is obvious that if a certain shipment is 11.5 euro pallets, it takes the space of 12 euro pallets in the container. As the shipments cannot be cut, we cannot work with fractions of shipments. This required the creation of the column **"Europallets rounded"** which rounds up all the values from the previous column and is a better reflection of the actual space that the given shipment takes in the container. This final column is crucial for the model and dictates its' solution.

Data Analysis

Given that we have both the differences between loading and unloading dates as well as the number of euro pallets per shipment, we can make an analysis. Below is a graph that reflects the relation between the day difference and the truckload.

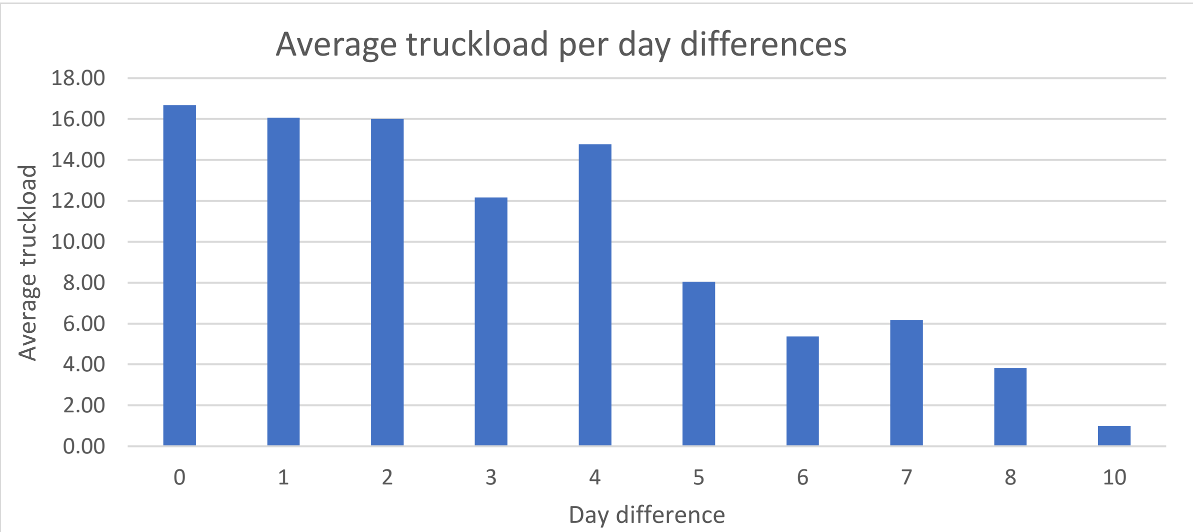

Figure 9: Average truckload per day difference

As we can see from Figure 9, the average number of euro pallets is higher when there are fewer days between loading and unloading. This is intuitive as having an FTL or a large number of pallets in a shipment means it is better to ship that container directly, rather than delaying it. While, if there are smaller truckloads, such as only a few pallets, then it is better to postpone the delivery in order to allow for the accumulation of more orders in order to reduce the overall costs.

Furthermore, the data shows the number of shipments per day for every unique day difference between loading and unloading. This can be seen in Figure 10.

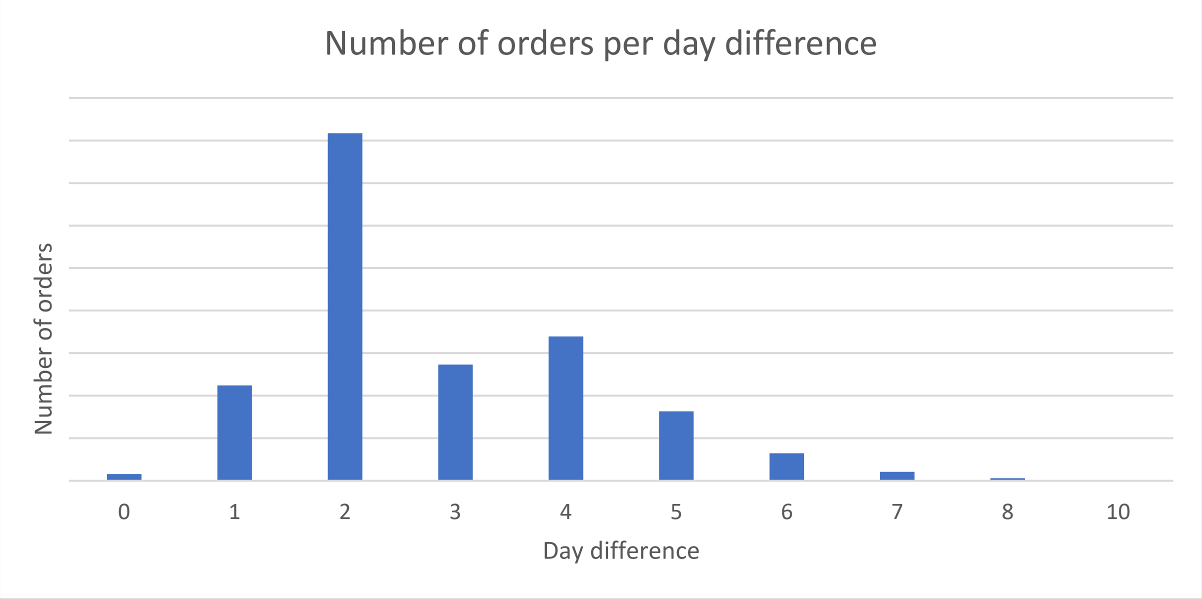

Figure 10: Number of orders per day difference

It is evident that the amount of orders with 2 days difference is significantly larger than all the others. We can also see a higher number of orders when the difference is 1, 3 and 4 days. These results are considered during the model creation.

Moreover, we can see that 25% of all orders are FTLs. Figure 11 shows a better perspective on the different truckloads associated with the shipments. Further details are removed for confidentiality.

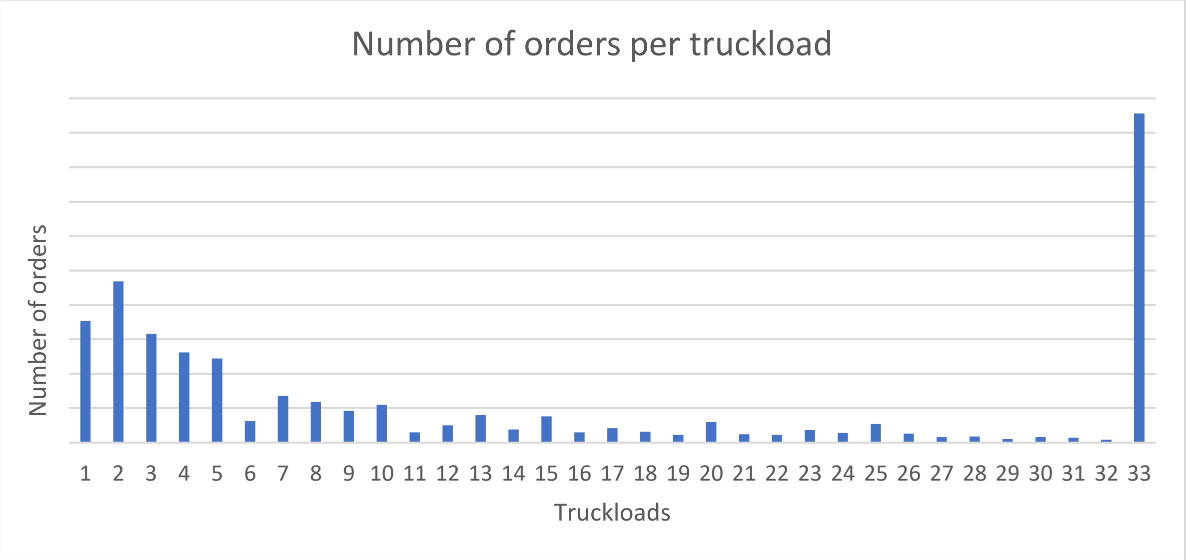

Figure 11: Number of orders per truckload

We can see the large amount of FTLs. However, it is also obvious that there is a great number of small truckloads between 1 and 5, as well as a significant amount at 10, 15 and 25. All of these aspects are considered in the model formulation.

Financial Data

Furthermore, the company has available data for the different costs included in the transportation process. There are four different types of costs in the transportation process at EvW – costs within NL, costs in the warehouse, costs for transportation between NL and PL and the costs within PL. Figure 12 shows these values (Removed for confidentiality). The costs within NL and PL are expressed in terms of pallets. Moreover, the prices for processing a pallet in the warehouse in XL Businesspark Almelo are available. Lastly, the price for transportation between NL and PL is calculated based on the KMs between the hub in Almelo and the warehouse in Poznan- 762 KMs.

5. Problem Formulation

Having created the mathematical model and gathered all the necessary information in the Theoretical Framework, we can proceed further with the problem formulation and all the necessary assumptions.

As discussed previously, the main aspect of the logistic hub is going to be the consolidation of goods. As this is the focus of the research, the model evaluates the differences between the current situation and the logistic hub with a consolidation procedure, based on a selection of KPIs. In this chapter, we describe both the modelling specifications of the current and desired situations in order to compare them.

Solution Approach Visualisation

Figure 13 represents a flowchart of the whole solution approach. It shows how the data and the theoretical framework fit within the model creation as well as what is the output. Figure 13 gives an overview of the whole approach and allows to understand how each part fits within the whole project.

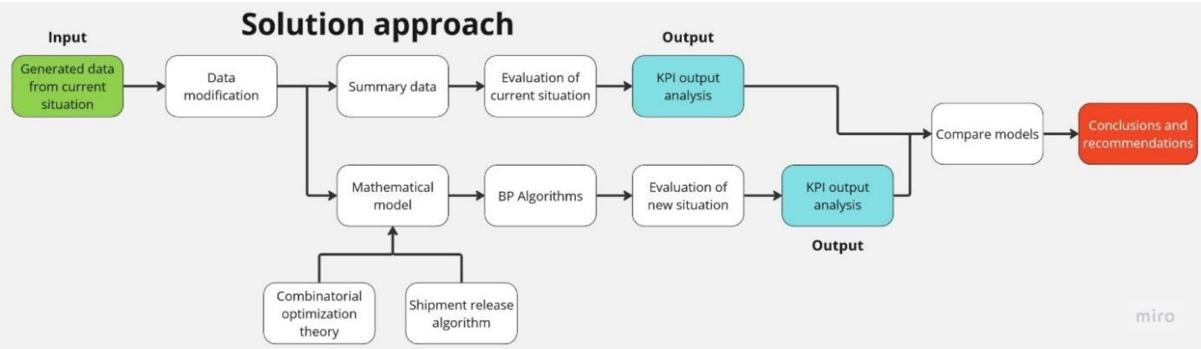

Figure 13: Solution approach flowchart

Modelling Specifications of the Current Situation

The evaluation of the model is going to happen with a comparison between the two situations. The most important specifications are listed below.

- ***All shipments travel alone***

In the current situation, we take the orders as they are and assume that the truckloads travel alone, without the rest of the container filled. This assumption is made due to the fact that EvW does not know whether and how full the container is, as this is organised by the transporting partner.

- ***The shipments travel directly from NL to PL***

Another important clarification in the current situation is that the shipments travel from the destination of origin in NL (e.g. Amsterdam, Eindhoven, etc.) to the final destination in PL (e.g. Warsaw, Krakow, etc.) directly. This is very undesirable as there are many single shipments, which are LTLs, that travel separately between NL and PL. This not only increases costs but also creates a huge carbon footprint (Ülkü, 2012).

- ***The financial analysis is made based on current data***

Furthermore, the financial analysis is made based on the data of the current situation as that reflects the price that EvW pays to their partners. Overall, the analysis of the current situation is similar to a summary of the existing data, as it reflects reality and shows what is currently happening, given the assumptions.

Logistic Hub Model Design

In this section, we describe the main changes of the new situation and visualise the desired process. This includes a high-level overview of the new situation and design specifications of the consolidation strategy.

The process starts with picking up the required shipment from the destination of origin in NL. After the shipment has been loaded, it travels to the logistic hub in Almelo, where it is consolidated. In the warehouse, the shipment is stored until there is a combination of items to combine into an FTL or the delivery date of the order has arrived. Then, the combined container leaves for PL. There, the shipment can be processed in the warehouse of JAS FBG in Poznan, as explained in the Desired Processes section. As soon as the order is received in Poznan it gets dispatched to its final delivery.

Figure 14 represents the high-level overview of the process, however there are many assumptions and clarifications to be made.

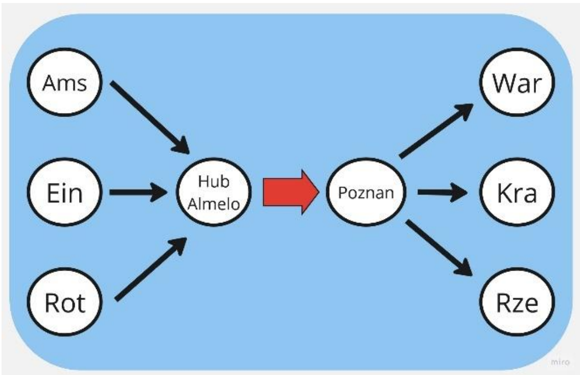

Figure 14: Model visualisation

Model Assumptions

This paragraph describes the key assumptions of the model. These assumptions define the scope and limitations of the model, enabling accurate interpretation of its results. Evaluating these assumptions is essential for ensuring the validity of the model's outputs.

- ***All transportations is be executed by a trusted partner***
  One of the assumptions is about the transportation activities. The loading and transportation will happen with a trusted partner of EvW, as the company itself does not have its own fleet of vehicles. It is important to clarify that all the transportation processes in the new model are executed by trusted partners who is specialised in this specific route and has large availability to

accommodate the high quantity of orders for EvW. EvW is going to be the one who organises the logistical planning, while the partners provide the trucks and the drivers.

- ***Transportation within NL is same-day delivery***
  Within NL, the transportation from the specific locations to the hub in Almelo is executed by EvW Logistics, which has its own fleet. The transport within the Netherlands is same-day delivery (***A-A***), which means that the shipment are in the hub in Almelo on the same day as the loading. This assumption is possible due to the partnership with EvW Logistics, which allows for regularly-scheduled deliveries.

- ***FTLs and same-day shipments do not go through the hub in NL and are directly delivered to the final destination in PL***
  The plan is to transport most of the shipments to the warehouse of JAS FBG in Poznan as this is the part of the process which takes the longest and can benefit most from consolidation. The only exceptions are FTLs or shipments that require next-day delivery. This is because if the shipment is an FTL then it cannot benefit from consolidation, hence there is no point in coming to the logistic hub in Almelo or the warehouse in Poznan and it is directly delivered to its final destination in PL. Furthermore, in most cases, those FTLs require next-day delivery which makes it impossible to go through the hub in XL Businesspark, as they will encounter delays, therefore they need to be delivered directly. This moreover extends to the case when we have an LTL shipment with a next-day delivery. Due to the minimum transportation time requirements, these shipments cannot go through the logistic hub and have to be directly delivered to the final destination. Therefore, next-day LTLs also cannot benefit from the consolidation procedure.

- ***Transportation time between NL and PL is one day (A-B)***
  Apart from FTLs and next-day delivery shipments, all other ones initially are going to come to the logistic hub in Almelo and then be delivered to the warehouse in Poznan. The transport time between Almelo and Poznan is 1 day, or ***A-B*** (loading on the 15^{th} and delivering on the 16^{th}).

- ***Transportation time within PL is one day (A-B)***
  When a shipment arrives in Poznan, it gets redistributed to the different regions of PL to be delivered locally. This process also takes 1 day and is ***A-B***. These assumptions mean that the given shipment should leave the logistic hub in Almelo 2 days before its final delivery date in PL. This is the case as it takes one day to transfer the shipment between Almelo and Poznan and one more day for it to reach its final destination in PL, given that it has to be unloaded from the consolidated truckload. For example, if the delivery date is set for the 20^{th}, that means that the shipment has to leave the logistic hub in Almelo on the 18^{th}.

- ***Any order is known to EvW between one and seven days in advance***
  Another assumption to be made is about the time between the order creation, namely when the customer contacts EvW to request their services, and the loading date. This can vary between 1 day and 1 week, in most cases. Of course, the given shipment can be scheduled well into the future, but this is rarely the case. Hence, we can be certain that most of the time, the days between ordering and loading are 1 to 7.

Mathematical Model Specifications

Table 1 summarizes the values for the case of EvW based on the mathematical model presented in the Theoretical Framework section. These values are implemented in the mathematical model and allow us to solve it using the selected heuristic. Specific values are removed for confidentiality.

j: number of containers	$j \in \{1\ to\ n\}$
i: set of shipments	$i \in \{1\ to\ 1925\}$
S_i: volume of shipment i	$S_i \in \{1\ to\ 33\}$
BC: container capacity	$BC = 33$
BR_j: container release date for bin j	$BR_j \in \{44679\ to\ 45030\}$
SD_i: shipment delivery date for shipment i	$SD_i \in \{44679\ to\ 45030\}$
DT: required delivery time in days	$DT = 2$

Table 1: Case-specific values for the mathematical model

We can see that the number of containers is unlimited as EvW can utilise as many containers as needed. The set of shipments consists of 1925 items. The volume (pallets) of each shipment can vary between 1 and 33, as the upper bound is an FTL. Hence, the container capacity for EvW's case is equal to 33. The container release dates and shipment delivery dates are between 44679 and 45030 as those represent the days expressed in numbers (Specifications removed for confidentiality). Lastly, the variable DT is equal to 2 as that is the required delivery time from the hub in Almelo to the final destination in PL, as discussed in the Model Assumptions section. These are the specific values for EvW's case and are used in solving the model.

Case-Specific Algorithm

Having discussed different methods to solve a BPP and the assumptions of EvW's case, we can proceed to developing the solution. As discussed in the Solution Methods section, we are going to use a heuristic to solve the given BPP. There are a couple of reasons for choosing a heuristic in our case. First of all, a heuristic represents a more accessible approach to solving the problem than using an exact solver. The commercial solvers used for solving problems such as the BPP, are really expensive and difficult to operate. Using such a solver requires an extensive amount of expertise and knowledge about the software and the coding language, which EvW does not currently have. The company needs to invest a lot of time and resources into implementing such a solver and introducing the necessary trainings, which is something that the company would like to avoid. Moreover, a heuristic approach is more understandable by the company. Designing a heuristic allows the management to understand the solution method, due to their limited knowledge of the topic, and be able to change it, if needed. Because a heuristic is a rather simple approach, the company can easily evaluate it and make conclusions accordingly. Another important reason is the fact that this heuristic is customised according to EvW's requirements and best represents the processes in the company. The heuristic has been adjusted to the specifications of the company, such as delivery dates, time-quantity shipment-release policy and same-day deliveries, hence it solves a real-world situation. The company would like to evaluate the specific business situation and therefore a custom heuristic provides the best comparison. Lastly, in order to confirm the performance of the heuristic, we perform an analysis to validate the results.

In EvW's case, we are going to implement an offline heuristic with an FFD algorithm and a time-quantity shipment-release policy. First of all, the offline heuristic is going to apply the FFD algorithm for each loading date in the data. Otherwise said, the algorithm is going to collect the shipments for a certain date and apply the FFD algorithm on that set. Afterwards, it keeps track of the container updates and proceeds to the next day to perform the algorithm again. There are two reasons for choosing an offline heuristic. First of all, offline heuristics showed better performance than the online ones for similar problems, as discussed by Martello and Toth (1990) and Johnson (1973). Secondly, we chose the FFD algorithm as it represents a more realistic approach to the process at EvW. This is true as the company plans the shipments in order and always selects the first available container. Given all these aspects, we choose the offline FFD algorithm as it best represents the operational processes at EvW and performs close to optimality, as shown by Korf (2002).

Heuristic Visualisation

Figure 15 demonstrates a flowchart of the offline FFD consolidation algorithm. The figure summarises the whole consolidation process and allows for visualising the different aspects of it.

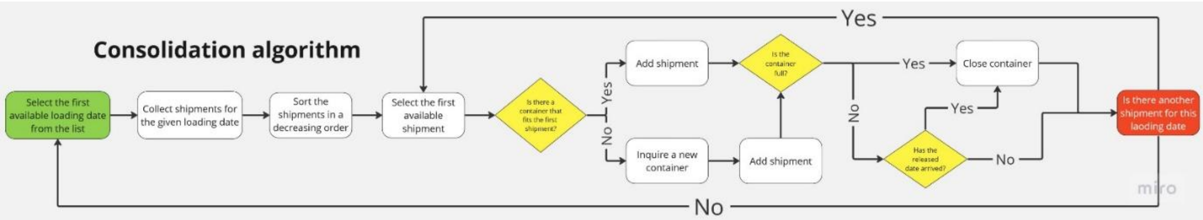

Figure 15: Consolidation algorithm flowchart

Constructive Heuristic

Firstly, an initial solution needs to be generated in order to solve the BPP. The solution stores the number of containers and the associated items, which gives us the final solution. The constructive heuristics is based on the offline FFD algorithm, which was chosen from the analysis. The algorithm follows the mathematical model developed in the Theoretical Framework chapter and ensures that none of the constraints are violated which is crucial for the validity of the heuristic.

The offline FFD algorithm is described below.

Steps:

0. *Let D be the list of loading dates, S the array of items for a given day and B the list of all bins*
1. *Select the first loading date from D*
2. *Collect and store the items for this date in the array S*
3. *Sort the array S in decreasing order of volume*
4. *Check which bins from B are open based on capacity constraints*
5. *Take the first item of the array S*
6. *Put the item in the first open container in B that has enough capacity. If there is no container with enough capacity, open a new one in B*

7. *Update the delivery date, release date and capacity of the container in B*

8. *Pack the next item of the array S*

9. *Repeat steps 6-8 until S is empty*

10. *Check which bins of B have to be released (closed) based on capacity or time constraints*

11. *Select the next loading date from D*

12. *Repeat steps 2-11 until D is completed*

13. *Check if all items have been packed*

6. Heuristic Evaluation and Results

In this chapter, we analyse the performance of the model and compare the current and desired situations based on the identified set of KPIs. This gives us insights into the performance of the heuristic and furthermore whether it is beneficial for EvW to invest in developing a logistic hub. This chapter answers the question **what is the performance of the model based on the KPIs.**

Heuristic Output

The heuristic is implemented in MS Excel VBA and solves the problem with the given dataset. The code can be found in the appendix. Figure 16 represents the heuristic's output.

Model												
Containers	Orders combined	Loading date	Release date	Delivery date	Bin fullness	Bin utilisation %	Capacity left	Bin open?	NR Orders	Direct?	Nr of trucks	977
1	/ 1	28-04-22	28-04-22	29-04-22	33	100.00%	0	FALSE	1	TRUE	Avg truckload	28.02
2	/ 2	28-04-22	28-04-22	29-04-22	2	6.06%	31	FALSE	1	TRUE	Avg LTL truckload	19.20
3	/ 6	02-05-22	02-05-22	04-05-22	33	100.00%	0	FALSE	1	FALSE		
4	/ 4 / 3 / 5	02-05-22	02-05-22	04-05-22	28	84.85%	5	FALSE	3	FALSE		
5	/ 7	03-05-22	03-05-22	05-05-22	33	100.00%	0	FALSE	1	FALSE		
6	/ 8	04-05-22	04-05-22	06-05-22	12	36.36%	21	FALSE	1	FALSE		
7	/ 10	05-05-22	07-05-22	09-05-22	33	100.00%	0	FALSE	1	FALSE		
8	/ 9 / 13	05-05-22	07-05-22	09-05-22	25	75.76%	8	FALSE	2	FALSE		
9	/ 11	06-05-22	07-05-22	09-05-22	33	100.00%	0	FALSE	1	FALSE		
10	/ 14	06-05-22	07-05-22	09-05-22	33	100.00%	0	FALSE	1	FALSE		
11	/ 16	06-05-22	07-05-22	09-05-22	33	100.00%	0	FALSE	1	FALSE		
12	/ 15 / 12	06-05-22	08-05-22	10-05-22	27	81.82%	6	FALSE	2	FALSE		
13	/ 18 / 19 / 17	09-05-22	09-05-22	11-05-22	12	36.36%	21	FALSE	3	FALSE		
14	/ 21	10-05-22	10-05-22	11-05-22	33	100.00%	0	FALSE	1	TRUE		
15	/ 24	10-05-22	10-05-22	11-05-22	33	100.00%	0	FALSE	1	TRUE		
16	/ 23 / 22	10-05-22	10-05-22	12-05-22	27	81.82%	6	FALSE	2	FALSE		
17	/ 20	10-05-22	10-05-22	12-05-22	8	24.24%	25	FALSE	1	FALSE		
18	/ 36 / 37	11-05-22	11-05-22	13-05-22	33	100.00%	0	FALSE	2	FALSE		
19	/ 28 / 29 / 25	11-05-22	11-05-22	13-05-22	33	100.00%	0	FALSE	3	FALSE		
20	/ 34 / 30 / 38	11-05-22	11-05-22	13-05-22	33	100.00%	0	FALSE	3	FALSE		
21	/ 31 / 26 / 32 / 33 / 35 / 27	11-05-22	11-05-22	13-05-22	22	66.67%	11	FALSE	6	FALSE		
22	/ 41	12-05-22	14-05-22	16-05-22	33	100.00%	0	FALSE	1	FALSE		
23	/ 40	12-05-22	12-05-22	13-05-22	26	78.79%	7	FALSE	1	TRUE		
24	/ 39	12-05-22	12-05-22	13-05-22	15	45.45%	18	FALSE	1	TRUE		
25	/ 42 / 43	13-05-22	14-05-22	16-05-22	12	36.36%	21	FALSE	2	FALSE		

Figure 16: Heuristic output

The output in Figure 16 contains all of the important characteristics of the solution. The first column represents the container number. Column 2 notes the combined shipments in a given container. This allows us to see where each shipment was packed. Columns 3, 4 and 5 are, respectively, the loading, release and delivery dates of the container. These columns allow us to check the time that each container spent in the hub before being released as well as determine which containers had to be sent directly. Columns 6, 7 and 8 describe how full the bin is, its utilisation as a percentage and the free capacity. This allows us to analyse how well the consolidation is performing in terms of truckloads. Column 9 contains the order costs as calculated in the code (Hidden for confidentiality). The costs are dependent on the type of shipment, namely whether it is direct or not and how many orders are included. Based on these characteristics, the order costs are calculated differently, as explained in the financial data section. The rest of the columns contain information about how many shipments are combined in a given container and whether the shipments were delivered directly, without going through the hub. This output is analysed in order to understand the differences between the current situation and the new approach. In the top right corner of Figure 16, we can see the total amount containers being used. The output also contains the average truckloads of all containers (FTLs and LTLs) and the average truckload of LTLs only. This is the main output of the heuristic and can be used for initial analysis. The full comparison and analysis of both situations can be found in the Performance Analysis section.

Costs Explanation

The different costs in Figure 16 allow the comparison of both situations. The costs for the different shipments are calculated based on the truckloads, whether they are direct (when the day difference is smaller than 2) and the time they spent in the hub. If the shipments are direct, then their costs are the same as they are in the current situation. As they need to be delivered directly, therefore there is no change or effect from the logistic hub. If the shipments are not direct and go through the logistic hub, then their costs are calculated differently. The costs of shipments going through the hub are calculated based on a combination of inbound costs (transport within NL), warehousing costs (storage and processing pallets), transportation between NL and PL and final-mile delivery costs (transport within PL). These calculations allow for analysing the financial performance of the heuristic and making appropriate conclusions about the worth of the logistic hub for EvW.

These costs are calculated after the model has been solved and the number of containers is minimised, as the costs are not part of the decision process and do not influence the solution. There is no trade-off between costs and number of containers in this case. This is because the BPP does not focus on costs. The goal of the BPP is to minimize the number of containers required, but this is not based on costs. One of the reasons for this is the fact that all of the shipments have to be transported regardless, therefore there is no selection based on value or costs. Furthermore, the shipments become cheaper when combining multiple ones together. This happens as transportation costs are shared between multiple orders and the total costs become less. Therefore, by minimizing the total number of containers, the model is also naturally minimising the costs. Thus, there is no need for including costs in the objective function, as they do not influence the decision. The costs are calculated after solving the model and having the minimum number of required containers with their truckloads.

Heuristic Performance Validation

Before continuing with the performance analysis of the heuristic and the model, it is important to validate that the heuristic is performing well. Without a performance comparison or analysis, the heuristic is worthless and cannot give a definite conclusion to the company. In order to make the appropriate conclusions, we need to validate the heuristic's solution.

One of the ways to validate the heuristic is to perform an exact algorithm on a small sample of data. After discussing the different exact algorithms by Korf (2002) and Martello & Toth (1990) for solving the BPP in the Theoretical Framework chapter, it was evident that they were constructed for the classical BPP. Therefore, they would not be suitable for EvW's case as it requires additional constraints and different policies. EvW's case is a modification of the classical BPP, where we need to include a shipment-release policy based on the delivery and release dates, hence these exact algorithms cannot be performed. Even if we try to use such an algorithm, it will not give a comparable output as our model solves a BPP for every loading date in the dataset and does not have knowledge about all shipments in advance. This means that there is an overlap between the days for some items and no clear differentiation between the shipments and the loading dates. The combination of the above-mentioned restrictions does not allow us to perform an exact algorithm with enough accuracy to evaluate the performance of the heuristic.

Nevertheless, we should still measure the performance in order to validate the heuristic. As discussed by Korf (2002) and Martello & Toth (1990), another way to evaluate the performance is to use the lower bound restriction of the BPP. This lower bound approach has been discussed in the Theoretical Framework section of this report and allows us to compare the performance of the heuristic in comparison to the lowest possible solution value. In the BPP, the lower bound is obtained by dividing the total sum of the volumes of the items by the maximum bin capacity. In EvW's case, this means summing up the volume of each shipment, for a given period, and dividing by the maximum container capacity, 33. This value needs to be rounded up as we cannot use only half a container. For example, if the equation results in 5.3, this means that the optimal solution is 6 containers. We randomly select 20 loading dates. For each of these loading dates, we calculate the lower bound, based on the volumes (pallets) of each shipment and compare this value with the solution of the heuristic to assess its performance.

Random number loading date	Sum of volume (pallets)	Lower bound	Number of containers required	Actual heuristic performance	Performance ratio
18	49	1.48	2	2	1
185	203	6.15	7	9	1.29
214	172	5.21	6	6	1
154	221	6.7	7	7	1
31	91	2.76	3	3	1
25	104	3.15	4	4	1
218	79	2.4	3	3	1
10	74	2.24	3	3	1
97	111	3.36	4	5	1.25
17	193	5.85	6	7	1.17
2	61	1.85	2	3	1.5
91	144	4.36	5	5	1
203	77	2.33	3	3	1
238	99	3	3	3	1
90	230	6.97	7	8	1.14
24	43	1.3	2	3	1.5
197	98	2.97	3	4	1.33
6	146	4.42	5	5	1
116	70	2.12	3	3	1
43	33	1	1	1	1

Table 2: Heuristic performance evaluation

Table 2 presents the evaluation of the heuristic based on the comparison with the lower bound (Certain columns have been removed for confidentiality). Column 3 shows the lower bound for the given set of shipments, namely the sum of pallets divided by 33. Column 4 is the actual minimum number of required containers for this set of items, which is the rounded-up lower bound value. Column 5 is the actual performance of the heuristic or the number of containers that the heuristic uses to combine the given shipments. These values are taken from the heuristic's output. Lastly, Column 6 is the performance ratio, which is the actual performance of the heuristic from Column 5 divided by the value in Column 4 (the minimum number of containers required). This calculates the performance of the heuristic for the given set of items.

Based on the sample of 20 random loading dates, we can see that the heuristic is performing optimally in 13 out of 20 cases. In some instances, the heuristic is not performing optimally, but this can be happening for many reasons, namely because of already open containers (from the previous days), or because of sorting in decreasing order of volume. The average performance ratio of Table 2 is 1.11, meaning that the heuristic if performing on average 11% worse than the minimum lower bound. Overall, the heuristic performs well with comparable results in most cases. Hence, we can conclude that the heuristic is valid and presents a reasonable solution.

After running the full heuristic in EvW's case, the minimum number of containers required is 977. The minimum required number of containers of the current situation is 829.42, rounded up to 830 (Full calculations are removed for confidentiality). In this case, our heuristic is performing 18% (977/830 = 1.18) worse than the minimum number of containers required (lower bound). Considering the full dataset (Specific data removed for confidentiality), this is a relevant performance, which validates the approach and the heuristic. Furthermore, we can validate the heuristic by the fact that Martello & Toth (1990) have proved that an offline FFD heuristic has a worst-case performance ratio of 11/9*optimal value or 1.22* optimal value. This heuristic's performance of 1.18 is smaller than 1.22, which means that it fits their analysis. Therefore, the heuristic is applied correctly and the FFD algorithm works according to theory. This concludes that the heuristic performs reasonably and the output can be analysed to form conclusions.

Output Performance Comparison

After evaluating the performance of the heuristic, we can be certain about its validity and therefore we can proceed with the performance comparison of the model. Tables 3, 4 and 5 present the comparison between the results from both the old and the new situation. The values for the old situation are based on the dataset for the shipment between Netherlands and Poland. The results for the new situation are obtained from the heuristic's output.

Table 3 contains information about the comparison in terms of transformational KPIs.

	KPI	Percentage	Conclusions
Transportation KPIs	Number of containers used	-49.25%	**50% less containers**
	Average truckload used	97.03%	**97% more truckload**
	Average LTL truckload	47.28%	**47% more LTL truckload**
	Average truckload utilisation rate	97.03%	**97% more truckload utilisation rate**
	Total KMs travelled (Average distance of 1000 KMs)	-49.25%	**50% less KMs travelled**
	Average KMs per pallet	-49.25%	**50% less KMs per pallet**
	Average KMs per pallet per container	-77.34%	**77% less KM per pallet per container**

Table 3: Performance comparison of transportation KPIs

The table contains the identified KPIs and their values from the old and new situations (Hidden for confidentiality). Furthermore, the table includes the difference between the new and the old values as well as the percentage difference in the KPIs. Lastly, there is a short conclusion based on the results. The table shows significant improvement in all KPIs.

Table 4 presents the comparison between the old and new situations with regard to financial KPIs.

	KPI	Percentage	Conclusions
Financial KPIs	Total costs	-5.14%	**5% less total costs**
	Average costs per container	86.90%	**87% more costs per container**
	Average costs per pallet	-5.14%	**5% less costs per pallet**
	Average costs per pallet per container	-39.24%	**39% less costs per pallet per container**
	Average costs per KM	86.90%	**87% more costs per KM**

Table 4:Performance comparison of financial KPIs

The format of the table is the same as Table 3, however, here the values are expressed in terms of euros (Hidden for confidentiality). In the last column, we can see the main conclusion which gives a suggestion and helps to understand the difference between the situations.

Table 5 evaluates the performance of the new situation based on KPIs related to time (Altered for confidentiality).

	KPI	Percentage	Conclusions
Time KPIs	Average number of days in the hub before release		Average of half a day spent in the hub
	Average number of days from loading to final delivery	-18.84%	Average of half a day less in total travel

Table 5: Performance comparison of time KPIs

This table contains the difference in KPIs from both situations. The values are expressed in terms of days and the conclusions column indicates how the value can be translated (Hidden for confidentiality).

Tables 3, 4 and 5 give a preliminary overview of the performance of the different situations. Nevertheless, in the following section, we perform a systematic analysis to form concrete conclusions.

Results Analysis

In this section, we further analyse the results and explain the conclusions. All of the results can be found in Table 6.

	KPI	Percentage	Conclusions
Transportation KPIs	Number of containers used	-49.25%	50% less containers
	Average truckload used	97.03%	97% more truckload
	Average LTL truckload	47.28%	47% more LTL truckload
	Average truckload utilisation rate	97.03%	97% more truckload utilisation rate
	Total KMs travelled (Average distance of 1000 KMs)	-49.25%	50% less KMs travelled
	Average KMs per pallet	-49.25%	50% less KMs per pallet
	Average KMs per pallet per container	-77.34%	77% less KM per pallet per container
	KPI	**Percentage**	**Conclusions**
Financial KPIs	Total costs	-5.14%	5% less total costs
	Average costs per container	86.90%	87% more costs per container
	Average costs per pallet	-5.14%	5% less costs per pallet
	Average costs per pallet per container	-39.24%	39% less costs per pallet per container
	Average costs per KM	86.90%	87% more costs per KM
	KPI	**Percentage**	**Conclusions**
Time KPIs	Average number of days in the hub before release		Average of half a day spent in the hub
	Average number of days from loading to final delivery	-18.84%	Average of half a day less in total travel

Table 6: Full performance comparison

Starting with the transformational KPIs, we can see that the logistic hub has a significant impact on the performance of the KPIs. The main KPI that has been evaluated through the BPP is the total number of containers used. In the old situation, every shipment is considered to be travelling in a separate container because EvW does not know how the partner organises the transportation. This means that 1925 separate containers are travelling between NL and PL. In the new situation, we can see that this number has been reduced by almost 50%, to 977. After implementing the logistic hub, EvW only requires 977 containers to transport the same volume due to the new consolidation procedure. The decrease of 50% is substantial. Furthermore, we can make an analysis of the number of LTLs in both situations. If we compare the numbers of LTLs in both the current and the new situations, we see that there is a 66% decrease after implementing the consolidation procedure (Full calculations are removed for confidentiality). There is a significant decrease of using the consolidation procedure as most of the LTLs are combined in order to reduce the total travel distance and costs, respectively. This is a positive result in forming a conclusion on whether a hub is beneficial for EvW.

The above-mentioned conclusions influence many aspects, amongst which are the KPIs related to KMs travelled. Table 3 shows the KPIs related to KMs and we can see that both the total number of KMs and the average KMs per pallet are 50% lower after implementing the hub. Moreover, the average KMs per pallet per container are even lower, by 77%, in comparison to before introducing a consolidation procedure. Other important factors are the truckloads. The table shows that all KPIs related to truckloads are significantly improved (Specific values are hidden for confidentiality). The consolidation scheme allows for an almost 100% increase in average truckloads (both FTL and LTL) and truckload utilisation rate. Furthermore, the average LTL truckload has an increase of 50%. This is a very important factor as it excludes FTLs and gives a better indication of how well the heuristic combines LTLs. This allows us to check the actual impact of the consolidation procedure. This means that EvW is able to transfer on average 50% more pallets when the container is not an FTL. This is substantial as it proves that the consolidation has a major effect and increases the LTL truckload by 50%.

Also, we can analyse the financial KPIs. The main indicator is the total costs. The difference between the two situations is a 5.14% decrease in the new scenario. This is a positive outcome as it means that the company can both benefit from consolidation and have lower costs. However, the value for the total costs does not show the full picture and does not allow for further conclusions. The total costs depend on four different aspects as explained in the Financial Data section. As discussed in the Problem Formulation chapter, the costs for the old situation are based on what has already happened and the prices that EvW paid to their partners, however the costs in the new situation are calculated by the heuristic. Therefore, these values can be altered in order to assess the performance when changes are required. Such changes can be in terms of the rate per KM or inbound/outbound costs. Prominent reasons for updating the values include fluctuations in fuel prices or inflation adjustments, which EvW should be aware of and take into consideration.

Other relevant financial values are the average costs per container, per pallet, per pallet per container and per KM. The average costs per container and KM are higher due to the fewer containers. The total costs are divided by the number of containers in the new situation, which is twice as low, therefore this makes the average costs per container and KM higher. This happens as the difference in costs between the two situations is similar but it is divided by twice as few containers, hence the average is increased. At the same time, a very representative value is the average costs per pallet per container which are 40% lower in the new situation. This shows that by consolidating shipments we can achieve lower costs per pallet and respectively increase profits. All of the financial KPIs show substantially positive outcomes. Meanwhile, they can be explored further for a more in-depth analysis of the costs.

Lastly, we can examine the KPIs related to time, which can be found in Table 5. One of them is the average number of days in the hub before release, which is only relevant for the new scenario. In the old situation, the shipments do not go through or spend time at the hub, hence this KPI is only relevant for the new situation. We can see that this value is 0.53 or half a day. This means that, on average, the shipments spend either 0 or 1 day at the hub before being released. This is a time that can be used for consolidation, without compromising timely delivery. The other KPI is the number of days from loading to final delivery. The difference between the old and the new situations is 18.84% (Further analysis removed for confidentiality). This value indicates that the hub is performing well and does not induce any delays. These KPIs give crucial insights into the time-related performance of the hub.

The full analysis shows positive results from the new situation in comparison to the old one. We can see significant improvements in all KPIs. This validates the approach and the heuristic. Furthermore, we proved that the performance of the heuristic is comparable to the lower bound restriction and nearly optimal. This ensures that the results are trustworthy and can form conclusions.

7. Conclusion

EvW Forwarding is a forwarding company in the B2B market. They act as the intermediary between the customers and the transportation companies. The company helps customers to transport given goods from *A* to *B*. They do not have their own fleet of vehicles, but rather outsource the transportation to their partners. Recently, the company has identified a change in the customers' needs, as they require a full-service provider. This presents a possibility for business expansion that EvW can exploit. Some of the possible developments include an improved customs department, greater modality options and the possibility of tracking shipments. However, EvW's currently limited reach over the control of the supply chain restricts its progress and expansion possibilities. The company has proposed the introduction of a centralised logistic hub to gain more control over its operations. Nevertheless, EvW does not have insights into the implementation possibilities of such an establishment, which is the main core problem. Therefore, the main goal of the thesis is to evaluate how to optimally operate a logistic hub to improve a set of KPIs.

The first step of the research was to map out the current and desired situations in order to understand the bottlenecks and possible improvements. Based on the input from the company and the research scope of the project, a process flowchart of the desired situation was created to comprehend the improvement possibilities. This analysis distinguished the plausible benefits of a logistic hub, namely tracking goods, in-house customs department and consolidation of goods. Consolidation of goods is the primary topic of interest because it can be measured and exerts influence on other operational aspects. Moreover, a set of KPIs was selected to evaluate the performance of the consolidation procedure. By analysing the KPI results, we can conclude whether the company should invest in implementing such an establishment.

We conducted a literature review to find different consolidation strategies. The research pointed to three main consolidation methods - terminal consolidation, vehicle consolidation and inventory consolidation. This research was focused on inventory consolidation, as the company would like to assess the consolidation possibilities of using a logistic hub for combining multiple LTLs in a greater truckload. Inventory consolidation consists of two main aspects – packing goods and shipment-release policies. Packing the goods ensures that every item is assigned to a certain container, given a set of constraints, while the shipment-release policies guarantee timely delivery. Therefore, the research focuses on solving a Bin packing problem with a shipment-release policy. Furthermore, the literature has revealed two main ways of solving a BPP – exact methods and heuristics. Exact algorithms were not suitable for this case, as they are based on the classical BPP and do not suit the additional constraints of this case. Hence, the selected solution method is a heuristic. Lastly, the performance of different heuristics was compared and evaluated.

Prior to proceeding with solving the BPP, it was crucial to analyze the available data. The company's dataset was normalised and analysed to ensure its suitability for the BPP. Subsequently, several analyses were conducted, unveiling significant insights into the data, which were beneficial in the model creation phase.

Following the evaluation of available data and the literature review, we developed a mathematical model based on the classical BPP with additional shipment-release constraints. The mathematical model consists of an objective function and a strict set of constraints, that were adapted to EvW's case. To solve the BPP, a First Fit Decreasing offline algorithm was chosen, based on its performance and the resemblance to EvW's processes. The model is solved with a heuristic, due to the large dataset, the specifics of EvW's case and its reasonable performance. The choice for the specific model and heuristic algorithm was supported by the literature discussed in the Theoretical Framework section.

The model and the heuristic were implemented in MS Excel VBA. Once we validated the functionality and output of the model, it was necessary to validate the performance of the heuristic. The heuristic was evaluated based on a comparison between its output and the lower bound restriction of the given sample. This approach was discussed extensively in the Theoretical Framework section and has been confirmed by Korf (2002) and Martello & Toth (1990). Given that the analysis of the heuristic's performance indicates that it is closely related to the values found in the literature, we can deduce that the results are valid and can be evaluated to draw meaningful conclusions.

At last, the performance of the new model, based on the consolidation procedure was evaluated. The previously identified set of KPIs was compared in both situations. The improvements in the new situation are significant as there is a 50% reduction in the total number of containers used and a 5.14% decrease in total costs. Other relevant results include a 97% increase in average truckload and truckload utilization rate. In terms of costs, there is a 40% decrease in average costs per pallet per container and a 5.14% decrease in average costs per pallet. Furthermore, each shipment takes on average half a day less from loading to the final destination. Based on the comparison of both situations and the set of KPIs, we observe significant improvements in the new scenario. This demonstrates the effectiveness of the consolidation procedure and the successful implementation of the logistic hub.

Overall, we can conclude that the model has a positive outcome, which validates the idea of investing in a logistic hub. According to the findings, we can confidently conclude an answer to the research question of how to optimally operate a logistic hub to improve a set of KPIs at EvW**.** As seen from the results, a consolidation procedure based on a time-quantity shipment-release policy performs substantially better and significantly improves all KPIs, therefore is a reasonable way to operate a logistic hub. Nevertheless, the performance of the model can be further improved by a specific solution approach. In EvW’s case, a BPP has to be solved each day and given the small number of daily shipments, this can be optimally done in a reasonable amount of time by an employee of the company. Meanwhile, the given shipments are known to EvW between 1 and 7 days in advance, which allows for optimal planning of the packing procedures. Consequently, possessing prior information about upcoming orders and leveraging human expertise to effectively operate the consolidation process further amplifies the advantages of a logistic hub, resulting in cost reduction and increased truckload capacity.

Another important point of discussion is the possible introduction of additional consolidation strategies. Currently, each shipment travels separately from its original destination in the Netherlands to the warehouse in Almelo. The current approach is suboptimal since these shipments can be consolidated to minimize costs and total distance travelled. Such an improvement can be facilitated with a vehicle consolidation strategy. This strategy creates an efficient multi-stop route for a single vehicle to optimise the container capacity throughout the route. Therefore, this approach allows EvW to pick up multiple shipments with a single truck and bring them to the hub, which further reduces transportation costs. This strategy has not been developed in this thesis as it was not a priority for the company. EvW’s goal was to evaluate the improvement possibilities of the already existing warehouse through shipment consolidation. Nevertheless, based on our research findings, we believe that implementing an additional vehicle consolidation strategy would yield significant benefits.

Lastly, introducing a logistic hub and its included improvements, such as an in-house customs department, tracking of goods and a consolidation procedure, will bring additional benefits to EvW. These advantages can be expressed in terms of competitiveness, bigger market share and a more complete service offer. Therefore, looking solely at the current solution does not represent the complete picture. EvW should further consider the indirect benefits that cannot be quantified solely in numbers. The current solution and model are based on a single dataset including past shipment, warehousing costs and transportation rates, however these values can be revisited and recalibrated after further consultations with the respective partners. Moreover, after introducing new improvements and creating a more centralised process, EvW can become a more attractive partner and therefore can request different rates. This can influence the overall business and financial analysis, which can further enhance the positive effects of the introduced hub.

The new improvements that EvW can offer by implementing a logistic hub, such as tracking of goods, a more complete service offer and a shipment consolidation strategy, can bring benefits beyond increased truckload and reduced costs and allow them to become a market leader in the near future.

8. Recommendations

The results of this study suggest that there are significant benefits to introducing a logistic hub at EvW. Such an implementation does not only bring direct improvements in main KPIs, but furthermore allows the company to become more competitive and offer a more complete service to their customers. This can increase profits and revenue, respectively. Moreover, the introduction of a logistic hub improves the operations of EvW as it reduces the total number of containers required and improves all KPIs related to transportation. Naturally, a recommendation for the company is to invest in implementing a logistic hub based on the proven enhancements and the further possibilities it creates.

The main aspect that was proven in this study was the benefit of a shipment consolidation strategy. Therefore, this is a valuable way to operate the logistic hub and certainly brings added value to the business operations at EvW. Nevertheless, further analysis shows that combining the shipment consolidation strategy with a vehicle consolidation strategy can further emphasise its advantages and can lead to a more complete remodelling of EvW's operations. Introducing a vehicle consolation procedure for creating the optimal routing plan during the loading process, can intensify the effects of combining multiple, as it can reduce costs further. The possibility of using a single truck for collecting multiple shipments can significantly improve the costs of the shipment consolidating process as it substantially reduces the inbound costs. This in turn significantly effects container costs and ultimately can lead to considerably lower overall costs. Therefore, we can confidently suggest that EvW should consider an additional vehicle consolidation strategy to greatly benefit from the logistic hub and further emphasize its impact on the operations of the company.

As discussed above, a vehicle consolidation strategy significantly reduces one aspect of the total costs, namely inbound expenses. Nonetheless, the transportation between NL and PL is a major portion of the total costs. These costs are calculated based on a standard rate per KM. This value should be revisited after implementing the logistic hub as EvW will have a greater advantage over its competitors and hence can benefit from different pricing. The added benefits from the consolidation procedures undeniably have implications on all operations in logistics and can even influence the partnerships with transportation companies. Therefore, EvW should emphasise the importance and significance of the newly introduced improvements to prove the overall added value and compete for a better cost-pricing.

Another possibility for EvW is to explore the prospects of introducing shipment delays as that can greatly reduce the costs and allow for more consolidation time. Currently, the company would like to introduce a consolidation procedure without disturbing the transportation process, namely allowing delays. However, such a relaxation can have a substantial impact on the total number of containers used and can reduce costs further, as it allows for a greater shipment consolidation effect. This is a suggestion that EvW should explore further and find the trade-off between shipment delays, additional reductions in costs and container truckloads.

Ultimately, EvW should invest in implementing a logistic hub. Ideally, the company would also like to introduce a vehicle consolidation strategy to further amplify the effect of the shipment consolidation. Nevertheless, the company should explore different options for reducing transportation costs and allowing shipment delays to further increase the consolidation impact on logistics.

9. Future Research

The abovementioned recommendations are aspects that the company can introduce shortly in order to significantly improve their business operations. Nevertheless, future research can be conducted in order to enhance this study and explore other opportunities at EvW.

One avenue for future research is to get a better overview of the costs and the required steps of implementing a logistic hub. In this project so far, we have discussed the results of a consolidation strategy, however, in order to become a reality, there are certain in-between steps. EvW can further research what are the exact procedures and required changes for introducing the consolidation process and what are the associated costs. The research should include the exact steps but also what are the implications on the current operations and the expenses associated with such a change. This allows EvW to have a better understanding of how to implement a consolidation strategy.

Future research about required implementation steps allows EvW to transform its current warehouse into a consolidation hub, but nevertheless the company can explore a larger consolidation scheme. This project is focused solely on the shipments between NL and PL, hence the reach of the consolidation strategy is limited. EvW can further research how such a consolidation strategy can be implemented at other locations in Europe or Asia. This can create a vast network of consolidation hubs which in turn can largely impact the logistics of EvW.

This expanded consolidation strategy should also consider evaluating the location of hubs in other countries. EvW currently has its own warehouses only in certain countries. This means that in other countries they use a partner’s warehouse as a receiving point, such as the one in Poznan from JAS FBG. Nevertheless, the location of these hubs might not be ideal and can lead to longer delivery times. Therefore, EvW should further research the best locations for warehouses in different countries in order to ensure the best logistic connections. This not only reduces overall costs but leads to lower delivery times and greater networks of hubs.

Another point for expanding this research is about evaluating the carbon footprint of the logistics hub. As we found out in this project, introducing a logistic hub with a consolidation procedure significantly reduces the total number of containers and improves all KPIs. All of these improvements can be further translated into carbon emissions. Just the fact that in the new situation there is a 50% reduction in the required containers means that the carbon footprint is significantly lower. EvW should look further into what is the exact effect of consolidation on the carbon footprint of the company and evaluate how it can be reduced further. This analysis allows EvW to create a more competitive service and attract new customers, which value a sustainable approach.

This research has established the basis for implementing a full consolidation procedure at EvW and offering a new service to customers. As seen from the results, using a logistic hub to consolidate shipments significantly improves all KPIs and therefore is a valuable investment and can create new business opportunities for EvW. The company should further research other aspects of introducing a consolation procedure, as discussed previously, which can have a positive impact on the logistics. A complete consolation scheme creates new business opportunities for EvW and increases its competitiveness in the logistics sector.

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Appendix

Order costs transformation

The order costs column was added additionally to the initial dataset. This column reflects the costs that EvW has to pay to their partner for organising the transport. This data is crucial for the analysis of the current situation. After the final dataset for the shipment was selected, I asked the sales department for the data about the costs. They sent me a file with many shipments and I used some VBA code to connect the order costs to the given shipments. Most of the shipments were connected but there were still some missing ones. There were 2 types of missing ones. Sometimes the value was 0 and after consultation with the operations department they told me that those were not real shipments and they were not executed, hence those were removed from the dataset. The other ones were empty. This happens because of 2 reasons. Either the costs dataset did not contain this shipment or the shipment was wrong. There were some cases where the shipments were not leaving from the Netherlands, but for example from Turkey or France. Those shipments were deleted as they do not belong to our case. In the other cases, where there was a missing value but the shipments were correct, we multiplied the sale price by 0.8. This is the case as EvW tries to maintain a 20% margin hence the sale price is 20% higher than their costs. This was the last formulation and this allowed us to gather a full list of the order costs without any errors or missing information.

Code example

Below, a small sample of the code for the offline FFD algorithm is presented.

```
bincount(c) = bincount(c) + 1
binorders(c) = binorders(c) & " / " & ordernr(orderstoday(r))
firstorderinbin(c) = ordernr(orderstoday(r))
binloaddate(c) = orderloaddate(orderstoday(r))
bindelivery(c) = orderdeliverydate(orderstoday(r))
bincapacity(c) = bincapacity(c) - orderpallets(orderstoday(r))
bintotalcosts(c) = bintotalcosts(c) + ordercosts(orderstoday(r))
        For p = r + 1 To UB
        If p <= UB Then
            If orderloadplace(orderstoday(r)) = orderloadplace(orderstoday(p)) And (bincapacity(c) -
            bincount(c) = bincount(c) + 1
            binorders(c) = binorders(c) & " / " & ordernr(orderstoday(p))
            firstorderinbin(c) = ordernr(orderstoday(p))
            If bindelivery(c) > orderdeliverydate(orderstoday(p)) Then
                bindelivery(c) = orderdeliverydate(orderstoday(p))
            End If
            bincapacity(c) = bincapacity(c) - orderpallets(orderstoday(p))
            bintotalcosts(c) = bintotalcosts(c) + ordercosts(orderstoday(p))
            'orderstoday(p) = 0
            orderstoday(p) = orderstoday(UB)
            ReDim Preserve orderstoday(1 To UB - 1)
            UB = UB - 1
                        Dim FirstItem As Long, LastItem As Long
                        Dim i As Long, j As Long
                        Dim Tmp As Long 'Swap variable
                        FirstItem = LBound(orderstoday)
                        LastItem = UBound(orderstoday)
                        For i = FirstItem To LastItem - 1
                            For j = i + 1 To LastItem
                                If orderpallets(orderstoday(j)) > orderpallets(orderstoday(i)) Then
                                    Tmp = orderstoday(j)
                                    orderstoday(j) = orderstoday(i)
                                    orderstoday(i) = Tmp
                                    End If
                                Next j
                            Next i
```