A Dynamic Optimization Algorithm for Supply Chain Planning

Pedro Miguel Vieira Esmeriz Pereira

Master's Dissertation

Supervisor FEUP: Prof. Maria Teresa Bianchi Aguiar

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

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"Insanity is doing the same thing over and over and expecting different results."

\- *Albert Einstein*

Um algoritmo de otimização dinâmica para o planeamento da cadeia de abastecimento

Resumo

A análise de uma cadeia de abastecimento evoluiu do estudo de processos individuais para a consideração de todo o sistema como um elemento único. Neste contexto, a seguinte dissertação aborda o planeamento da cadeia de abastecimento da HUUB, uma empresa que oferece serviços logísticos, e o processo de tomada de decisão sobre a agregação de armazéns adicionais através de uma parceria com outra empresa.

Neste projeto, é proposto a implementação de um algoritmo de otimização dinâmica de programação inteira que irá realizar o planeamento da operação, onde a função objetivo é a minimização do custo total. O resultado do planeamento permitirá também inferir se a associação com outra empresa e a realização de tarefas operacionais nos respetivos armazéns é uma opção viável.

Para apoiar a recolha de dados sobre os procedimentos a serem planeados, foi elaborada uma estrutura de custos com base no método *Activity-Based Costing* com imputação de custos baseada no tempo de execução de cada atividade. Em relação à construção da estrutura de custeio, a operação foi dividida em 5 processos principais: (i) receção, (ii) *pick* para *stock*, (iii) *pick* de *stock*, (iv) embalamento e (v) envio. Além disso, o processo e a estrutura de custos de outros armazéns também foram incluídos.

Para implementar este modelo, foi desenvolvido um algoritmo de programação em Python onde (i) os dados de entrada são obtidos através de consultas em SQL, (ii) o processamento de dados e construção do modelo é executado através de várias bibliotecas Python, (iii) a computação iterativa da solução é obtida através de *solvers* externos e (iv) o resultado é enviado como um arquivo JSON para uma base de dados e posteriormente consumido por uma plataforma web.

Concluiu-se que o modelo é capaz gerar a solução ótima, dentro da janela de tempo imposta. Além disso, concluiu-se que a opção de parceria é uma escolha viável que permite uma diminuição de custos, considerando a estrutura de preços apresentada nesta dissertação. Esta opção pouco impacto tem na concretização de vendas de comércio eletrónico, em comparação com as vendas para retalhistas onde a influência é significativa.

Abstract

The analysis of a supply chain has evolved from the study of individual processes to the consideration of the whole system as a single element. In this context, the following dissertation addresses the supply chain planning of HUUB, a company that offers logistics services, and the decision-making process of aggregating additional warehouses through a partnership with another company.

Within this project, it is proposed the implementation of a dynamic mixed integer programming optimization algorithm that will perform the planning of the operation, where the objective function is the minimization of the total cost. The result of the planning will allow to infer if the option to partner with another company and deploy operational task on its warehouse is a viable option

To support the input of information regarding the procedures to plan, a cost framework was devised based on Time-Driven Activity-Based Costing and on the Cost-to-Serve approach. Regarding the construction of the cost framework, the operation was divided into five main processes: (i) reception, (ii) pick to stock, (iii) pick from stock, (iv) packing and (v) shipping. Additionally, the process and cost structure of other warehouses were also included.

To implement this model, a Python programming algorithm was developed where (i) the input data is obtained through SQL queries, (ii) the processing of data and construction of the model is executed through several Python libraries, (iii) the iterative computation of the solution is obtained through external solvers and (iv) the result is sent as a JSON file to the database and posteriorly consumed by a web platform.

It was concluded that the model was able to generate an optimal solution in all cases, within the time window imposed. Furthermore, it was concluded that the outsourcing option is a viable choice that enables cost savings, for the price structure presented. While the inclusion of another company may not influence the fulfilment of e-commerce sales orders, its influence on wholesale ones is significantly high.

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Nomenclature

ABC – Activity-Based Costing

API – Application Programming Interface

B2B – Business to Business

B2C – Business to Consumer

DMS – Distribution Management System

DPP – Direct Product Profitability

JSON – JavaScript Object Notation

OMS – Order Management System

SKU – Stock Keeping Unit

SQL – Structured Query Language

TCO – Total Cost Ownership

WMS – Warehouse Management System

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1 Introduction

The following dissertation addresses the operational and tactical supply chain planning of HUUB and the decision-making process of which warehouses to open and where. For any given moment in time, an optimization model will consider the limitations of each distribution centre and allocate the resources that allow the fulfillment of deliveries at the lowest cost. To achieve the lowest cost, actions such as cross-docking and bulk shipments are considered to minimize the impact of costs related to last-mile delivery, storage and warehousing processes. In this methodology, there are three major components of interest regarding the performance of the algorithm: (a) an appropriate cost quantification method, (b) the optimization model employed and (c) the practical implementation of the model.

The analysis of a supply chain has evolved from the study of individual processes to the consideration of the whole system as a single element. This methodology became a necessary measure due to the insurgence of rising costs concerning manufacturing as well as reduced product life cycles and the globalization of commerce (Beamon 1998). In order to further extend the efficiency and flexibility of the supply chain, new models are being created with a greater level of complexity to try to tackle issues regarding (i) product postponement, (ii) scope of analysis and (iii) the bullwhip effect (Cohen and Lee 1988).

1.1 Company Overview

HUUB is a start-up company created in 2015 that provides logistic services and management of the supply chain of brands in the fashion industry. These services concern the warehouse handling of products and the offering of technological features that let brands control their supply chain without the burden of managing it. The objective of this company is to become the central element of supply chain management, providing a value proposition of an end-to-end service that connects of every stakeholder, as seen in Figure 1.

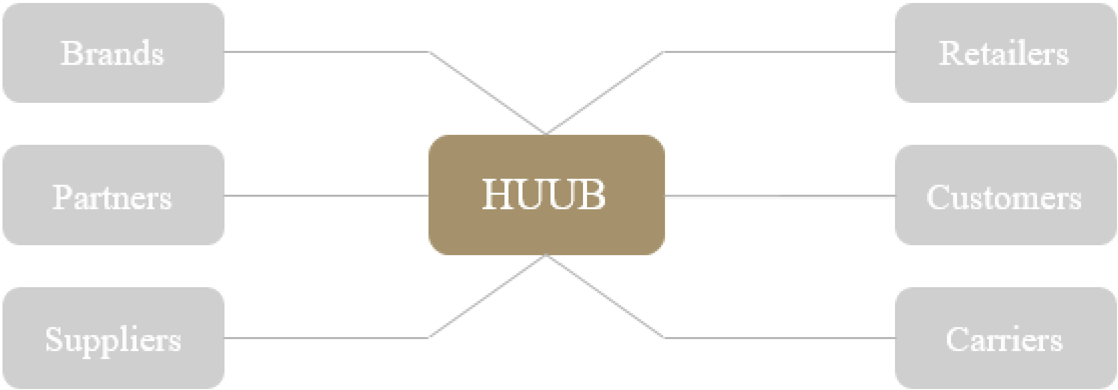

Figure 1 - HUUB's central positioning regarding the stakeholders

The vision of this company is to offer a “plug and play” service where, after the inclusion of a brand, every component of the supply chain is instantly connected and available at any moment. Behind this concept is the goal to simplify the operation of the customers in conjunction with a reduction of its operating costs. To achieve this, the company is currently dedicated to developing a data structure to improve the physical flow coordination. Future additions count with financial support where the relationship with the brands evolves from a customer-provider to a partnership.

To support this information sharing and connection between stakeholders, HUUB developed a web platform known as Spoke, being this the cornerstone of the value proposition. This platform can deploy repeatable and automatic processes, supported by a transactional database that enables the management of data. Moreover, Spoke already supports warehouse management features as well as order fulfilment and the management of its respective delivery, aiding the operational management. This platform stands to technological processes as HUUB stands to its customers: the central component of an ecosystem. However, to assure a good performance and agility, the services provided on this platform are supported by Application Programming Interfaces (APIs). Instead of performing all the activities in the system, Spoke will only consume the information already processed by other modules. This allows greater flexibility due the autonomy granted to each process but also safety regarding service failure since the breakdown of one component does not affect the remaining ones, among other benefits.

Through its web platform, HUUB acts as a broad network that starts working with brands at the moment of creation of a collection until the delivery to the final customer. The whole operation is divided into four major areas: Product, Production, Logistics, and Sales. After being enrolled within the network, brands start attending fairs where most of their sales emerge, especially the ones regarding the wholesale sector. From this point forward HUUB does the follow-up of the production designated for the fulfillment of the sales orders and manages the Inbound. Additional activities include inventory management, fulfilment of sales orders and analysis of the best transportation method, among others.

Regarding its price structure, HUUB aims to maintain simplicity in this aspect as well. The current approach is the offering of a single price per product where all warehouse procedures are assured, being considered as a fee. The prices regarding transportation are the only component that is not included in this fee, being negotiated only after the onboarding of the customer. Acting as a merger of supply chains, HUUB is capable of achieving the best transportation costs, which in turn represent lower transportation costs for the brands. Nonetheless, HUUB has the objective of including the transportation prices within the fee, providing a single pricing element to the brands where all processes, within or outside the warehouse, are included.

At the current moment, HUUB possesses one warehouse in Portugal and has access to another one in the Netherlands through a partnership with DAMCO where future operations will be executed. The overall storage and shipment include over 180.000 products concerning 20.000 stock keeping units and 6600 deliveries related to two seasons per year (fall/winter and spring/summer), though some brands require the existence of a third partition. Nonetheless, due to the accelerated onboarding of brands, these numbers have and will continue to rise, which leads to a more intense operation and, consequently, a more difficult planning process.

1.2 Problem Definition

At the start of this project, the planning of the operation was a manual task performed on a weekly basis. In this process, a person would analyse the sales orders to fulfil and the receptions to process and then a schedule would be devised for the whole week. The information received concerns mainly wholesale sales orders regarding the preparation of a season. Depending on the expected number of sales, the brands communicate the expedition dates and quantities that require fulfilment and the suppliers inform when and how many items they will supply to meet that demand. However, some variations may occur such as delays in the operation as well as supplementary sales orders that were inserted into the system on that day, which influence the planning to great extent. E-commerce sales orders are not planned with the same precedence as wholesale sales and, due to their shorter deadlines, they cannot be planned with the same antecedence. Furthermore, HUUB is responsible for the planning of the operation but the deadlines are imposed by the brands and the suppliers, restricting the capability to produce a smooth operational flow.

To assure that the execution followed the planning, three daily meetings were made, where the progress of the operation was registered and variations were accommodated. This approach disregarded the costs of each warehousing procedure and the accommodation of variations was a repetitive and time-consuming process. Due to these limitations, this approach was unable to assess if the inclusion of additional warehouses would bring benefits to the operational flow of the company.

Up until recently, HUUB operated on a single warehouse in Portugal where all processes occurred, including the storage of products. From this location, every shipment was prepared and the transportation was made in a one to one basis. However, with the growing number of deliveries and the expansion to different countries, the complexity of the system increased. Furthermore, due to capacity restrictions, a single warehouse would not be sufficient to support the whole operation. As such, a partnership was made to assure the presence of a warehouse in the Netherlands. This enables the utilization of another distribution centre and consequently achieve economies of scale through the implementation of aggregated activities. These activities include bulk shipments between warehouses and the respective cross-docking of products to the end customer. Despite enabling a larger flexibility and overall capacity in the system, this comes at the cost of a greater complexity regarding the scheduling of processes. Another factor that increases the complexity of coordinating the flow of items is the seasonal aspect of this sector. Due to its proximity with brands, HUUB is also affected by this characteristic, resulting in the presence of bullwhip effect.

This project was developed to address this problem where a decision-support algorithm was developed to determine the economic and operational viability of the second warehouse and to allocate tasks, considering the conditions of the system. This algorithm will consider optimization techniques where the objective is to minimize the overall costs within the constraints applicable to the system. Among these constraints are the capacity of the warehouses, the service level agreements with brands and the resources available, to name a few. To achieve these points, an analysis of the information available was made as a preliminary step to assess the most problematic aspects of the operation. The development of this project was made in partnership with the department of Business Intelligence, where several functions of process analysis and research and development of technological solutions take place.

1.3 Objectives

This project was created to implement a solution that creates the best available planning for the operation of the supply chain while accommodating all the operational possibilities and its respective cost. This main goal was further divided into three specific objectives, each with its own context and relevance.

The first objective was to create a cost framework that promotes visibility over the individual impact of each task involved in warehousing activities. At the beginning of this project, the transportation cost of each sales order was the only cost considered in the analysis of the profit margin. The remaining costs would only be assessed at the end of each season by comparison of cash flows. Therefore, the assessment of the economic condition of the company could not be performed during the season but rather at the end of the period in analysis.

The second objective, and the main one was the development of an algorithm capable of responding to the requests of the system and delivering the best planning for the operation. In this context, the best practice involves a cost minimization that withstands the constraints applicable in each day. These constraints are related with (i) overall inventory capacity of each distribution centre, (ii) meeting the quantities required in each sales order, (iii) and shipping the items to the designated locations.

The third objective was to implement a dynamic structure that allows the simulation of different scenarios and, consequently, the possibility of executing sensitivity analysis regarding stress situations. Besides stress testing, the impact analysis of future warehouse locations can be simulated. To do so, the algorithm must be able to dynamically extract the parameters required instead of considering static values for every situation. With this principle, the program can be integrated as a tool on the web platform of the company and respond to distinct requests.

1.4 Structure of the Dissertation

This dissertation is structured in five chapters. The second chapter, “Literature Review”, approaches the state of the art of several areas of study included in the development of this project. Apart from the academic research, there is also the description of solutions being employed in industry at the present moment.

The third chapter, “Problem Context”, regards the organizational structure of the company, the processual analysis of HUUB and the description of the different flows available at each process. Complementarily, the methodology behind the cost quantification and assessment of each process is also explained.

The forth chapter, “Methodology”, exposes the construction of the cost framework and of the mathematical model created during this project. Regarding the first element, it includes the specification of the main stages of analysis and its respective subtasks, followed by the measurement method employed. Concerning the mathematical model, it includes the explanation of the decision variables, the objective function, and the constraints applicable to this system.

The fifth chapter, “Implementation and Results”, concerns the implementation of each stage of the algorithm and the results obtained in each step. An analysis concerning each modification and subsequent consequences is also present.

The sixth and final chapter, “Conclusion and Future Projects”, concerns the conclusions of this dissertation, an analysis on the accomplishment of the goals proposed and the exposure of future projects that can be performed and/or add value to this project.

2 Literature Review

This chapter regards the main fields of study of this project regarding supply chain planning. These areas have a sequential order where the previous topic provides information that influences the approach of the following subject. The first topic concerns the comprehension of supply chain management, where concepts and the main problems of this field are exposed. After the prioritization of the main processes to address, there is an introduction to cost quantification of the system and the respective best practices on how to achieve the required data. The final section concerns optimization models and techniques that could be engaged.

2.1 Supply Chain Management

A supply chain can be defined as the integrated process between several business entities that collaborate in three main fields: (i) acquisition of raw materials, (ii) the utilization of these resources to produce final products and (iii) the respective delivery to retailers or end-customers (Beamon 1998). The capability of a supply chain to work as a unit dictates the achievement of required performance objectives. From a high-level observation, a supply chain can be divided into four major processes: (a) Procurement, (b) Production, (c) Distribution and (d) Sales (Meyr, Wagner, and Rohde 2002). For more information please consult Annex A. Given the nature of the supply chain structure approached on this project, the procurement of materials and the sales are not accounted since they are planned by external agents. Thus, the analysis of supply chain planning will focus on main stages of (i) Production Planning and Inventory Control and (ii) Distribution and Logistics.

2.1.1 Production Planning and Inventory Control

The scheduling of production and the inventory control are areas frequently associated with the capability of fulfilling demand volumes through a well-planned production flow model. For a continuous demand rate emerged the Economic Order Quantity model (Harris 1990), where the production rate is assumed constant. Regarding random output processes, several stochastic production rate (SRP) models have emerged to address the production and demand variations in a given time horizon (Kaminsky and Wang 2015).

While more recent models possess an integrated approach between production and inventory, other alternatives pass by the creation of a safety stock. This alternative serves as a prevention measure to avoid shortages due to uncertain factors in the supply chain (Korponai, Tóth, and Illés 2017). Nonetheless, in case of bad dimensioning, the overestimation of safety stock limits leads to increasing storage costs, a factor with increasing impact if several warehouses are considered. Besides storage costs, the accumulation of products leads to its respective obsolete state. To mitigate this risk, forecasting methods have been developed as a mean to reduce uncertainty and have more accurate provisions of needs (Prak, Teunter, and Syntetos 2017).

2.1.2 Distribution and Logistics

This segment of supply chain dictates how products and transported between the different actors of the supply chain. According to Cohen and Moon (1990), the supply chain is typically characterized by a forward flow of materials in conjunction with a backward flow of information, where the main cost driver is transportation.

Within transportation, one topic of current research is the last part of the delivery process, known as the “last-mile problem”. Punakivi, Yrjölä, and Holmström (2001) refer home delivery logistics, the last part of a distribution route, as the most complex aspect of the distribution process since the demand of B2C shipments comprehends a wide spectrum of requirements. These include the lower dimension of an order from a B2C customer than a B2B, the higher number of individual shipments for B2C sales, the tight delivery time windows and the correct conditioning of each individual parcel. In addition, Esper et al. (2003) discuss this component as the most relevant one of the order fulfilment process, where on-time delivery and privacy play an important role in the decision of the consumer. As such, this component is considered to be the most expensive, pollutant and the least efficient factor of the supply chain (Gevaers, Van de Voorde, and Vanelslander 2014).

To minimize the impact of this factor, some companies have designed policies of direct customer pick-up or even tried to expand their distribution centres to a location closer to the end customer (Tavana et al. 2017). Through distribution centres located near the end customer, the division into smaller shipments occurs in a posterior instance of the delivery process, minimizing the impact of the last-mile delivery.

The most common approach to tackle this problem is the implementation of a cross-docking strategy. Cross-docking is a distribution strategy where goods are unloaded from Inbound vehicles to Outbound ones without storing them in between (Van Belle, Valckenaers, and Cattrysse 2012). From the main four functions of warehousing (receiving, storage, order picking, and shipping), storage and picking tend to be the most expensive. The first due to holding costs and the second because it is labour intensive. Cross-docking represents a huge benefit in supply chain inventory management mainly because it eliminates these two stages (Bartholdi and Gue 2004).

The concept of cross-docking considers the immediate unloading of products upon their arrival at the distribution centre, resulting in shorter delivery lead times and a reduction on the fleet size. Such practice is not possible for must companies since it involves a perfect time alignment with both carriers and suppliers. As such, this method, denominated by *one-touch* or *pure* cross-docking, is frequently adapted to *two-touch* or *single stage* cross-docking or even *multiple* stage cross-docking (Apte and Viswanathan 2000). Of these two, the first concerns the reception of items at the dock and posterior loading for the Outbound transportation, with no work involved in between. The second stems from the first, with the inclusion of the reconfiguration of parcels before the unloading process on Outbound trucks.

To maximize the benefits of cross-docking, the transportation of products is often executed with the aggregation of products in one bulk shipment. With this premise, there is a decrease of flexibility to accommodate *product demand rate* variations, as either situations of stock-out or accumulation of stock might occur. In fact, if the *unit stock-out cost* is high and *the product demand rate* is unstable, the traditional distribution method is preferable. However, if the *unit stock-out cost* is low and the demand rate is stable, adopting cross-docking is the better alternative. For the remaining situations, the inclusion of cross-docking can be a good solution if complemented with adequate systems and planning tools (Apte and Viswanathan 2000).

2.2 Costing Models

Despite the large base of studies regarding supply chain cost quantification, it is still a difficult task to isolate every cost factor. While the target focus is on cost reduction, companies have faced difficulties implementing a costing model that fits their supply chain structure, leading to inaccurate cost analysis, especially regarding overhead and indirect costs (LaLonde and Pohlen 1996). Several costing models have been created to try to accommodate more aspects of the operation. For the purpose of this dissertation, a selection of the most widely used/known models are exposed

2.2.1 Direct Product Profitability

Direct Product Profitability (DPP) is one technique where the profit contribution considers handling, freight, direct labour and space costs incurred by an item (LaLonde and Pohlen 1996). This method was vastly used by retailers to determine the shelf space allocation that yields the higher profit margin based on the profitability of each product. The cost imputation of this method starts with the calculation of the gross margin as the result of the difference between the sales price and the purchase cost. Upon this value, warehouse, transport and store costs are deducted to obtain the direct product profit (Associates 1993).

Despite aiding the retailers in the decision process of which and how many products to acquire, this method is not an adequate approach on supply chain cost quantification (Ernst and Young LPP 1994, LaLonde and Pohlen 1996). As the name suggests, the costs in its formulation only concern the direct costs of a product. In supply chain planning, due to the high range of stakeholders involved, this model loses relevance as indirect costs play a major role on the assessment of the overall cost (Doherty, Maier, and Simkin 1993).

2.2.2 Total Cost Ownership

Total Cost Ownership (TCO) is a model that enables the cost analysis since the moment of purchase until the end of the life (Carr and Ittner Fall 1992). This technique has a dual meaning where it can be considered as a purchasing tool or as a philosophy of understanding of the total cost of a purchase. Either way, it is a particularly useful technique to employ to evaluate a supplier. Furthermore, TCO analysis allows a better understanding of which areas each supplier provides the most value as well as their issues and cost structure (Jackson and Ostrom 1980, Burt and Anklesaria 1990). Due to its long-term analysis emphasis, this technique is useful to determine the viability of investments in the long run, thus providing good information for negotiations (Monckza and Trecha 1988, Ellram and Siferd 1993).

Despite the easiness to understand the overall concept, several authors and studies have reported the difficulty to put this method in practice (Ellram 1995, 1993). To fully support its greater need of information, in comparison to other methods, an information system to support wide-scale data supply is required, representing a major investment. Lacking this resource, companies face a labour intensive process of performing this task manually (Ellram 1995). In addition, LaLonde and Pohlen (1996) refer that, due to the focus on the stage of acquisition, this method highlights the relationship between a company and its suppliers. Simultaneously, it also narrows the scope of analysis to existing partnerships and, thus, opportunities for making inter-firm cost trade-offs might be missed. To adopt this method some cultural modifications might have to be put in place in a company, being this the main reason behind the consideration of this technique as a philosophy. However, the management may offer resistance to these changes, compromising the success of cost assessment (Ellram 1993).

2.2.3 Activity-Based Costing

Activity-Based Costing (ABC) is a technique to assign direct and indirect costs based on the distinct activities an item is subject to and is frequently used as a part of total cost management (Cooper Winter 1989). The imputation of cost focuses on the definition of activities instead of production costs and this stands as the differentiation factor in comparison with other models. According to Turney (2008), cost estimation methods can be categorized as: intuitive, analogical, parametric and analytical, each with its unique benefits. From these, ABC fits in the last category since the determination of cost is based on the decomposition of a process into activities with known cost drivers.

Turney (2008) discusses the insurgence of ABC as a tool particularly useful to examine overhead costs, being this the motive for the hype generated in the industry at its beginning. Before ABC, the overhead costs were considered as a whole, being directly and equally distributed along the various stages of the operation. Such measure proved to be a dangerous assumption where the decision making process was influenced by a potentially incorrect quantification since most overhead costs do not impact every activity in the same proportion. Miller and Vollmann (1985) highlight the relevance of this in electronic manufacturing companies that experienced an increased proportion of overhead costs, sometimes exceeding 50%, between 1980 and 1985. To complement the internal company analysis with customer satisfaction several additions to this method have been developed. Of these, the Cost-to-Serve, stands out as a secondary step of ABC, introducing the customer as a differentiation factor where the analysis of a process goes deeper and variates depending on the customer (Kone and Karwan 2011).

Duh et al. (2009) provide a thorough comparison between traditional costing models and ABC and the determination of success factors in ABC implementation, complemented with a survey about ABC practice. This study as well as others (Ellram Winter 1995) converge on the benefits and barriers that this technique provides. The advantages of ABC include improved costing accuracy, offering of useful cost information for decision-making and detailed tracking of indirect cost-to-cost objectives. However, due to its analytical focus on the activities, this technique is unable to report bad working habits. Thus, little to no change of old management behaviour can be employed directly from this technique, not driving companies to change their fundamental views about how to organize work. A fundamental aspect that also serves as a main barrier regarding ABC implementation is the amount of resources that need to be allocated to fully analyse each activity. Initial efforts to quantify tasks involved the deployment of a team that would interview, observe and measure each process (Lewis 1995). Not only is this process time consuming as the results obtained are static since every modification, concerning the flow or the performance of a process, requires a new analysis. Nonetheless, the main issue of this analysis is the unit of measurement of each task since different kinds of units make the total cost analysis more complex.

The most recent approach to address these issues is the implementation of a time-driven activity-based costing supported by an extensive and processual based information system (Kaplan and Anderson 2003). A continuously updated information system disables the need to allocate staff to perform measurements. Furthermore, this updating process requires only two parameters: (i) unit cost of supplying capacity and (ii) the time required to perform a transaction/activity. This accelerates the performance of the model, enables a data collection directly from transactional enterprise resource planning systems and enables the handling of greater volume of transactions, among other benefits (Pernot, Roodhooft, and Van den Abbeele 2007, Kaplan and Anderson 2013, Demeere, Stouthuysen, and Roodhooft 2009, Kaplan and Anderson 2003).

2.3 Optimization Models

The basis of a decision-making process is the identification and modelling of the problem to address and the search for the optimal solution (Zhang, Lu, and Gao 2015). Optimization models can be implemented and solved with (i) exact algorithms, (ii) heuristics or (iii) metaheuristics (Schneider and Kirkpatrick 2006). The first solves the problem by returning the best solution available supported with mathematical evidence. The second is problem-dependent and returns a reasonable solution, though proof of optimality is not assured, lacking a mechanism to avoid local optimal solutions. The third one derives from the previous one but through mechanisms to avoid being stuck in local optimal solutions and has the benefit of being problem-independent. The main disadvantage of exact algorithms is the computational time needed to achieve the optimal solution, thus the increasing popularity of heuristics as a good trade-off between performance and time (Schneider and Kirkpatrick 2006). Nonetheless, most exact solvers currently available employ several methods to decrease their running time.

2.3.1 Modelling Approaches

The basic concept behind an optimization model is the creation of a mathematical formulation where the variables represent the subject of analysis, the restrictions bound the domain of possible solutions and the objective function represents the goal to achieve. Depending on the type of variables and restrictions considered in the modelling of an optimization problem, the nature of the model differs. The most widely used approach is linear programming where the constraints and the objective functions possess linear combinations of the decision variables (Dantzig 2016). Within this subject, mixed-integer linear programming has been the preferable method among authors. This method is popular mainly due to the capability of assigning integer values to variables that represent real quantities and the utilization of binary variables to represent dual decisions. Nonetheless, non-linear, stochastic and fuzzy logic programming models have been implemented with success, despite its diminished utilization (Mula et al. 2010).

As previously mentioned, a mathematical formulation of a problem can result in a model that is unsuitable in a practical situation due its long processing time. Additionally, to implement a decision-making tool in a company, one must consider that the model should be able to adapt to the period upon which a decision should be made. Sarimveis et al. (2008) propose the application of dynamic programming to address both these blockers. The dynamic programming proceeds towards optimality by dividing the time horizon into multiple sub-problems. Therefore, each instance has a lower impact on the computation of the optimal solution.

2.3.2 Linear Programming Solvers

The main benefit of executing a linear programming model is the convergence towards an optimal solution, assuming a feasible domain of solutions. To solve these models, software tools known as solvers have been created that include several methods to compute a solution with the lowest number of iterations.

Meindl and Templ (2012) give an overview over the main existing free and open source solvers as well as the ones commercially distributed, all of them related with linear programming. Out of the free ones, GLPK and LP_SOLVE are written in ANSI C and solve mixed integer problems. CLP was created within the Coin-OR project and is written in C++. Within Coin-OR, this solver is used in SIMPHONY, BCP and CBC libraries. SCIP is presented as a framework for solving integer and constraint programming and is available as a C callable library. Regarding commercial solvers, IBM ILOG CPLEX Optimization Studio, also known as simply Cplex, and Gurobi are the most powerful and well-known solvers, particularly in large mixed integer linear programming, and support several interfaces that connect with other programming languages. The Xpress Optimization Suite is also a proprietary software that supports several common computer platforms and provides several interfaces.

The overall conclusion of this study was that commercial software tools are both faster and more capable of solving linear programming problems, especially the ones that concern a large size problems. Nevertheless, these tools are expensive for most companies and for small/mid-sized problems, the usage of open source solvers can still be possible if multithread processing is applicable on the model (Mittelman 2011).

2.3.3 Optimization models for supply chain management

In supply chain management, the objective function is related with performance measures and tend to focus on cost/profit analysis, inventory minimization and return on investment maximization. Other objectives focus on the customer experience where the maximization of service level and other customer related metrics are used (Beamon 1998).

Supply chain optimization has been the focus of study for a long time. Mula et al. (2010) published a study that reviews the decision level and criteria used on previous models. According to this study, most works focus on tactical decision level operations related with production and distribution planning. Koç, Toptal, and Sabuncuoglu (2017) propose a model for the coordination of Inbound and Outbound shipment schedules of a single stage supply chain. The objective is to determine both the production and shipment schedules that minimizes the sum of transportation costs and inventory holding costs. Cohen and Lee (1989) developed a mixed-integer linear programming optimization model to determine which distribution and manufacturing facilities should be open, considering the cost impact of each parameter on the objective function. On the operational decision level, other authors have focused on extending the granularity of analysis with models that support operational choices. Rizk, Martel, and D'Amours (2008) restricted their model to address only operational optimization based on the flow synchronization between a single manufacturing location and multiple destinations.

To analyse both decision levels, Goetschalckx, Vidal, and Dogan (2002) propose a framework that includes both the tactical as well as the operational aspects of a supply chain. Their research focused on how to combine the design of strategic global supply chain networks with the production and distribution allocations of a global logistics system. Their goal is to create savings opportunities through two different models that employ an iterative heuristic solution algorithm based on mixed integer linear programming. Sabri and Beamon (2000) possess a similar approach with a multi-objective supply chain model dedicated for strategic and operational supply chain planning. In this study, the considered structure includes suppliers, plants, distribution centres and customer zones and the objective functions consider cost minimization and maximization of plant volume flexibility.

2.4 Industry solutions

At the present, there are already a couple of companies that manage supply chains through planning algorithms. Amazon possesses an integrated supply chain where the scheduling of activities minimizes human intervention. Apple, Intel, Dell, and Walmart are some of the best companies at managing their supply chain, though a complete and automated system is not present in their operations.

On the other hand, there are companies whose value proposition is specifically this subject: the offering of solutions that enable supply chain planning and management. These solutions typically involve software modules or improvement programs.

Regarding the first topic, LLamasoft and VCK logistics stand as providers of software modules designed for supply chain design, management, and planning. Similarly, QuintiQ provides several packages that allow supply chain planning and management, with the flexibility to implement automated, semi-automated or manual procedures. Logility allows its customers to perform real-time analysis of their supply chain and plan through the usage of software components that employ what-if scenarios.

Concerning improvement programs, the objective is to enhance the overall supply chain flow without implementing additional tasks but rather enhance the current ones in order to avoid bottleneck situations. On this sphere of solutions, companies as Bain, UPS, and MEP have developed frameworks of improvement where specific goals are set to try to improve the supply chain performance.

2.5 Critic analysis

The expected evolution of HUUB's operation was to generate increasing number of bulk shipments along with cross-docking processes to DAMCO. Despite lowering last-mile costs, such action must be carefully analysed to avoid the accumulation of stock since the storage cost in the Netherlands is greater than in Portugal. Thus, the main objective of this project was to create the best plan where a trade-off between inventory control and the distribution process is always present.

Following the example of several authors, this project was based on the creation of an optimization algorithm as the backbone of the decision process. To determine the impact of each variable, we employed an ABC based on Time-driven processes merged with the philosophy of Cost to Serve. As the beginning of the supply chain concerns the arrival of products from suppliers, one might think that TCO would be a better alternative. However, such is the case when the option to choose between suppliers is considered in this evaluation. In this system, the supplier is chosen by the brand and HUUB proceeds to act from this point forward, thus, the opportunity to select suppliers is non-existing. Due to the disadvantages mentioned in chapter 2.2.2, the fact that this method is not an integrated overall approach, and that the main advantage has no impact in this scenario, the TCO is excluded. Regarding the DPP, several authors mention this tool as inadequate to supply chain costing since only the direct costs are considered, therefore this option is also excluded. The ABC model does not provide feedback on how to change the processes but rather transmits cost data regarding each activity. Additionally, high human effort is required to implement this technique and maintain it updated. On the context of this project, the first disadvantage does not influence the decision process since the objective is to plan the operation based on the impact of each current process. To eliminate the human effort, the acquisition of data will be made directly from the information system. This action is even easier when imposing a Time-driven quantification because only one parameter is obtained and kept on the database. With the inclusion of the Cost-to-Serve, the analysis of the process is more thorough since the same process can have a distinct impact between brands and/or sales channel.

The optimization model was designed based on mixed integer linear programming that will be run every week to provide the planning of the following fifteen days. Since the scheduling of activities is divided into periods, and the information regarding sales orders, receptions and cost drivers may vary between weeks, this model has a dynamic approach, following the behaviour suggested by Sarimveis et al. (2008). Moreover, this model integrates both the tactical decision of which warehouses and respective processes to employ and the operational decision of which and how many products to allocate to each process. This optimization process is similar to the one developed by Goetschalckx, Vidal, and Dogan (2002) but with the upside of including all stages into a single model. Furthermore, this model is classified as a deterministic analytical model, according to LaLonde and Pohlen (1996) and its processing involves the usage of one of the solvers mentioned in chapter 2.3.3.

Concerning currently available industry solutions, it was concluded that solutions that optimize all sectors of a supply chain supported by optimization algorithms are still missing. Improvement programs are mainly focused on improving efficiency levels instead of creating a sustainable and autonomous tool and current software units do not provide a complete solution. Instead, these solutions are divided into packages where each has a specific target of improvement/planning. Moreover, within these software programs, the results are mainly obtained through alert signals, what-if analysis, and illustrative frameworks.

3 Problem Context

The overall operation of HUUB incorporates several stakeholders that affect the development of the company. This section aims to understand the relationship between the teams of the organization and its suppliers and customers through an analysis on the organizational structure. Additionally, an explanation of the operation as-is was made to decompose each process and to identify problems and bottleneck situations. After this, an analysis of the cost structure of DAMCO was made to assess the characteristics to include in the optimization model.

3.1 Organizational Structure

Despite being a start-up, the internal organization of HUUB is built upon 6 different departments: Information & Technology, Business Intelligence & Artificial Intelligence, Marketing & Sales, Financial & HR, Account Management, and Operations.

Information & Technology (IT)

The IT department main responsibilities are the development and maintenance of the information system Spoke. The Spoke is a web-based platform which, amongst other features, aims to connect every stakeholder of the supply chain of a brand. This is the backbone of all logistic operations since it has a Warehouse Management System (WMS), an Order Management System (OMS) and a Distribution Management System (DMS). In what concerns IOT, the main objective is to build a mashup of sensors through the supply chain that will allow a quicker and more accurate collection of data and thus a better supply chain optimization.

Operations

The Operations team is responsible for the coordination of activities to fulfil sales orders and store incoming goods, all this at the warehouse in Portugal. The warehouse in the Netherlands will not be coordinated by this team, even if validated as a viable distribution centre. Instead, a designated volume is planned beforehand and communicated. With this information, DAMCO will devise its own schedule and guarantee the delivery process within the boundaries set by HUUB.

Marketing & Sales

The Marketing & Sales department has an important role in personal relationships and customer acquisition. Regarding sales, the direct contact with prospect brands at fashion fairs has been the principal way to acquire new customers. This strategy, like any other strategy, has its advantages and disadvantages. On one hand, every lead that enters the acquisition funnel is well qualified, meaning that the conversion ratio is high. On the hother hand, the cost of reaching new brands is considered to be high due to high expenses.

Business Intelligent & Artifitial Intelligence (BI&AI)

The Business Intelligence and Artificial Intelligence department has two major responsibilities. The first is the analysis of collected data and the identification of business insights from it. The second is the development of algorithms, including machine learning functions, that optimize the operational aspect of the company. Both these responsibilities can be grouped into descriptive, predictive and prescriptive analysis as seen in Figure 2.

By guaranteeing an alignment between the team developments and the company strategy this team has the resources and know-how to develop ground-breaking solutions, consequently leveraging the value proposition of the company. After developing and testing a module, the BI&AI team partners with IT to evaluate the best way to incorporate that module in Spoke. One example of this approach is this project, whose implementation counted with a collaborative work between BI&AI and the IT departments.

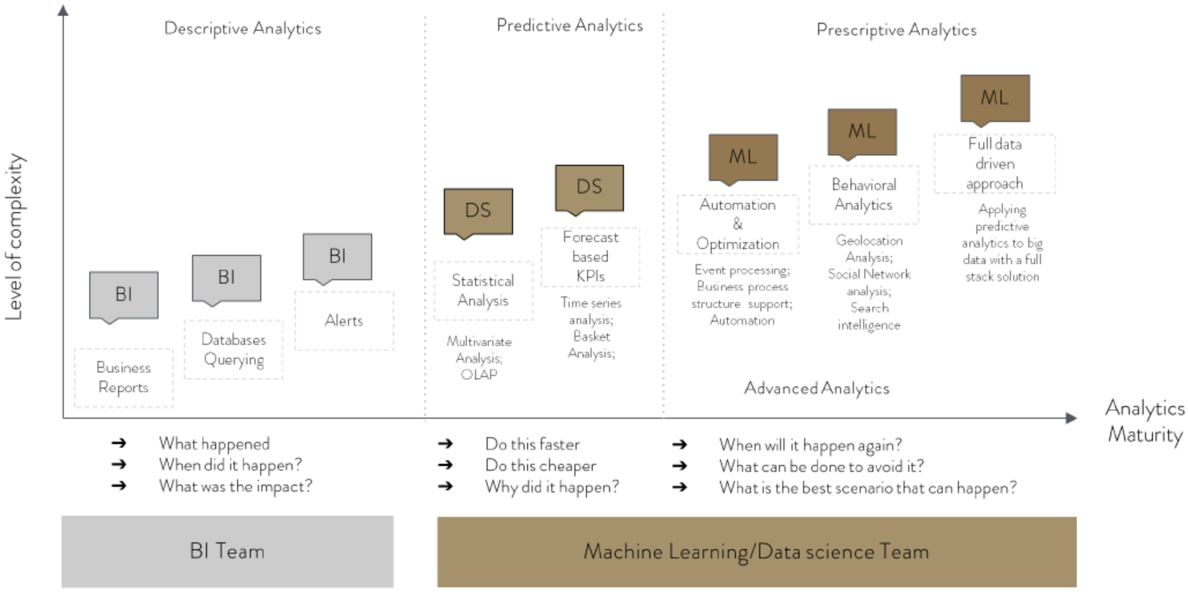

Figure 2 - BI&AI Functions

Account Management

The Account Management Team is the main point of contact between HUUB and its brands. Because of this positioning, the Account Management team has two major tasks. The first is to ensure that the brands joining HUUB know how to use the platform, meaning that they provide them all the information and instructions required to join HUUB's ecosystem. The second is to use HUUB's capabilities to help brands on their own businesses. This approach, where service suppliers provide business insights to their customers, is employed because there is a high correlation between the success of HUUB and the success of its customer. If the brands have better business approaches, they will sell more, which translates into bigger projects with HUUB and, therefore, higher revenue values.

Financial

The Financial team has the objective of controlling the company financial status and to ensure that every transaction is made according to all norms. In parallel, this team is also responsible for the development of a cost framework so that several key performance indicators can be built. This project does not provide a full cost framework but supplies information that will be integrated in the future.

3.2 Operation AS-IS

Despite being a continuous action, this chapter will expose the operational characteristics of HUUB considering a season, which is approximately six months, as a sample. The beginning of this process starts at fashion fairs where the marketing & sales team approach brands and introduce the company and the service that it offers. If a brand desires to acquire the service, the team will start the onboarding. In this stage, a profile is created in Spoke, the web platform of the company, and all the information about already performed sales orders is introduced in the system. From this moment on, an account manager is designated to perform the follow-up of the brand along the season and the brand gains access to a web platform where all the details concerning their merchandise is available. After the full onboarding stage, all the sales orders and respective supply of products is directly inserted on Spoke thanks to an integration procedure between Spoke and the information system of the brand, made by the IT team. From this point forward, the processes involve warehousing activities, starting with the arrival of products.

3.2.1 Process Structure

Concerning the reception of items, the number of actions to perform depends on the number of sales orders to fulfil that are already in the system. If there are no sales orders that require products from the reception, then the items are received and picked to stock. On a posterior stage, when a sales order is activated, the items are picked from stock, the pack is prepared and the final procedures regarding the shipping details are executed. The stream ends with the transportation of the items from the warehouse. This case is represented in Figure 3 as the Stock Flow, where all five major activities are performed.

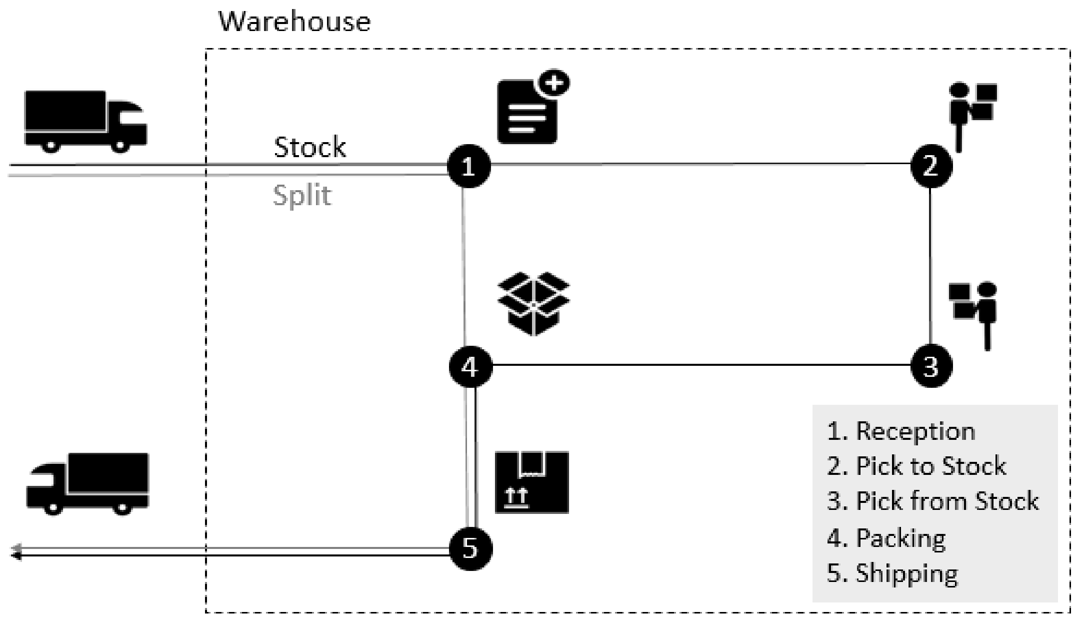

Figure 3 - Stock and Split operations

If there are already sales orders that require its fulfilment upon the arrival of goods, then the items undergo a flow known as Split Flow. In this case, packs are already prepared and the items are directly sent to the shipping packs and the remaining ones are picked to stock. If the pack possesses all the required items then they are sealed and the final shipping details are made, ending with the transportation of the pack. Avoiding the storage and the picking (the 2nd and 3rd processes on Figure 3), which are the most time-consuming activities, minimizes the work-in-progress and the cycle time of the operation. Consequently, the division of the operation into these two streams enables an increased response capacity with the same resources.

Within the processes of Figure 3, the reception of items involves the manual verification of the real quantity versus the estimated quantity expected to arrive. After all, components are checked, the operators close the reception and the system automatically reports if the quantities match or not. If the result is a mismatch, the system informs the brand and an alert to contact the supplier is generated to address this kind of issues in the shortest possible time.

Both picking (to and from stock) involve the deposition/removal of items on racks. If the item is catalogued as a *high rotation item*, then the designated rack is closer to the shipping/reception dock as a measure to shorten the picking time. The packing occurs after all the necessary items have been picked to the designated pack. At this moment, the confirmation of the items and the closing and taping of the packs is made. The last step involves the weigh-in of the pack, the insertion of the shipping information and the printing of labels and documents need for the transportation. At the end of the process, the packs are stored in a shipping dock stage and wait the arrival of the carrier.

3.2.2 Sales Channels

Regarding the type of sales channel, the service provided responds to both e-commerce and wholesale sales. Between these two channels, the e-commerce stands out as the most frequent kind due to its granularity of direct shipping to the final customer. The wholesale orders are characterized by high volume of products per order, as seen in Figure 4, and a larger period to deliver the products. Moreover, the sales orders, mainly of the wholesale segment, are further divided into smaller batches known as *drops*. While a sales order concerns a sale of a brand to a single customer for a specific season, brands usually ship the items in two to three periods known as pre-season, mid-season, and end-season, where each one of them corresponds to a *drop*.

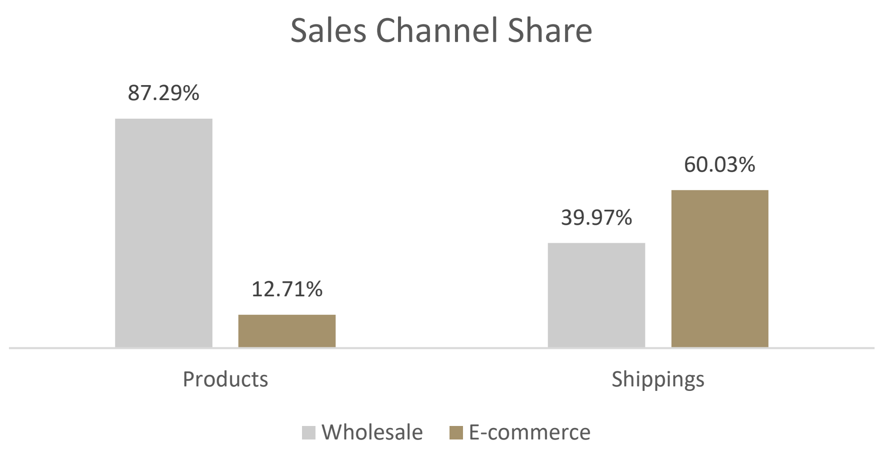

Figure 4 - Sales Chanel share on Product/ Shipping perspective

When comparing these two channels, the e-commerce sales emerge as the ones with higher operating costs for HUUB. Wholesale orders concern the negotiations between brands and retailers where brands first acquire the amount to produce based on the sales they obtain. Therefore, the sales orders are planned with weeks in advance and when the items are finally produced and shipped to HUUB, the company already devised a schedule of fulfilment that maximizes the Split Stream. For e-commerce sales, the brand estimates a designated amount to produce, the items are produced, sent and stored at the warehouse and the preparation and shipping of the items is only made when a sales order emerges. Thus, e-commerce related receptions are processed mainly through the Stock Stream, representing higher costs for the company.

3.2.3 Data Insertion

Aside from the operational aspects, there are parallel activities that provide useful information for the planning process. While the Operations team is responsible for the regulation and control of the operation, the account managers insert information in the system. Most of the data inserted concerns sales orders of brands that are still to complete the onboarding process. Since this information is the trigger to start the fulfilment of sales orders/drops, a delay on the insertion results on a tighter schedule for the operation. Being time a crucial aspect, there are several functions built in Spoke to generate information on an autonomous way. Such measure not only eases the work of the Account Management team but also smoothens the overall flow of information and, consequently, of the operation planning.

To support this independent work, there is a data warehouse responsible for the incremental collection of data from the database based on specific rules and time schedules. While this structure provides the same data as the database, the access and methods to work it are more adequate to perform analytical procedures. Each time a sales order is introduced, a trigger is activated to deploy other mechanisms. In the context of this project, since the planning is affected by expected receptions and incoming sales orders, these must be fully described to widen the scope of the planning. The receptions represent a component that is fully defined by the brands and the suppliers, so all the respective information must come from them. The sales orders, on the other hand, only depict the quantity to ship, the destination and the deadline. Every other component can be defined by HUUB as long as these requirements are met.

Every new sales order is analysed and each missing field is updated with the latest intel provided by an application programming interface (API). The first API module, the API Pack, checks each item and the respective characteristics as kind, size, and fabric, to name a few, and predicts the best pack set for the sales order, its volume and weight. To avoid dependency of human measurement, this software module was built upon machine learning techniques that analyse data of previous sales orders and train the estimation model. With increasing volume of data, the model improves its accuracy over time, minimising the error involved in the prediction.

After returning this information, a second API, the API Ship is activated to find the two best options of delivery from HUUB to the final customer. These options concern an economic shipping with a larger lead time and an express shipping, which is more expensive but faster. These options are generated by simulating a shipping on the website of each carrier and returning all the different rates. From these, the best economic and express options are selected and returned to the data warehouse. Every week, all drops yet to be shipped are revaluated on this API to update the shipping price. This is done as a precautionary measure in case a carrier changes the cost structure of its service. At the end, the data warehouse receives this information and returns it to the database. This set of activities can be observed on Figure 5.

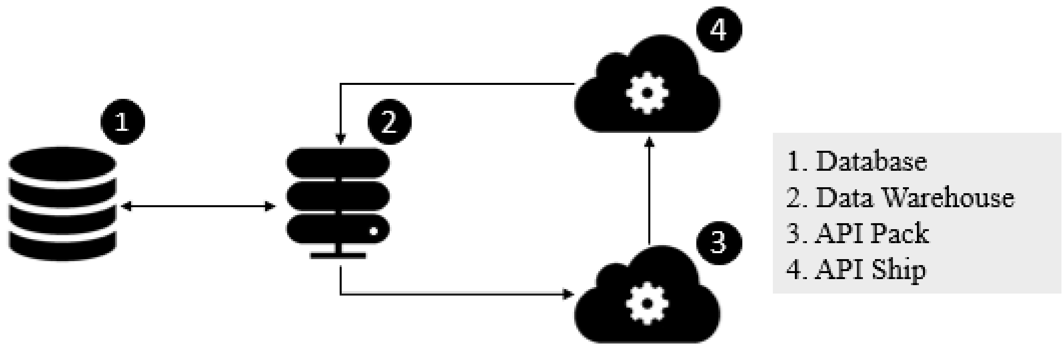

Figure 5 - Data insertion mechanisms

3.3 Operation To-Be: Analysis of multi-staging

One of the main considerations of HUUB is to outsource warehousing procedures and last-mile transportation to other companies. In this segment, the company currently in analysis to perform this partnership is DAMCO. This company, part of A.P.Moller – Maersk, is one of the world's leading providers of freight transport and supply chain management services with warehouses in every continent. The decision to partner with DAMCO came as an opportunity to fulfil deliveries from a warehouse in the Netherlands to diminish the transportation cost to the end customer. At the core of this idea, was the allocation of high-rotation items on that warehouse to fulfil e-commerce sales and the planning of bulk shipments to perform cross-docking of higher volume sales to retailers. Therefore, the shipping rates provided by DAMCO should at least be lower than the rates obtained by HUUB. In fact, depending on the work involved, the marginal difference on the last-mile delivery should accommodate the costs incurred with the new route.

3.3.1 Last-mile Price Comparison

To evaluate this possibility, a study about the benefits of partnering with DAMCO was made prior to the start of this project. The methodology employed concerned only the direct comparison between the last-mile prices over the countries that represent the most customers. From the major destinations, only the ones concerning central European countries were able to generate cost savings, as seen in Table 1.

Table 1 - Comparison of main shipping destinations

Country	Percentage	Best rate	Avg. Savings per delivery
United States	21.24%	HUUB	-
South Korea	12.97%	HUUB	-
Japan	10.33%	HUUB	-
Portugal	8.61%	HUUB	-
United Kingdom	7.70%	DAMCO	2.83 €
Belgium	4.35%	DAMCO	5.21 €
Germany	4.21%	DAMCO	7.46 €
Netherlands	3.06%	DAMCO	6.92 €
Australia	2.92%	HUUB	-
Italy	2.73%	HUUB	-
Others	21.87%	Mixed	-

While this first analysis concerns a basic price comparison, the possibility to deploy distribution centres in other areas can still be advantageous. The clearest example is the impact on service level agreements between HUUB and its customers. On the peak of a season, the company faces a surge of products to process that might be so intense that the work-in-progress tends to delay the operation and, consequently, delay the delivery of items. To avoid an operational meltdown, HUUB may resort to DAMCO as an increased work capacity. In the short-term, though, all receptions must cross the Portuguese distribution centre before reaching other facilities. Direct shipping will be possible when suppliers become more rigorous on their production deadlines.

The main conclusion from this initial evaluation is that DAMCO seems to provide a cheaper transportation service regarding certain countries. Complementary to this conclusion is the assumption that this alternative may be used to prevent delays. However, both these statements could be proven wrong since they are based on static situations that, in reality, might not be possible. Hence, to perform a more rigorous validation, this scenario should also be considered when optimizing the overall planning. Since the goal is to analyse the impact of every operational aspect, the processes of DAMCO must also be analysed.

3.3.2 Operational Considerations

The main restriction regarding the supply chain planning of HUUB is the fulfilment of sales orders within the proposed deadlines. Since most activities depend on the progress of other activities, the occurrence of work pipelines may happen, resulting in bottleneck situations. The partnership with DAMCO emerged as an aid in this context, where more resources can be allocated to resolve stress situations. This solution represents an additional cost to the company and may provide an innocuous improvement if the lead time of the operation is also greater than the one required by the brand.

At the present moment, the operation in the Netherlands concerns only (i) cross-docking mechanisms and (ii) high rotation items where every week a large shipment is sent from HUUB. The cost imputation on this transport is proportional to the number of pallets transhipped and the respective lead time is four days. This step is where economies of scale can be reached since a set of products are grouped into pallets and shipped. In this case, higher number of products per transhipment causes a decrease on the cost per unit being transhipped. Upon the arrival, the items that are not intended to fulfil a sale are registered and stored within the warehouse in what is called the Inbound of goods, as seen in Figure 6. A cross docking operation is executed to deal with the items designated for the sales orders and then they are shipped. The whole process always takes, at the minimum, six days to process.

Due to these conditions, every sales order that is placed with an antecedence lower that six days will never contemplate the hypothesis of being included on the transhipment to the Netherlands. Moreover, even six days is a positive scenario since most countries involve a delivery process with a lead time of several days and the operations at HUUB may also take time to finish. Annex B represents overall shipments so far.

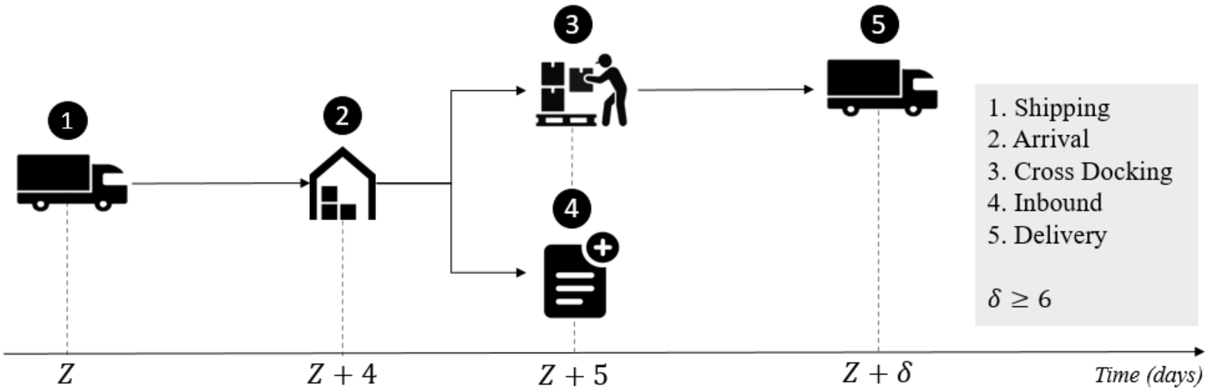

Figure 6 - Transhipment process to the Netherlands

Apart from the service conditions, the option to ship to DAMCO must also account with the operational costs involved. For cross docking items, the cost is reflected on a fee per box that arrives. However, if an item is to be shipped on the next day or any other day, then the protocol is to pick it to stock and then proceed to execute the Outbound. In this case, there is a fee for the number of boxes, another one for each item and a storage fee for each item. Therefore, if a transhipment is made between HUUB and DAMCO that requires a temporary storage then it is possible that the overall cost is higher than expected. Concerning the Outbound movement, the cost structure depends if the delivery is for B2B or for a B2C destination. On the first one, the cost is only reflected on the number of boxes to be shipped. For the second case, there is an additional fee based on the number of products.

Based on this analysis it was concluded that, due to all this complexity, a mathematical optimization model will be a significant contribution to future management. Thus, the main focus of this project was the development and implementation of an optimization model that consumes all the information relative to these processes and computes a solution.

4 Methodology

This chapter explains the creation of an optimization algorithm to provide knowledge about the planning of HUUB's operation on a daily basis and, consequently, propose transfers of stock between the warehouse of Portugal and additional warehouses. Prior to the formulation of the problem, there will be a section that describes the methodology used, where the main approach on how to attack the goals proposed is defined. Based on this structure, the next step exposes the methods to achieve the data required for the optimization algorithm. These data will be analysed and simplified to allow a cost quantification structure on the assignment of variables. The final aspect is the discussion of the model formulated.

4.1 Data Preparation

The collection of data required for this model is divided into two segments. The first concerns the reading of drops and receptions that require fulfilment and, upon which, no planning has been formulated. Regarding this subject, the data has been generated in an independent process, as explained in chapter 3.2.3, and is then consumed from the database. This is based on already fully structured database mechanisms, being these data directly imported. How this import mechanism works will be addressed in chapter 5. The second one is related with the cost structure that involves the whole operation, both of HUUB and DAMCO. For this case, a framework has been formulated to enable the cost analysis of every operational component and to do so using a predictive method.

4.1.1 Cost Quantification

The cost definition of an activity differs depending on the warehouse where it is being executed. In the warehouse of DAMCO, the cost is determined through predefined price rates. These price rates are divided into two different segments. The first concerns the warehousing activities, being indexed at the level of the product or pack. The second concerns the transportation to the final customer. This varies between B2C and B2B customers and several carriers are available to perform this action.

Hence, the cost framework was only defined for warehouses owned by HUUB, following a Time-driven Activity-Based Costing. From a high-level perspective, the movement of the operation starts with the Inbound, the stage that involves all the actions concerning the arrival and reception of products at the warehouse. After this stage, warehousing activities such as setup of packs, labelling, and handling, to name a few, are considered. The final element of this perspective is the Outbound, where products are prepared and drops are finalized and shipped to the customers.

This perspective, portrayed in Figure 7, is the one used on the definition of decision variables and how to structure the flow of materials from suppliers until the final customer. Nonetheless, these stages require a deeper analysis where each process must be analysed individually, as well as all inherent tasks.

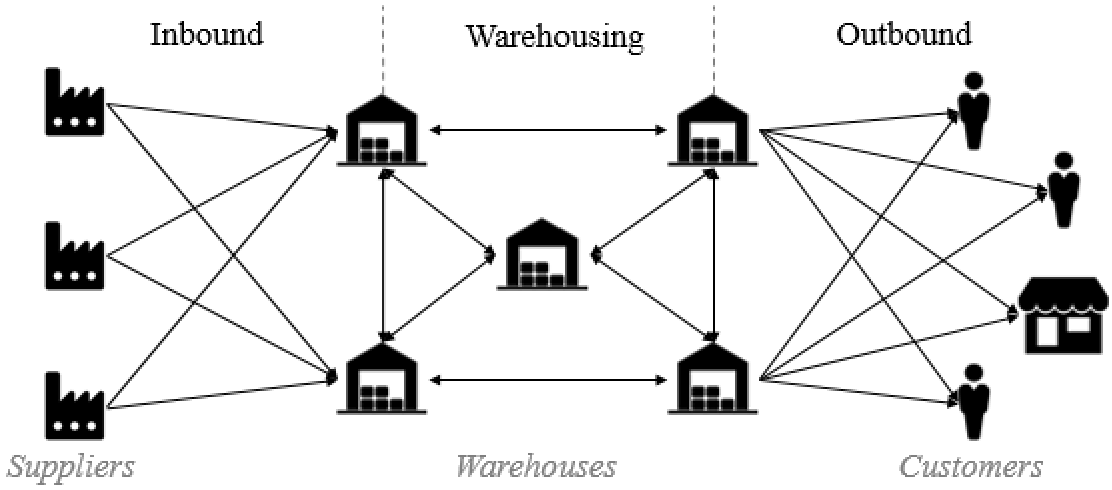

Figure 7 - Structure of the operation

The first step was to consider the actions of every stakeholder and which of them influence the planning of the operation. The analysis is based on the activities and on the time it takes for a person to perform it, being this the focus of the Time-driven ABC approach. Out of all agents of the company, only the variations concerning the Operational team influence the scheduling. Though every member of the remaining teams represents a cost to the company, the decision to ship products to DAMCO or directly to the consumer is not affected by them. Therefore, the allocation of human resources will only contemplate the Operational team.

The second step was to determine which components can already be fully accounted by a direct measure, making its cost determination pointless. Within this stage, the consideration of costs that do not impact the model are not considered since a decrease or increase in the utilization of these resources does not make a difference. From this analysis, four segments emerge:

- Materials for warehousing activities,
- Taxes and Duties,
- Shipping rates from carriers,
- Storage of products.

The last step is the analysis of these elements from a Cost to Serve perspective. Some customers demand specific handling procedures on their products that influence the cycle time of specific handling processes. This includes a specific kind of pack, personalized tape or even the insertion of props in each drop.

On the other hand, as stated in chapter 3.2.2, the sales channel of a sales order influences the flow of materials in the warehouse. Therefore, the first part of the process measurement was to analyse each brand and the cycle time of each activity. The second part involves the analysis of which sales channel each brand possesses. If a brand had both segments, the measure of its respective activities would include two different moments where each was designated to assess each sales channel.

4.1.2 Process measurement

The principal idea behind this costing method was to implement it with the information already stored in Spoke and execute a cost determination method based on antique data. Through previous values, the ratio time/unit could be estimated, providing a cost driver for each activity, brand and sales channel combination. The database holds the information about which and how many items where handled in the warehouse and the corresponding activity. However, the acquisition of these data is done in groups instead of single exchanges to prevent an overload of the information system due to high volume of data transfer. Thus, while every product is registered in the system, the exact time it took to perform any activity is inexistent.

Due to this inability, the measurement procedure was changed to a manual one, until further information system developments are made that enable the autonomous time estimation of each process. For the sake of simplicity, only four brands were chosen and fully analysed from the Inbound until the Outbound, including wholesale and e-commerce distributions. For the remaining brands, the cost structure was copied from a similar brand, of the four selected. Based on the analysis presented on chapter 3.2.1, there are five major stages of the operation: (i) reception, (ii) pick to stock, (iii) pick from stock, (iv) packing and (v) shipping. Each of these stages was further fragmented and analysed in detail.

In order to include the cost drivers in the algorithm and to maintain the linearity of the model, the imputation of cost on a decision variable needs to be a constant value, otherwise, the model becomes non-linear, adding complexity to the computation of a solution. However, there are variables that specify a decision over a drop, and others that reflect the number of products. This factor introduces greater flexibility on the cost imputation since the delineation of cost drivers with distinct units, such as pack or item, can be included. Moreover, in certain cases, a time/unit ratio can be directly converted to another ratio without incurring in the risk of misusing the information. Bearing these conditions, the method was to perform several measures and assess the ratio from average of all measures, with the removal of outlier values. The classification of these outliers was based on situations where an unexpected action took place that would otherwise bias the evaluation. Table 2 demonstrates the values obtained for the wholesale shipping process of one brand, but values were also obtained for the remaining stages of the operation as well.

Table 2 - Average measurement of the Shipping stage of a brand concerning wholesale

Activity	Value	unit
Conference Check	4.10	s/item
Insertion of additional props	4.44	s/drop
Insertion of Packing list	5.50	s/drop
Assembly of Pack	9.00	s/pack
Fill Outbound process in Spoke	37.83	s/drop
Pack weight-in	13.88	s/pack
End Outbound filling	15.63	s/drop
Shipping labelling of the packs	31.50	s/pack
Store packs in shipping dock	22.33	s/pack

While each task was analysed with the highest level of detail and granularity possible, their inclusion in the optimization model was considered as part of a larger component. The reason behind this aggregation is that these tasks can be grouped together and associated to a single variable since the start of one task implies the continuation of the process until the end. Therefore, these tasks are viewed as parts of a single activity that cannot be divided. On the other hand, this promotes a simpler structure and, consequently, a simpler delineation of the optimization model.

4.2 Decision Variables & Objective Function

The decision variables used in this model are displayed on Table 3, along with a description of their meaning. The variables of binary nature possess a description that translates their meaning when they are set to 1 (stated as =1 before the explanation). Regarding the indexes and parameters of the model, please consult Annex C.

Table 3 - Decision Variables

Variables	Description
$Flow_{ij}^{z}$	Flow of product *i* on warehouse *j* on day z
Y_{jdkt}^{z}	(=1) allow transfer from warehouse *j* to *d* for drop *k* on day *z* via *t*
X_{djkt}^{z}	(=1) receive drop *k* on warehouse *j* from *d*, on day *z* via *t*
I_{ij}^{z}	Pick to Stock of product *i* on warehouse *j* on day *z*
$Split_{ijdk}^{z}$	Split Stream of product *i* of drop *k*
$Ship_{ijdk}^{z}$	Cumulative Split Stream of product *i* of *k*
O_{ij}^{z}	Pick from Stock of product *i* on warehouse *j* on day *z*
S_{ij}^{z}	(=1) allow Pick to Stock of product *i* on warehouse *j* on day *z*
N_{ij}^{z}	Need of inventory of product *i* on warehouse *j* on day *z*
H_{j}^{z}	Additional working capacity at warehouse *j* on day *z*
R_{ija}^{z}	Reception of product *i* on warehouse *j* on day *z* from arrival *a*
Inv_{j}^{z}	Total inventory of warehouse *j* on day *z*

The objective of this optimization model is to provide the ideal number of products and drops to handle on each day and the corresponding processes to perform over the course of fifteen days, for every warehouse available. In this situation, the concept of best solution reflects a planning that minimizes the overall cost. From a high-level perspective, this can be represented in an objective function with four components, presented in equation (4.1).

$$minimize\ z - \sum_{j=0}^{J}\sum_{z=0}^{Z}\sum_{k=0}^{K}\sum_{t=0}^{T}\sum_{d=0}^{J} Y_{jdkt}^{z}.Transport_{jdkt}^{z} + \sum_{j=0}^{J}\sum_{z=0}^{Z} H_{j}^{z}.Work_{j}^{z} + \sum_{j=0}^{J}\sum_{z=0}^{Z} Inv_{j}^{z}.Storage_{j} + \sum_{i=0}^{I}\sum_{j=0}^{J}\sum_{z=0}^{Z} M.N_{ij}^{z} \tag{4.1}$$

The first parcel of the objective function concerns the transportation cost of every delivery and of every transfer, represented by the variable *Y*, based on the origin warehouse *j*, the destination *d*, the day *z*, the drop *k* and the transportation method *t*. In this denotation, when the origin warehouse equals the destination, the meaning is that that shipment concerns a delivery to the end customer. For the remaining cases, this variable represents a transfer. The second parcel expresses the additional amount of human resource allocation needed, H_j^z, for each warehouse and for each day. In this component, the resources are multiplied by a ratio of cost/unit of work. The third parcel determines the storage cost of all the items kept in a warehouse Inv_j^z for every day. The last parcel represents virtual stock of every item in every warehouse *N*, which is only used in case of missing items, being regarded as an alert that the stock of an item will not be sufficient to cover the fulfilment of all the designated drops. Furthermore, for all the remaining equations, *h* will represent warehouse "HUUB" in indexes *j* and *d*.

4.3 Problem Constraints

As seen in chapter 3.2.1, the handling of products can include several stages. The start of the operation concerns the arrival of items from reception directly from suppliers, A^z_{ija}, where a corresponds to the reception ID, or from a transfer from another warehouse, X^z_{jdkt}. Concerning the arrival of items, a specific amount of products R^z_{ija} is processed on the reception stage and, depending on the drops already in the system, these products are either stored, I^z_{ij}, or they are picked directly to shipping packs, $Split^z_{ijdk}$. However, since the processing of a drop is considered as a whole, if a transfer X^z_{jdkt} is expected then the Split reception of items for a specific drop k, will not occur. Additionally, if a transportation is activated either to a customer, Y^z_{jjkt}, or to another warehouse, Y^z_{jdkt}, then all the items already accumulated on split stream for drop k, $Ship^z_{ijdk}$, will be moved to the shipping docks for posterior shipment. If there are still items missing from a drop, then pick to stock, O^z_{ij}, is activated to fill this gap. All these mechanisms are represented on Figure 8.

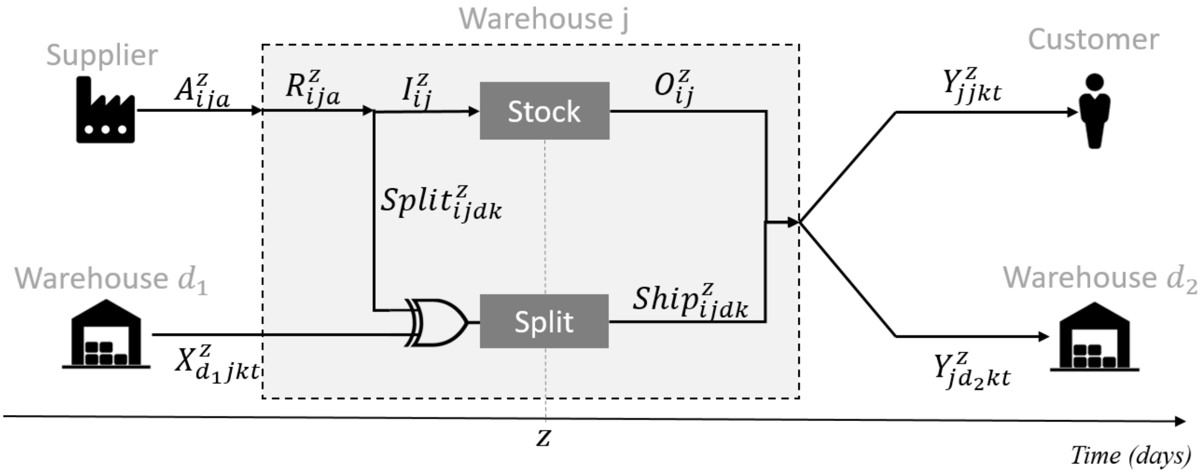

Figure 8 - Material flows of the operations

The relationship between all these processes can be simplified into a single equation that relates all the external flows with the internal ones. The reasoning behind this relationship is that the total amount of items to ship, Y^z_{jdkt}, minus the total amount of items received, A^z_{ija} and X^z_{djkt}, is related with the Inbound and the Outbound stage. Furthermore, the items received and available can be further simplified and account variable R^z_{ija} and the reception of goods from other warehouses only influences the Split stream, mainly on the decision variable $Ship^z_{ijdk}$.

$$Flow^z_{ij} = \sum_{a=0}^{A} R^z_{ija} + \sum_{k=0}^{K}\sum_{d=0}^{J}\left(Ship^z_{ijdk} - \sum_{t=0}^{T} Y^z_{jdkt} * Q_{ik}\right), \qquad \forall i,j,z \tag{4.2}$$

Equation (4.2) describes this relationship through variable $Flow^z_{ij}$, where a positive result means that there were more items available than the ones assigned for shipping/transferring. In this case, the items are sent to the Inbound stage where they can be assigned to the Stock Stream or the Split Stream. If the result is negative, then there were more items assigned for shipping/transferring than the ones available. Thus, the absolute value of that result represents the amount of that item that was picked from stock, corresponding to the Outbound stage. This is translated on Table 4.

Table 4 - Decision to perform Inbound or Outbound operations

$$\begin{cases} Flow^z_{ij} > 0\,, & Inbound\ operations\ occur\ \left(Split^z_{ijdk}\ and\ I^z_{ij}\right) \\ Flow^z_{ij} < 0, & Outbound\ operations\ occur\ \left(O^z_{ij}\right) \end{cases}$$

Inbound

Concerning the Inbound stage, if $Flow_{ij}^{z}$ is positive, S_{ij}^{z} is set to 1, and the flow is directly allocated to the Inbound warehousing processes through equations (4.3) and (4.4). If $Flow_{ij}^{z}$ is negative, then S_{ij}^{z} is set to 0, disabling the allocation to Inbound stage, through equation (4.5). M represents a significantly high value constant.

$$\sum_{d=0}^{J}\sum_{k=0}^{K} Split_{ijdk}^{z} + I_{ij}^{z} \leq Flow_{ij}^{z} + M\left(1 - S_{ij}^{z}\right), \qquad \forall i, j, z \tag{4.3}$$

$$\sum_{d=0}^{J}\sum_{k=0}^{K} Split_{ijdk}^{z} + I_{ij}^{z} \geq Flow_{ij}^{z} - M\left(1 - S_{ij}^{z}\right), \qquad \forall i, j, z \tag{4.4}$$

$$\sum_{d=0}^{J}\sum_{k=0}^{K} Split_{ijdk}^{z} + I_{ij}^{z} \leq M.S_{ij}^{z}, \qquad \forall i, j, z \tag{4.5}$$

Outbound

When the result of the flow is negative, the decision variable S_{ij}^{z} is set to 0 and the equations (4.6) and (4.7) set the value of O_{ij}^{z} as the negative of that result. Equation (4.8) sets O_{ij}^{z} to 0 if the Outbound is not allowed, forbidding pick from stock operations.

$$O_{ij}^{z} \leq -Flow_{ij}^{z} + M.S_{ij}^{z}, \qquad \forall i, j, z \tag{4.6}$$

$$O_{ij}^{z} \geq -Flow_{ij}^{z} - M.S_{ij}^{z}, \qquad \forall i, j, z \tag{4.7}$$

$$O_{ij}^{z} \leq M\left(1 - S_{ij}^{z}\right), \qquad \forall\, i, j, z \tag{4.8}$$

Quantity

These equations define how the Inbound and Outbound stages are addressed. However, the activities within those restrictions have restrictions on their own. One of those restrictions is (i) the availability of a product at any given moment must be equal or superior to 0 and (ii) the total amount of products must be inferior to the limit capacity of each warehouse. These constraints refer to equations (4.9) and (4.10) respectively.

$$\sum_{l=0}^{z}\left(I_{ij}^{l} - O_{ij}^{l}\right) + N_{ij}^{z} + Inv_{ij} \geq 0, \qquad \forall\, i, j, z \tag{4.9}$$

$$\sum_{i=0}^{I}\left(\sum_{l=0}^{z}\left(\sum_{d=0}^{J}\sum_{k=0}^{K}\left(Split_{ijdk}^{l} - \sum_{t=0}^{T} Y_{jdkt}^{l}.Q_{ik}\right) + \sum_{k=0}^{K}\sum_{t=0}^{T}\sum_{d:d\neq j}^{J} X_{djkt}^{l}.Q_{ik} + I_{ij}^{l}\right) + Inv_{ij}\right) = Inv_{j}^{z},$$

$$Inv_{j}^{z} \leq Cap_{j}, \qquad \forall\, j, z \tag{4.10}$$

One of the requirements of this supply chain is the transportation of a drop as a single unit, meaning that only one warehouse on a specific day will be activated to perform the shipping process, as seen in equation (4.11). However, each warehouse can be responsible for either a transfer of drops or the delivery of those drops. There is also the possibility of not being used at all, as portrayed in equation (4.12).

$$\sum_{j=0}^{J}\sum_{z=0}^{Z}\sum_{t=0}^{T} Y_{jjkt}^{z} = 1, \qquad \forall\, k \tag{4.11}$$

$$\sum_{z=0}^{Z}\sum_{d=0}^{J}\sum_{t=0}^{T} Y_{jdkt}^{z} \leq 1, \qquad \forall j, k \tag{4.12}$$

Concerning the arrival of items, these must be received on the warehouse and the processing of items can only be deployed when they arrive, as demonstrated on equation (4.13) and (4.14).

$$\sum_{l=0}^{z} R_{ija}^{l} \leq \sum_{l=0}^{z} A_{ija}^{l}, \qquad \forall i,j,a,z \tag{4.13}$$

$$\sum_{z=0}^{Z} R_{ija}^{z} = \sum_{z=0}^{Z} A_{ija}^{z}, \qquad \forall i,j,a \tag{4.14}$$

Split

Ideally, if the Flow results in a positive value, the Inbound stage would allocate all the remaining products to $Split_{ijdk}^{z}$, since the Split Stream is both cheaper and faster. However, this stream depends on several conditions. Thanks to equations (4.11) and (4.12), the allocation of items to drops is always a unimodal decision where either one delivery or one transfer is made. Thus, when referring to the allocation of items through Split, there is no need to separate the allocation between delivery and transfer. The first consideration when addressing the Split stream is to restrict the possibility to handle products in this segment only when a warehouse is either (i) responsible for the final shipment or (ii) responsible for the preparation of a drop to transfer to another warehouse. This is expressed in equation (4.15). Additionally, the allocation of items to drops in this stream can only occur on days prior to the date of shipping/transferring the drop, being this constraint set in equation (4.16). The last consideration concerning the Split stream, equation (4.17), is that this option is only available on warehouses owned by HUUB.

$$\sum_{z=0}^{Z} Split_{ijdk}^{z} \leq \sum_{z=0}^{Z}\sum_{t=0}^{T}\left(Y_{jdkt}^{z} - \sum_{d:d\neq j}^{J} X_{djkt}^{z}\right).Q_{ik}, \qquad \forall i,j,d,k \tag{4.15}$$

$$Split_{ijdk}^{z} \leq \left(1 - \sum_{l=0}^{z}\sum_{t=0}^{T} Y_{jdkt}^{l}\right).M, \qquad \forall i,j,d,k,z \tag{4.16}$$

$$Split_{ijdk}^{z} \leq 0, \qquad \forall i,d,k,z,\forall j \neq h \tag{4.17}$$

The advantage of the Split Stream is that the handling of a drop can be divided into several days until the day of delivery/transfer. On a day, if there are still items to pick, then they are retrieved from stock. Thus, the flow should include the items that were already collected through the Split Stream, to correctly assess the total balance. However, the items from Split should only be considered on day z if the delivery/transfer is planned for that day. If not, the inclusion of items on Split would cause this equation to always consider these quantities, even when no shipment/transfer was made. Thus, the creation of a decision variable that allows the consideration of items from Split on equation (4.2) only when the shipment/transfer is planned. In this case, the variable will correspond to the cumulative number of items on Split until that day and that value will impact the result of the flow. Equations (4.18) refers to the first aspect and equations (4.19) and (4.20) refer to the second point.

$$\sum_{i=0}^{I} Ship_{ijdk}^{z} \leq M.\sum_{t=0}^{T} Y_{jdkt}^{z}, \qquad \forall j,d,k,z \tag{4.18}$$

$$Ship_{ijdk}^{z} \leq \sum_{l=0}^{z} Split_{ijdk}^{l} + M(1 - \sum_{t=0}^{T} Y_{jdkt}^{z}) + \sum_{l=0}^{z}\sum_{t=0}^{T}\sum_{d:d\neq j}^{J} X_{djkt}^{l}.Q_{ik}, \qquad \forall i,j,k,z \tag{4.19}$$

$$Ship_{ijdk}^{z} \geq \sum_{l=0}^{z} Split_{ijdk}^{l} - M(1 - \sum_{t=0}^{T} Y_{jdkt}^{z}) + \sum_{l=0}^{z}\sum_{t=0}^{T}\sum_{d:d\neq j}^{J} X_{djkt}^{l}.Q_{ik}, \qquad \forall i,j,k,z \tag{4.20}$$

Time

The selection of the transportation for the last-mile delivery depends on the lead time associated to the transportation method. Thus, equation (4.21) only allows transportation means that meet the proposed deadlines. Normally, the method with the highest lead time is also the cheapest one. This method will be the one used as long as its lead time meets the deadline. Equation (4.22), on the other hand, considers the existence of a lead time concerning the transfer of products between warehouses. Moreover, that constraint exposes that referring to the outbound of a transfer from warehouse *j* to warehouse *d* on day *z* is the same as referring to the inbound of a transfer on warehouse *d* from warehouse *j* on day *z* plus the lead time of that transfer.

$$\Delta_{jkt}^{z}.Y_{jjkt}^{z} \leq D_k, \qquad \forall\, j,z,k,t \tag{4.21}$$

$$Y_{jdkt}^{z} = X_{djkt}^{z+\delta_{jd}^{z}}, \qquad \forall\, j,z,k,t,d: d \neq j \tag{4.22}$$

Another time component of problem is the time associated with each activity and the work capacity needed to be performed. For the case of HUUB, the time it takes for every action to be made is considered when allocating additional work capacity, based on the assumption that there is also a fixed amount of capacity already available. This is expressed on constraint (4.23). For the remaining warehouses, the cost is accounted directly and this is represented by constraint, where *h* refers to HUUB (4.24).

$$\sum_{i=0}^{I}\left(\sum_{a=0}^{A}(TR_{i0a} + TA_{i0a}^{z}) + TI_{i0}^{z} + TO_{i0}^{z} + \sum_{k=0}^{K}\sum_{d=0}^{J}\left(TSplit_{i0dk}^{z} + \sum_{t}^{T}(TY_{0dkt}^{z} + TX_{d0kt}^{z})\right)\right) \leq W_0^{z} + H_0^{z}, \qquad \forall z \tag{4.23}$$

$$\sum_{i=0}^{I}\left(\sum_{a=0}^{A} CR_{ija}^{z} + CI_{ij}^{z} + CO_{ij}^{z} + \sum_{k=0}^{K}\sum_{d=0}^{J}\sum_{t=0}^{T}(CY_{jdkt}^{z} + CX_{djkt}^{z})\right) \leq W_j^{z} + H_j^{z}, \qquad \forall z, \forall j \neq h \tag{4.24}$$

Every variable of Table 3 whose description mentions the activation of an action when the value is 1 are of binary nature. All the remaining ones, except $Flow_{ij}^{z}$, are integer variables whose value must be greater or equal to 0. Having Var as the designation for each of these variables, equation (4.25) exposes these constraint

$$Var \geq 0, \qquad \forall i,j,d,k,z,t \tag{4.25}$$

5 Implementation and Results

This chapter approaches the technological implementation of the mathematical model into a software tool that supports the planning of the operation. Given that Spoke is already used as the backbone of the operation, this component should be integrated in this platform. Moreover, the performance of this module must withstand the processing of several drops and receptions and allow the computation of a solution within twelve hours. Therefore, this section also refers to the benchmarking of its performance based on several samples of different sizes. Furthermore, these samples concern real data of drops and receptions that happened. Thus, the last part of this chapter concerns the analysis of results regarding (i) the accuracy of the cost framework and (ii) the viability of partnering with DAMCO and having a second warehouse in the Netherlands.

5.1 Programming Approach

The main programming language used in this project was Python. This high-level language has been the target of several academic developments that enhanced its usability, with many libraries being created over the years. Its focus on code readability and the usage of a syntax that allows programmers to express concepts in fewer lines of code when compared with other languages as C++ or Java, are some of the advantages that this language provides.

Within this programming language, several libraries have been used to structure the code. From these, two stand out as the most important ones. The first, Pandas, is a library that allows to structure data into datasets with built-in functions that accelerate the performance of the code. This acceleration is due to the nature of this library where the execution of critical code paths is made in C or Cython. Furthermore, the usage of datasets eases the readability of the information and allows the usage of lambda functions, which synthetizes the lines of code. The second, PuLP, is a library used to formulate optimization problems in several formats and call external solvers to solve the problem. This can be used as a "wrapper" since one can just use it to write an optimization model file that can be used on other platforms. Nonetheless, the best advantage of this library is that it has built-in functions that allow testing different kinds of solvers as long as they are installed on the machine running the script, without modifying the code structure. The only modification needed is the argument of one function where the selected solver is specified.

Due to the need to extract data from a database, SQL has also been employed for all queries concerning the selection of data about drops, receptions, and stock. These queries are directly used in the main Python code through external libraries that allow database connection and data transfer. However, information related with the cost assessment of operations is still not available in the database. Thus, every information that has been manually obtained will be included in a separate file when all additional information is saved. Moreover, since this tool will be used to determine the viability of including an additional warehouse, data concerning the activities of external warehouses is also in this file.

To enable a faster and more efficient transmission of information, the output of this module has been split into (i) a moment where the data is processed and results are produced and (ii) another where the data is consulted by a user. This approach relies on presenting a response from a web API perspective. Due to the high amount of data that this model requires, perform a run-on-request structure would trigger a high waiting time and, in most cases, the original plan would not suffer differences. To enable this approach, the model was set on a web server that will run daily executions and save the results of each run. Consequently, every time a user requests a schedule on Spoke, the server will retrieve the latest planning available, as observable in Figure 9. Whenever a result is required, a JSON file is sent where all information is contained. The information is sent in this lightweight format to ease the transformation of the data and allow a faster response.

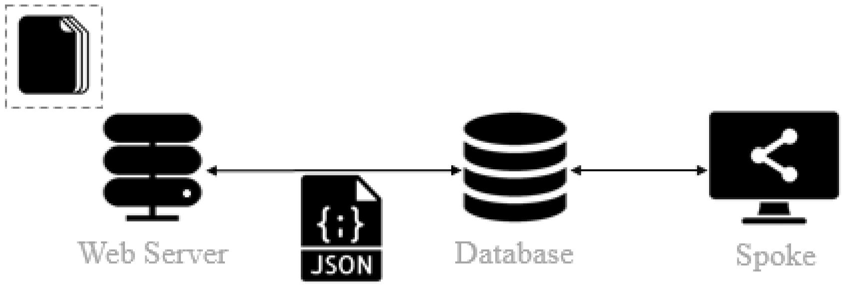

Figure 9 - Request planning structure

Regarding the sections of the code itself, the first part concerns initialization rules and preliminary data that will configure the model for each run. This concerns processes related with database connection and importation of external libraries. The following step is the preparation of data, where information is retrieved from queries into datasets. From these datasets, every decision variable is created. After this, the objective function is constructed, followed by the inclusion of the constraints. With the full definition of the problem, the last step is to compute a solution.

5.2 Model Validation

To perform the validation of the model, a sample was created to analyse if the results met the expectations. In this analysis, several variations were made in the parameters/cost drivers to evaluate their influence on the result and how they behaved in comparison with reality.

To assure that the model is well-built and that different input data will be reflected on different outputs, an analysis was made where several scenarios were elaborated to compare the results obtained through the model with the desired outcome. The idea is to assess the variability of the external and internal flows while maintaining a simple structure to allow a manual confirmation of the results. Thus, the following data was structured:

- $A_{iha}^{z=0} = 10.000$
- $D_k = z + 15$
- $Q_{ik} = 10.000$
- $W_j = 0$
- $\delta_{jd}^{z} = 4$ days
- $\Delta_{jkt}^{z} = 3\ days,\ when\ j = h$
- $\Delta_{jkt}^{z} = 2\ days,\ \forall j \neq h$
- $Transport_{jdkt}^{z} = 100€\ \ \forall j \neq h$
- $Transport_{jjkt}^{z} = 200€,\ \ \forall j \neq h$
- $Transport_{hhkt}^{z} = 400€$
- $Work_j^z = 500€,\ \forall j$

All remaining parameters will have values that do not influence the decision process.

In these conditions, and assuming that the items received can be processed, all items would be directly received to the shipping packs and sent to DAMCO, who in turn would ship to the final customer, since the transportation cost is lower with this route. This would result on only one worker to receive the products and ship them to the Netherlands, thus minimizing cost related with the working capacity. A worker at HUUB would always be a necessary measure since the rescheduling of $A_{iha}^{z=0}$ is not possible. The shipment would also be made as soon as possible to avoid storage costs. The result obtained matched this prediction. To further increase the credibility of the model and to test its robustness to error, several scenarios were created, presented on Table 5, followed by the expected consequent of these modifications.

Table 5 - Scenarios in analysis and respective expectation

Scenario	Changes	Expected Output	Match
1	$A_{iha}^{z=0} > Q_{ik}$	Same as initial + $\mathrm{I}_{\mathrm{ij=h}}^{\mathrm{z}}$	Yes
2	$A_{iha}^{z=0} < Q_{ik}$	Same as initial + $N_{\mathrm{ij}}^{\mathrm{z}}$	Yes
3	D_k<5	$Y_{hhdt}^{z} = 1$	Yes
4	$W_{j=h}^{z=0} = 1$	*Same as initial*	Yes
5	$Transport_{jjkt}^{z} = 1000€, \quad \forall \mathrm{j} \neq \mathrm{h}$	$Y_{hhdt}^{z} = 1$	Yes

All these scenarios had results that matched the expectations. On the first scenario, due to an increased number of items received and that no other drops were requiring that SKU, the remaining products were picked back to stock while the rest of the decision variables stayed the same. On the second scenario implies a demand higher than the expected supply. Thus, virtual units where used while all the remaining results stayed the same. The third scenario reflects the case of a delivery with a tighter deadline, forbidding the last-mile transportation from DAMCO. Therefore, the drop was entirely fulfilled by HUUB's warehouse. The forth scenario was expected to result in the same result as the initial case. The reason behind this result is that a worker will always be needed to address $A_{iha}^{z=0}$ and, therefore, a fixed working capacity unit will perform the tasks that were previously set for the variable one. The last scenario involved a higher transportation cost in DAMCO, thus the route chosen for the last-mile delivery was the only available through HUUB.

This exercise demonstrated that the model was capable of accommodating these modifications and that a feasible solution was obtainable. However, this concerning a relatively simple sample where manual variations were induced. Further computational experiments were made where more drops and receptions are considered, generating higher variation on the system, to evaluate how the model behaves to real-life scenarios with greater amount of data.

5.3 Computational Experiments

The feasibility of an optimization algorithm of an optimization model and depends on two main components: its capability to provide a feasible solution for a given problem and the processing time involved on its processing. One way to enable these two conditions is the elaboration of a well-structured mathematical model with a domain properly defined. Moreover, the relevance of each decision variable and the way these are defined has also a strong influence on this matter. If these parameters are met, then the next approach is to optimize the coding involved in the model and the proper selection of a good solver. However, the selection of the best solver depends on the problem and on the needs required. If a problem is simple enough, several different open source solvers are more than capable of producing a good support. Nonetheless, for larger integer programming problems, the feasibility of these solvers tends to diminish, either due to long computation time to produce a solution.

For this project, the computer used during the testing stage of this algorithm possesses an Intel(R) Core(TM) i7-5500U 2.40GHz processor with 8GB of RAM and an NVIDIA GeForce 840M graphics card. The testing involved the usage of the CBC solver, which is used as the default solver of PuLP. In this first stage of testing, there were three scenarios that were used to analyse the impact. The first focused on the planning of only one drop and one reception and it was used to validate the model. In each, only one product type was used for the sake of simplicity. For this case, dummy data was generated several times to evaluate the response of the model to different cases. The model passed this testing with positive remarks, allocating resources as expected. The average time for the creation of the model and the processing of the solver are observable on Table 6. The second model served as an extension of the first analysis, considering five drops and two receptions, each having different SKUs. Again, the model proceeded to return the best solution, though an increase on the processing time was observed. Since the amount of data to include in a real-life scenario is always greater than the size of these samples, a third testing was made where all real drops and receptions, within a time window of two weeks, were considered. In this case, the data collected concerned the drops and receptions that were processed between January 14th and January 28th of year 2017. This period concerns one of the most intense operational periods of this company, thus the analysis of this one. Though the model was fully created, the algorithm failed to produce a result.

Table 6 - Testing of samples using different solvers

Test	Drops	Receptions	Variables	Creation (s)	Solving (s)
Sample 1 - CBC	1	1	144	9.87	0.83
Sample 2 - CBC	5	2	17270	323.85	34.97
Sample 2 - Gurobi	5	2	17270	323.85	1.41
Sample 2 - Cplex	5	2	17270	323.85	1.19
Sample 3 - CBC	248	36	136750	15682.93	-
Sample 3 - Cplex	248	36	136750	8988.72	7252.52
Sample 3 - Gurobi	248	36	136750	8988.72	5578.15

With the last sample, it was assessed that the model possesses two problems. The first, concerning the execution, is that for a sample with the size of a real-life case, the model cannot perform the planning of the operation. The second problem is that the time taken by the loading process alone represents 36.3% of the total time available for the planning. Thus, even if the algorithm could produce a solution, the processing time could be higher than desired.

Since the previous tests validated the model and that some mixed integer linear programming problems are either to complex or too large to be solved by an open-source solver, the hypothesis considered in this stage was that more powerful solvers should be able to produce a solution. To verify this hypothesis, both Gurobi 7.0.2 and IBM ILOG CPLEX Optimization Studio 12.7.1 were used to try to compute a solution for the third and second sample, since they possess an API structure for Python where these modules can also be used with PuLP. This way, the modifications on the algorithm are kept at a minimum while maintaining the possibility to compare different solutions.

As seen in Table 6, the results show that Gurobi and IBM ILOG CPLEX Optimization Studio are both capable of producing a solution for the greater sized sample. Both these solvers returned solutions where the status of the optimization was classified as “Optimum”, meaning that the best value for that problem was achieved. Additionally, the fastest solver for these cases is Gurobi, with a difference similar to benchmarks made by other authors (Mittelman 2011).

However, even with Gurobi, the overall time of the third sample represented 50.78% of the total available time. While this value is within the target, the execution time will increase if the number of drops/receptions and SKUs increases. As an attempt to improve performance, this model was implemented on a remote server through the usage of Amazon Web Services (AWS). On this service, a user can choose from a range of computers and pay by the amount of time used on that machine. The advantages include (i) being a service where hardware maintenance is assured, (ii) high flexibility to scale the resources needed and (iii) quick access to powerful computational power on a “pay to use” model. However, academic licensed materials as Gurobi and IBM ILOG CPLEX Optimization Studio cannot be implemented on these servers since these licenses were already used on another computer. On the other hand, the time it took to load the model was reduced to 9364,45 seconds, representing a reduction of 40.29%. Another relevant case is definition of constraints that may be included in the model in an implicit manner, saving time both on the preparation as well as the processing of a solution. One example is the constraint concerning equation (23) where only the delivery methods whose lead time meet the deadline are proposed. These methods can be filtered prior to the moment of creation of variables, simplifying the system. Applying these improvements on the code, the final preparation time achieved was 8988.72, where the total decrease from the initial result is of 42.69%.

Regarding the solving time, both Gurobi and IBM ILOG CPLEX Optimization Studio possess mechanisms that automatically detect the resources available on a computer and tune the processing of data accordingly. The consumption of resources is maximized to achieve higher capacity on the computation of a solution. With such capability, there is a strong evidence that the deployment of these solvers on more powerful machines would result in a faster solving time.

After these benchmarks, the final decision was to employ AWS servers to read the available data and prepare the model, since this option provides the fastest method. After the preparation, a file (lp format) is written in the database and the model is then solved on the machine, through *gurobipy*, the Python library associated with Gurobi 7.0.2. To implement a daily planning controlled remotely, a JENKINS platform was created, where several tasks can be programmed and scheduled. The usage of this platform has also the benefit of recording every result obtained for each planning as well as analyse the performance evolution. The result is then provided on Spoke each time a user makes a request on the latest planning, through the transmission of a JSON file. This file is then processed and the information is then presented on a front-end interface in a readable format. The Operational team will then consume this planning and an analysis is made each day to assess if the allocation of human resources matches the values obtained by this algorithm. The goal is to improve the Time-Driven ABC analysis until the information system provides sufficient structure to automatically adjust the values of the cost values.

5.4 Analysis of Results

The analysis of results has two main segments: the analysis of the cost framework, developed in parallel with the optimization algorithm, and the analysis of partnering with DAMCO. Concerning the first segment, the cost framework was also implemented as a separate process to aid other activities within the company. Concurrent to this implementation was the analysis of how accurate the results are in comparison with previous cost assessments. Regarding the second segment, one of the goals of this project was to assess the viability of partnering with DAMCO. Therefore, previous data was collected and processed on the optimization model, considering the possibility to include DAMCO as an additional warehouse. This analysis considered several scenarios where, in each, the relevance of including DAMCO is assessed.

5.4.1 Cost Framework

Up until this point, the main focus was on the creation of a tool that supports the decision-making process regarding the planning of the overall operation. In these efforts, a cost framework was devised to assess the cost driver of each activity to analyse the cost of the operation. These costs were then incorporated in the optimization algorithm with the objective of minimizing the overall cost. When addressing the cost associated with each activity, this approach is able to produce the real cost of those actions. On the other hand, another usage of this cost framework is to provide visibility over the operational costs in a predictive manner. This is particularly important when negotiating the onboarding of a client, where a proposal is made. With this framework, the company gains more insights on the estimated cost that a possible customer might have. Thus, the objective is to provide a simple tool that allows the Marketing & Sales team to propose a price/unit on a real-time basis. While this does not possess the same level of detail as the one obtained through the optimization algorithm it will be able to produce a good estimate of how much the operational cost will be with the onboarding of a brand. To minimize this difference, the framework considers that (i) the wholesale deliveries are fulfilled from Split and Stock streams, being this proportion estimated through the average of other brands already onboard, and (ii) the inventory level variation for a season will be estimated from averaging previous data of other brands as well. The e-commerce sales, as aforementioned in chapter 3.2.2, are fulfilled from the Stock Stream.

This tool will be available on Spoke as an API, where the Marketing & Sales team will access and insert the number of items and the number of sales and, if available, the proportion between wholesale and e-commerce sale. The output of this application is an estimated value of the cost/unit. If it is not available, the proportion is also estimated from other brands. The implementation of this tool will count with the partnership of the Information & Technology department, being this team responsible for creating the API that uses this cost framework.

To evaluate this tool, a brand was selected to estimate the total handling and storage costs through this tool. For this sample, a total of 45.394 units, 1697 e-commerce deliveries, and 426 wholesale deliveries were considered. The main criterion to choose this brand (A) as a sample was the selection of a brand whose number of units and deliveries were more similar to a brand already enrolled on the system (B).

For brand A, the average cost per unit is of 0.3543 €/unit, with the proportion of the cost per stage as the one observed on Figure 10. This result equals 88.11% of the cost of brand B, whose cost was 0.4021€/unit. However, being old data, the cost assessment of brand B was performed with an old costing mechanism, where the result is achieved from deducting several activities to the overall cost of the company. Thus, the cost imputation does not possess the same granularity and some process may not belong to the operational cost, being wrongly included.

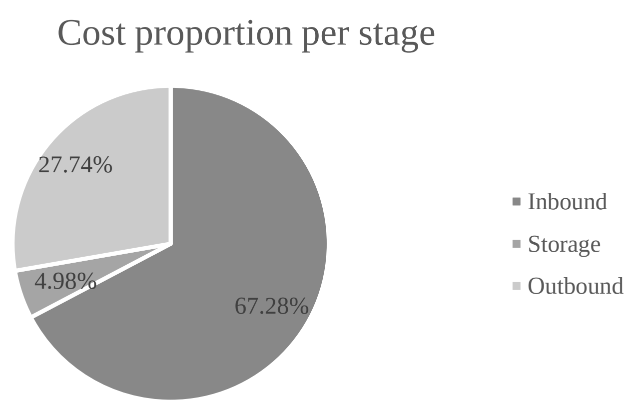

Figure 10 - Cost proportion per stage of the sample case

5.4.2 Partnership with DAMCO

To infer the impact of DAMCO in HUUB's operation, four different scenarios were considered, each referring to a distinct operational load, but always over a period of fourteen days. The first, with 457 drops, referred to a high operational load, normally the preparation of a season. The second, with 248 drops, referring to mid-high operational load, where the peak of the season has passed but some drops are still to process. The third, with 101 drops, referring to low operational load with mainly e-commerce brands and corresponding to the final moment of a season. The fourth is similar to the third, with the distinction of having e-commerce sales with higher lead times, with 95 drops involved. The receptions were also considered on this analysis, however, since (i) the items first arrive at HUUB and only after are they shipped to the Netherlands and (ii) the storage cost of DAMCO is higher, these do not influence the number of items processed on the second warehouse. The first analysis will consider a planning for only the warehouse in Portugal and the second scenario will account with the warehouse of DAMCO, followed by a comparison between the two. This can be consulted in Table 7.

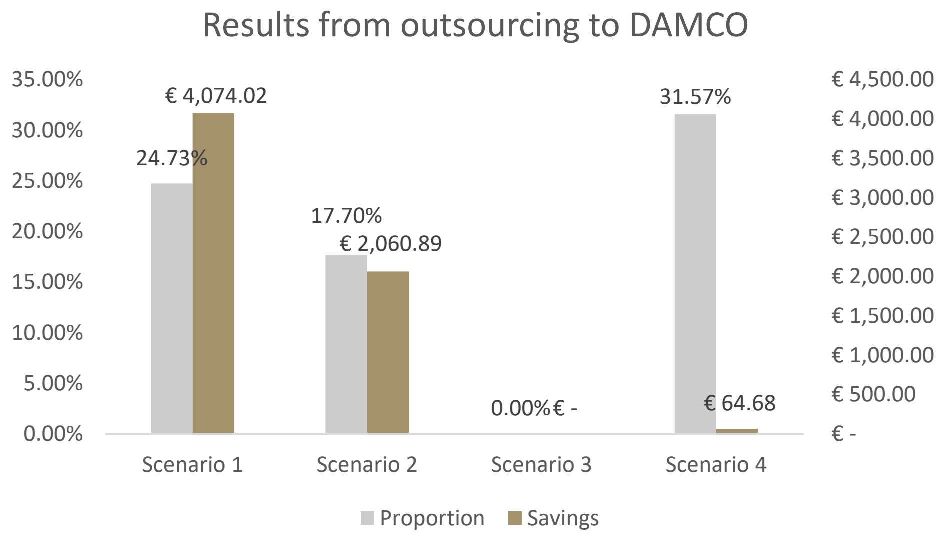

Figure 11 - Proportion of drops fulfilled by DAMCO and corresponding savings

As expected, the planning for scenario 3 did not include DAMCO, since the majority of drops belong to e-commerce sales with a transfer lead time higher than required to fulfil orders' lead-time. Thus, these drops should have their fulfilment from Portugal. However, there are cases when e-commerce drops have a larger time window, in which case there is the possibility to perform one transfer to DAMCO and then cross-dock the items and ship them to the final customer. In scenario 4 the delivery dates were all very similar and the volume of the items involved was high enough to make the transfer cost a viable option, but only 64.68€ for whole drops. Scenarios 1 and 2, related with wholesale, demonstrate that the inclusion of DAMCO would allow the generation of cost savings with over 17% of drops being fulfilled by DAMCO on both cases and a total cost saving of 6,134.91€, as seen in Figure 11. On an overall analysis, these tests validate the viability of having DAMCO as a partner and thus a warehouse in the Netherlands brings benefits to HUUB's operations, enabling cost savings.

Table 7 - Results of outsourcing to DAMCO

Scenarios	N. of Drops	DAMCO's Proportion	Cost Savings
1	457	24.73%	€ 4,074.02
2	243	17.70%	€ 2,060.89
3	101	0.00%	€ -
4	95	31.57%	€ 64.68

6 Conclusion and Future Projects

This dissertation addresses a new methodology regarding the supply chain planning and the operational cost analysis of HUUB. HUUB provides logistic services and management of the supply chain of brands in the fashion industry, owning a warehouse and a web platform, Spoke, that supports all the information required by brands and for the operation. The merging of all these supply chains into one has consequences on the planning of the operation, where each additional brand represents more complexity in the system.

Previously to this project, the planning of the operation was manually made. In this process, a person would analyse the sales orders to fulfil and the receptions to process and then a schedule would be devised considering this information. To assure that the execution followed the planning, three daily meetings were made, where the progress of the operation was registered and variations were accommodated. These variations regard delays on the operation as well as supplementary sales orders that were inserted on the system on that day, which influence the planning to great extent. This approach disregarded the costs of each warehousing procedure and the accommodation of variations was a repetitive and time-consuming process. Furthermore, this approach was unable to assess if the inclusion of additional warehouses would bring benefits to the operational flow of the company.

This project was created with the objective of implementing a solution that creates the best available planning for the operation of the supply chain while accommodating several operational possibilities and its respective cost. To meet this goal, a cost assessment of the whole operational structure was required, since this aspect represents the most important factor on the decisions made. Along with this analysis, a processual assessment was also made to distinguish the different flows that this supply chain possesses to respond to the requirements of the system. This includes all the warehousing procedures as well as the processes of other warehouses that might be included on the planning of the operation.

Within this project, it is proposed the implementation of an optimization algorithm that will perform the planning of the operation, where the objective function is the minimization of the total cost. To support the input of information regarding the procedures to plan, a cost framework was devised based on Time-Driven Activity-Based Costing and on the Cost-to-Serve approach. Thus, the determination of the cost drivers will be made through the measurement of time, respecting the differences between different activities and different brands. These two components will allow a greater visibility over the operational costs and the self-sufficient creation of an optimized planning. Additionally, the process and cost structure of other warehouses, in this case a warehouse owned by DAMCO, were also included on the analysis. By adding this factor to the system, the result of the planning will allow to infer if the option to partner with DAMCO and deploy operational task on its warehouse is a viable option.

Regarding the construction of the cost framework, the operation was divided into 5 main processes: (i) reception, (ii) pick to stock, (iii) pick from stock, (iv) packing and (v) shipping. After this division, each process was measured considering all the sub-tasks that all implicitly involved. Apart from these processes, the cost of 4 other factors can be directly obtained at the present moment: (i) Materials for warehousing activities, (ii) Taxes and Duties, (iii) Shipping rates from carriers and (iv) Storage of products.

Concerning the optimization model, the mathematical formulation was made as a mixed integer programming problem due to the nature of this case where integer values are required and some decisions possess a binary outcome. To implement this model, a Python programming algorithm was developed where (i) the input data is obtained through SQL queries, (ii) the processing of data and construction of the model is executed through several Python libraries, (iii) the iterative computation of the solution is obtained through external solvers and (iv) the result is sent as a JSON file to the database and posteriorly consumed by Spoke.

6.1 Main results

In order for this project to be fully implemented, the model would have to be able to produce a feasible solution, having a time window of twelve hours to do so. Two different processes must be executed in this period: (i) the collection of data and the loading of the model to be executed and (ii) the processing of the model to achieve a solution. To increase the performance of the first point, the code was improved in order to synthetize constraints that can be directly applicable and the script was implemented on a more powerful computer. Concerning the processing of the model, only commercial solvers could generate a solution, being Gurobi the best of the ones tested. At the end of the benchmarking, the highest total time achieved represented only 33.72% of the time available, for a sample of 248 drops and 36 receptions, thus meeting all the targets devised for this project.

Regarding the cost framework, there are two possible usages. The first is its inclusion on the optimization algorithm, through which a specific cost is determined for each planning. The second, targeted to aid the Marketing & Sales team, is the estimation of how much will cost for a new brand or a new season to be prepared on HUUB. The utilization of this framework is the same, with the caveat of having several data estimated instead of using specific values. Nonetheless, the cost comparison between the estimated value of a brand and the real cost of another brand already on the system showed that the difference was only 11.89%,. Furthermore, it was possible to infer that the stage with the highest cost share is the Inbound, representing 67.28% of the total cost.

After performing several tests, it was concluded that partnering with DAMCO is a viable option that enables cost savings. While the effect when considering e-commerce, sales orders is little to none, the influence on the planning with a majority of wholesale drops is relatively high. In these samples, DAMCO was the selected warehouse to fulfil 113 drops out of 457, on the first sample, and 43 out of 243 on the second sample, achieving a total cost saving of 6,134.91€ on these samples alone.

6.2 Future projects

One of the main restrictions of this project was the implementation of the cost framework having as input data directly collected from the database. The alternative considered was to manually measure the activities, which has limited validity since cycle times evolve with experience. Thus, one of the future projects to implement is the redefinition of the database to allow the registering of each activity at the product level. From this, the time to perform each activity could be statistically inferred from the data and the system would always be up to date with the most recent values concerning every activity. Moreover, the costing mechanism of this project addresses only the differentiation between brands and between processes. By registering the activities of each item, the detail of the cost assessment can be further exploited and consider the differentiation between different products of product categories.

Another restriction was the availability of only one academic license to perform this study. Due to this constraint, Gurobi 7.0.2 and IBM ILOG CPLEX Optimization Studio 12.7.1 could not be implemented on another computer. Thus, the next step would be to obtain a license that would allow further investigation to be made but on more powerful computers, as the ones already employed through the AWS where the scale of the service can be regulated. With this measure, a future study emerges as how fast can the processing of a solution be, depending on the performance of a machine. Several studies have stated the advantage of multithreading processes as a mean to achieve great performance and the volume of products shipped by HUUB is expected to increase. Thus, this analysis is useful to understand the computational limit of using exact methods to achieve a planning within the proposed time period.

On another perspective, the algorithm provides a solution considering established quantities and deadlines imposed by the brands, concerning drops, and suppliers concerning receptions. As such, another project will be implemented to achieve two objectives: (i) take over the planning of the receptions by working with the suppliers and (ii) creation of a forecasting method regarding sales orders. Both targets enable more flexibility in the planning process since more options are available. By forecasting expected quantities, the planning does not depend strictly on the input of sales orders into the database, a process where the precedence might be too low. Therefore, inventory levels can be determined prior to the gathering of that information, minimizing the bullwhip effect on the supply chain.

Referências

Apte, Uday M., and S. Viswanathan. 2000. "Effective Cross Docking for Improving Distribution Efficiencies." *International Journal of Logistics Research and Applications* 3 (3):291-302. doi: 10.1080/713682769.

Associates, Kurt Salmon. 1993. *Efficient Consumer Response*. Washington , D.C.: Food Marketing Institute.

Bartholdi, John J., and Kevin R. Gue. 2004. "The Best Shape for a Crossdock." *Transportation Science* 38 (2):235-244. doi: 10.1287/trsc.1030.0077.

Beamon, Benita M. 1998. "Supply chain design and analysis:: Models and methods." *International Journal of Production Economics* 55 (3):281-294. doi: http://doi.org/10.1016/S0925-5273(98)00079-6.

Burt, D.N., and J. Anklesaria. 1990. *Zero Base Pricing*. Chicago, IL: Probus.

Carr, Lawrence P., and Christopher D. Ittner. Fall 1992. "Measuring the Cost of Ownership." *Journal of Cost Management* 6 (3):42.

Cohen, M. A., and H. L. Lee. 1988. "Strategic analysis of integrated production-distribution systems: models and methods." *Operations Research* 36 (2):216-228. doi: 10.1287/opre.36.2.216.

Cohen, M. A., and H. L. Lee. 1989. "Resource deployment analysis of global manufacturing and distribution networks." *Journal of Manufacturing and Operations Management* 2 (2):81-104.

Cohen, M. A., and S. Moon. 1990. "Impact of production scale economies, manufacturing complexity, and transportation costs on supply chain facility networks." *Journal of Manufacturing and Operations Management* 3:269-292.

Cooper, Robin. Winter 1989. "The Rise of Activity-Based Costing - Part Three: How Many Cost Drivers Do You Need, and How Do You Select Them?"." *Journal of Cost Management*:34-46.

Dantzig, George. 2016. *Linear programming and extensions*: Princeton university press.

Demeere, Nathalie, Kristof Stouthuysen, and Filip Roodhooft. 2009. "Time-driven activity-based costing in an outpatient clinic environment: development, relevance and managerial impact." *Health policy* 92 (2):296-304.

Doherty, C., J. Maier, and L. Simkin. 1993. "DPP decision support in retail merchandising." *Omega* 21 (1):25-33. doi: http://dx.doi.org/10.1016/0305-0483(93)90036-K.

Duh, Rong-Ruey, Thomas W Lin, Wen-Ying Wang, and Chao-Hsin Huang. 2009. "The design and implementation of Activity-Based Costing: a case study of a Taiwanese textile company." *International Journal of Accounting & Information Management* 17 (1):27-52.

Ellram, Lisa M. 1993. "A Framework for Total Cost of Ownership." *The International Journal of Logistics Management* 4 (2):49-60. doi: 10.1108/09574099310804984.

Ellram, Lisa M. 1995. "Total cost of ownership." *International Journal of Physical Distribution & Logistics Management* 25 (8):4-23. doi: 10.1108/09600039510099928.

Ellram, Lisa M. Winter 1995. "Activity-Based Costing and Total Cost of Ownership: A Critical Linkage." *Journal of Cost Management* 8 (4):22-30.

Ellram, Lisa M., and S.P. Siferd. 1993. "Purchasing: the cornerstone of the total cost of ownership concept." *Journal of Business Logistics* 14 (1):163-84.

Ernst and Young LPP. 1994. *Activity Based Costing: For Food Wholesalers and Retailers*: Joint Industry Project on Efficient Consumer Response.

Esper, Terry L., Thomas D. Jensen, Fernanda L. Turnipseed, and Scot Burton. 2003. "THE LAST MILE: AN EXAMINATION OF EFFECTS OF ONLINE RETAIL DELIVERY STRATEGIES ON CONSUMERS." *Journal of Business Logistics* 24 (2):177-203. doi: 10.1002/j.2158-1592.2003.tb00051.x.

Gevaers, Roel, Eddy Van de Voorde, and Thierry Vanelslander. 2014. "Cost Modelling and Simulation of Last-mile Characteristics in an Innovative B2C Supply Chain Environment with Implications on Urban Areas and Cities." *Procedia - Social and Behavioral Sciences* 125:398-411. doi: http://dx.doi.org/10.1016/j.sbspro.2014.01.1483.

Goetschalckx, Marc, Carlos J Vidal, and Koray Dogan. 2002. "Modeling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms." *European journal of operational research* 143 (1):1-18.

Harris, F.W. 1990. "How many parts to make at once." *Operations Research*:947-950. doi: https://doi.org/10.1016/j.ijpe.2014.07.003.

Jackson, D.W., and L.L. Ostrom. 1980. "Life cycle costing in industrial purchasing." *Journal of Purchasing and Materials Management* 18 (4):8-12.

Kaminsky, P., and Y. Wang. 2015. "Analytical models for biopharmaceutical operations

and supply chain management: a survey of research literature." *Pharmaceutical Bioprocessing* 3 (1):61-73.

Kaplan, Robert, and Steven R Anderson. 2013. *Time-driven activity-based costing: a simpler and more powerful path to higher profits*: Harvard business press.

Kaplan, Robert S, and Steven R Anderson. 2003. "Time-driven activity-based costing."

Koç, Utku, Ayşegül Toptal, and Ihsan Sabuncuoglu. 2017. "Coordination of inbound and outbound transportation schedules with the production schedule." *Computers & Industrial Engineering* 103:178-192. doi: 10.1016/j.cie.2016.11.020.

Kone, Estelle R. S., and Mark H. Karwan. 2011. "Combining a new data classification technique and regression analysis to predict the Cost-To-Serve new customers." *Computers & Industrial Engineering* 61 (1):184-197. doi: https://doi.org/10.1016/j.cie.2011.03.009.

Korponai, János, Ágota Bányainé Tóth, and Béla Illés. 2017. "Effect of the Safety Stock on the Probability of Occurrence of the Stock Shortage." *Procedia Engineering* 182:335-341. doi: https://doi.org/10.1016/j.proeng.2017.03.106.

LaLonde, Bernard J. , and Terrance L. Pohlen. 1996. "Issues in Supply Chain Costing." *The International Journal of Logistics Management* 7 (1):1-12.

Lewis, R. J. 1995. *Activity-based Models for Cost Management Systems*: Quorum Books.

Meindl, Bernhard, and Matthias Templ. 2012. "Analysis of commercial and free and open source solvers for linear optimization problems." *Eurostat and Statistics Netherlands within the project ESSnet on common tools and harmonised methodology for SDC in the ESS*.

Meyr, Herbert, Michael Wagner, and Jens Rohde. 2002. "Structure of Advanced Planning Systems." In *Supply Chain Management and Advanced Planning*, 99-104. Springer.

Miller, Jeffrey G, and Thomas E Vollmann. 1985. "The hidden factory." *Harvard business review* 63 (5):142-150.

Mittelman, Hans. 2011. "Benchmarks for optimization software." http://www.plato.asu.edu/bench.html.

Monckza, R.M., and S.J. Trecha. 1988. "Cost-based supplier performance evaluation." *Journal of Purchasing and Materials Management* 24 (1):2-7.

Mula, Josefa, David Peidro, Manuel Díaz-Madroñero, and Eduardo Vicens. 2010. "Mathematical programming models for supply chain production and transport planning." *European Journal of Operational Research* 204 (3):377-390. doi: 10.1016/j.ejor.2009.09.008.

Pernot, Eli, Filip Roodhooft, and Alexandra Van den Abbeele. 2007. "Time-driven activity-based costing for inter-library services: a case study in a university." *The Journal of Academic Librarianship* 33 (5):551-560.

Prak, Dennis, Ruud Teunter, and Aris Syntetos. 2017. "On the calculation of safety stocks when demand is forecasted." *European Journal of Operational Research* 256 (2):454-461. doi: https://doi.org/10.1016/j.ejor.2016.06.035.

Punakivi, Mikko, Hannu Yrjölä, and Jan Holmström. 2001. "Solving the last mile issue: reception box or delivery box?" *International Journal of Physical Distribution & Logistics Management* 31 (6):427-439. doi: 10.1108/09600030110399423.

Rizk, Nafee, Alain Martel, and Sophie D'Amours. 2008. "Synchronized production–distribution planning in a single-plant multi-destination network." *Journal of the Operational Research Society* 59 (1):90-104.

Sabri, Ehap H., and Benita M. Beamon. 2000. "A multi-objective approach to simultaneous strategic and operational planning in supply chain design." *Omega* 28 (5):581-598. doi: http://doi.org/10.1016/S0305-0483(99)00080-8.

Sarimveis, Haralambos, Panagiotis Patrinos, Chris D. Tarantilis, and Chris T. Kiranoudis. 2008. "Dynamic modeling and control of supply chain systems: A review." *Computers & Operations Research* 35 (11):3530-3561. doi: https://doi.org/10.1016/j.cor.2007.01.017.

Schneider, J. J., and S. Kirkpatrick. 2006. *Stochastic Optimization*: Springer.

Tavana, Madjid, Kaveh Khalili-Damghani, Francisco J. Santos-Arteaga, and Mohammad-Hossein Zandi. 2017. "Drone shipping versus truck delivery in a cross-docking system with multiple fleets and products." *Expert Systems with Applications* 72:93-107. doi: http://doi.org/10.1016/j.eswa.2016.12.014.

Turney, PBB. 2008. Activity-Based Costing An Emerging Foundation for Performance Management, Cost Technology. Inc.

Van Belle, Jan, Paul Valckenaers, and Dirk Cattrysse. 2012. "Cross-docking: State of the art." *Omega* 40 (6):827-846. doi: http://doi.org/10.1016/j.omega.2012.01.005.

Zhang, G., J. Lu, and Y. Gao. 2015. "Optimization Models." In *Multi-Level Decision Making Models, Methods and Applications* 25-46. Springer.

ANNEX A: Supply Chain Planning Matrix

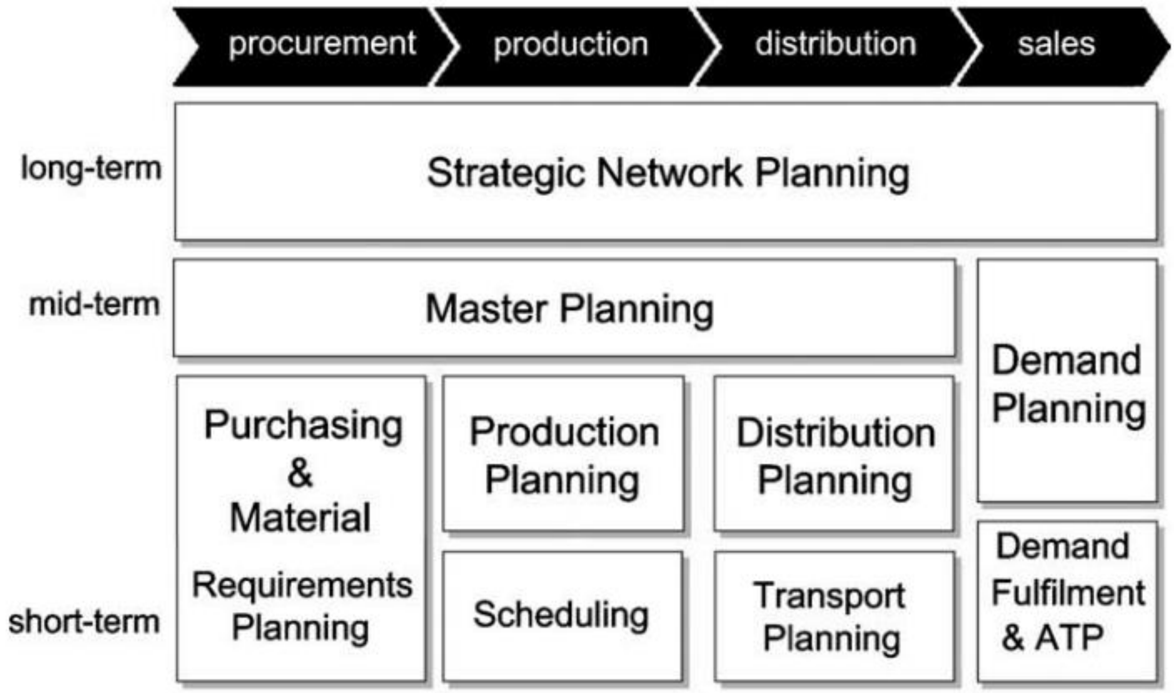

Figure 12 - Supply chain planning matrix (Meyr, Wagner, and Rohde 2002)

ANNEX B: Overall Shipments' Destination

The sales to fulfil are scattered all around the world, meaning that HUUB needs to have competitive distribution services to distribute to the whole world. This competitiveness (costs, quickness and visibility over a shipment) is increasingly important especially among e-commerce sales. The dispersion of overall shipments can be observed on Figure 13.

Figure 13 - Destination of deliveries of HUUB

ANNEX C: Indices and Parameters of the model

Table 8 - Indices of the model

Indices	Description
i	Product
j,d	Warehouse
k	Drop
z,l	Day
t	Shipping method/via

Table 9 - Parameters of the model

Parameter	Description
I	Last Product
J	Last Warehouse
K	Last Drop
Z	Last day
T	Last Shipping method
M	Large number
TY_{jdkt}^{z}	Time of performing Y_{jdkt}^{z}
TR_{ija}^{z}	Time of performing R_{ija}^{z}
TI_{ij}^{z}	Time of performing I_{ij}^{z}
TO_{ij}^{z}	Time of performing O_{ij}^{z}
TX_{djkt}^{z}	Time of performing X_{djkt}^{z}
$TSplit_{ijdk}^{z}$	Time of performing $Split_{ijdk}^{z}$
$TShip_{ijdk}^{z}$	Time of performing $Ship_{ijdk}^{z}$
CY_{jdkt}^{z}	Cost of performing Y_{jdkt}^{z}
CR_{ija}^{z}	Cost of performing R_{ija}^{z}
CI_{ij}^{z}	Cost of performing I_{ij}^{z}
CO_{ij}^{z}	Cost of performing O_{ij}^{z}
CX_{djkt}^{z}	Cost of performing X_{djkt}^{z}
Q_{ik}	Amount of product *i* in sales order *k*
D_k	Day of delivery of drop *k*
W_j	Fixed Working capacity of warehouse *j*
Cap_j	Inventory capacity of warehouse *j*
A_{ija}^{z}	Supply of product *i* at warehouse *j* on day *z*
Inv_{ij}	Inventory of product *i* on warehouse *j*
$\mathrm{Work}_{\mathrm{j}}^{\mathrm{z}}$	Warehouse working cost
$Storage_j$	Storage cost of warehouse *j*
$\mathrm{Transport}_{\mathrm{jdkt}}^{\mathrm{z}}$	Transport cost from warehouse *j* to *d* for drop *k* on day *z via f*
δ_{jd}^{z}	Shipping lead time from warehouse *j* to *d* on day *z*
Δ_{jkt}^{z}	Shipping lead time from warehouse *j* in drop *k* on day *z* via *t*