Decision Making Solution for Dynamic Stock Allocation

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Abstract

The market is currently living a moment of intense competition together with an urgent need to ensure the environmental sustainability in the activities executed. For a company performing in the field of logistics within the fashion business, the value proposition must be focused upon the optimization of its supply chain. Particularly, HUUB works as an orchestrator of the supply chain of fashion brands, coordinating all of the tasks associated with it.

The scope of this project focuses upon the development of an algorithm to dynamically allocate stock throughout the fashion season to the different points of the supply chain. As the pattern of demand varies throughout a season, it is needed to find an optimal solution for each moment where it is possible to reduce costs but also maintain high standards of quality with the fulfillment of clients' orders. To help to solve this problem, it is proposed the implementation of a mixed-integer linear programming optimization model that will perform the planning of the operation, where the main objective function will be the minimization of overall costs. Furthermore, as the planning horizon is somehow extensive, more orders might be placed in the meanwhile, meaning that the model will not take them into account as it works solely with the data that is available in a given moment. To work around this issue, a complementary model was developed with the aim of predicting potential orders that may arise and treat them as input for the main model to be able to make decisions, while taking into consideration the possibility of more orders than those previously considered.

The main decisions taken in this model are related to the reception of orders in each warehouse of the network, the transshipments between warehouses, and the shipment of orders from a warehouse to an end-customer. There are several restrictions that increase the complexity of the problem, related to warehousing activities, the fulfillment of Service Level Agreements and related to the AS-IS situation in the company.

To test the performance of the algorithm, a cost structure based on Activity Based Costing model was developed and compared with the results obtained from past decisions. The main sections to divide the costs will be upon receptions, transshipments, shipments, warehouse and delays.

For the implementation of the model, Python was used as the main development resource, where the data was acquired through queries designed in SQL. The construction of the model was developed in Python with the support of several libraries, the computation of the model and the search for the optimal solution was performed by external solvers and the output generated by the creation of a JSON file. This file will then be inserted into a database to be later on consumed by the company's web platform.

Finally, an optimal solution was found in every scenario within the time frame provided, regardless of the amount of data involved in the computation. A sensitivity analysis was also conducted in order to better advice regarding future strategic decisions and their impact on the business and its sustainability.

Resumo

O mercado caracteriza-se neste dado momento como um ambiente de intensa competição conjugado com uma necessidade de garantir a sustentabilidade ambiental nas atividades desenvolvidas. Para uma empresa a atuar na área da logística com um foco em empresas de moda, a proposta de valor tem de estar focada na garantia da máxima otimização da cadeia de abastecimento. Numa análise mais profunda, a HUUB funciona como um orquestrador das cadeias de abastecimento de marcas do mercado da moda, encarregando-se the coordenar todas as tarefas que daí derivam.

O âmbito deste projeto foca-se numa alocação dinâmica de *stock*, ao longo de uma temporada a diferentes pontos da cadeia de abastecimento. Dado que a procura é variável ao longo de uma tempoerada, é necessário encontrar a solução ótima para cada momento onde é possível reduzir custos enquanto se mantêm altos padrões de qualidade na entrega de encomendas aos clientes. Para ajudar a resolver o problem, é proposta a implementação de um modelo de otimização de Programação Linear Inteira Mista que irá atuar sobre o planeamento das operações e onde o principal objetivo será a minimização dos custos totais. Ademais, como o horizonte temporal é relativamente extenso, poderão existir encomendas que sejam colocadas na base de dados durante o desenrolar desse mesmo horizonte, pelo que o modelo não os terá em consideração dado que computa apenas com os dados que estão disponíveis num dado momento. Para contornar tal problema, um modelo complementar foi desenvolvido com o propósito de prever potenciais encomendas que possam surgir e enviar para o modelo principal como *input* para que este possa tomar decisões tendo em consideração a potencialidade de mais encomendas do que aquelas inicialmente previstas.

As principais decisões que o modelo irá tomar estão relacionadas com a receção das encomendas em cada armazém da rede, envios de produtos entre armazéns, e envios de encomendas de um armazém para um cliente final. Há diversas restrições que aumentam a complexidade do problem, tais como todas as limitações intrínsecas às atividades dos armazéns, o cumprimento do *Service Level* e restrições relacionadas com a situação atual da empresa.

Para testar a *performance* do algoritmo, uma estrutura de custos baseada em *Activity Based Costing* foi desenvolvida e comparada com os resultados obtidos com decisões tomadas no passado. As secções de custo dividem-se em receções, *transshipments*, envios, armazém e atrasos.

Para a implementação do modelo, Python foi utilizado como o principal recurso ao seu desenvolvimento, onde os dados foram adquiridos através de *queries* desenvolvidas em SQL. A construção do modelo e o processamento de dados foram desenvolvidos com suporte de variadas bibliotecas de Python, a computação do modelo e a procura pela solução ótima foi executada por *solvers* externos e o resultado final foi gerado pela criação de um ficheiro JSON. Posteriormente, este ficheiro é enviado para uma base de dados para ser posteriormente consumido por uma plataforma *web* da empresa.

Por fim, a solução ótima foi encontrada em todos os cenários, tendo em conta o tempo máximo considerado, sem ficar restringido pela quantidade de dados envolvidos na computação. Uma análise de sensibilidade foi também desenvolvida com o propósito de sustentar possível decisões estratégicas e o impacto que tais decisões terão no futuro da empresa e na sua sustentabilidade.

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"Strive for perfection in everything you do. Take the best that exists and make it better. When it does not exist, design it."

Sir Henry Royce

Contents

Acronyms and Symbols

ABC	Activity-Based Costing
API	Application Programming Interface
B2B	Business To Business
B2C	Business To Customer
BI & AI	Business Intelligence & Artificial Intelligence
DB	Database
IS	Information System
IT	Information Technology
LP	Linear Programming
KPI	Key Performance Indicator
MILP	Mixed Integer Linear Programming
PSO	Particle Swarm Optimization
SC	Supply Chain
SL	Service Level
SCM	Supply Chain Management
SKU	Stock Keeping Unit
SLA	Service Level Agreement
TMS	Transportation Management System
WMS	Warehouse Management System

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Chapter 1

Introduction

This dissertation, addressed the area of Supply Chain Management of a company specialized in the provision of logistical services to brands in the fashion industry, focuses mainly in the development of a decision-making solution for a dynamic allocation of stock to be employed while managing the supply chain of its clients.

Over the last few years, there has been an increasing number of logistics startup companies aiming to disrupt the *status quo* by implementing new technologies that provide a higher value to the clients than the one being offered by bigger players that currently control the market. Such technologies arise in the form of online platforms that handle problems with innovative solutions embedding Lean and Kaizen principles, providing such solutions in a quick and sustainable way.

Companies in the fashion industry often lack technical knowledge regarding supply chain, ending up creating opportunities for further improvements. For small and medium size brands, it is difficult to manage its SC, as they lack the means to handle it properly, are unable to have an accurate cost prediction model and do not have the necessary size to acquire market power. With this in mind and aiming to tackle and overcome such issues them that HUUB was founded.

1.1 Project Context

HUUB was founded in 2015 to revolutionize logistics in the fashion industry. The main objective is to handle the brands' entire supply chain as well as its management. Typically, HUUB's clients commercialize high quality products but have neither the technical nor the technological competences to either optimize the supply chain itself or develop a platform that allows them to manage and monitor it. This said, these brands outsource their supply chain to HUUB that will, from then on, be responsible in ensuring the fulfillment of all the logistical planning and flows.

Currently, HUUB provides its clients all the services regarding distribution and warehousing and offering technological features available through a platform entitled Spoke. The portfolio of such services integration of all stakeholders, planning deliveries of a brand, analytics, inventory management, among many others. These services will end up providing the brands with an overview of their entire SC without having to manage it.

HUUB's Mission is to place itself at the center of a dynamic ecosystem composed by brands, end-users, suppliers and alliance partners through a real end-to-end logistical service that can be adapted in a global arena, shaped by information, user experience, collaboration and productivity.

Such Mission is afterwards incorporated in long-term thinking, HUUB's Vision of building an orbit of brands through an envolving HUUB & Spoke structure.

HUUB is currently operating in Wholesale, usually denominated as B2B, as well as in e-commerce, also denominated as B2C. The stakeholders involved, as shown in Figure 1.1, are the brands, suppliers, carriers and customers. This linkage is sponsored by HUUB's product, Spoke, that is available to all the stakeholders.

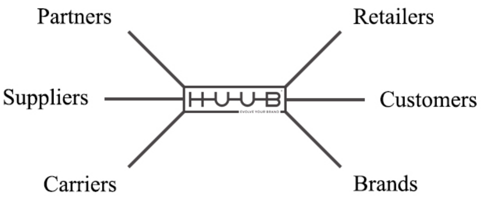

Figure 1.1: HUUB's Stakeholders

The revenues come from two distinct flows: HUUB defines a standardized price per item to guarantee the logistics and another price to be settled with each brand individually at the beginning of the season regarding the transportation of the products. Since any deviation from what is expected falls under the responsibility of HUUB, a need for an accurate system to predict potential sales and to allocate the corresponding products becomes crucial for HUUB's success.

HUUB holds a warehouse in Portugal and outsources another one in the Netherlands through a partnership with DAMCO, with a growing number of transactions executed per day. The planning required to handle each one of these transactions, as well as the expectations regarding further expansions, becomes more complicated and a crucial topic for the next steps of HUUB's strategy.

1.2 Project Overview

At the beginning of a season, HUUB receives from the brands an estimation of the number of products that aims to expedite and to which stores these are going to. However, there is still a certain amount of stock that is ordered to complement potential stock-outs in stores and provides enough flexibility to replenish them. Usually, all these orders are handled through the Wholesale channel. In a second perspective, after launching a new season, a brand can also offer its end-customers the possibility for clients to acquire items through an online platform, which usually consists of a shipment with a smaller amount of products to a specific customer and handled through the Webshop channel.

The scheduling of the transportation of the products made by HUUB still is a manual task that mainly takes into account the deadline as well as the Service Level previously agreed upon.

Although HUUB is responsible for the whole supply chain of its brands, the deadlines are still imposed by the brands themselves, being HUUB obliged to fulfill them.

Due to HUUB's constant growth, the warehouse maintained in Portugal was not enough to handle the complexity of all the SCs, provide competitive prices regarding transportation costs and, due to its limited capacity, be able to handle the entire demand. With this reasoning in mind, another warehouse in the Netherlands was settled in a partnership with DAMCO, allowing economies of scale both at transportation and storage as it becomes possible to ship aggregated products from different brands, either for storing or cross-docking.

This project comes now as a necessity to ensure sustainable growth, that together with the perspective of a higher volume being handled, strengthens the need for a reasoned decision regarding its allocation. The algorithm developed aims to minimize the total overall costs while condoning with the constraints present, such as capacity, Service Level Agreement, resources available, among others. Finally, in order to achieve this algorithm, all of the costs associated with both warehousing and distribution had to be analyzed, together with all the processes involved in these tasks.

1.3 Project Objectives

The main objective of the project was to develop an algorithm that supports a decision regarding the allocation of stock within the supply chain throughout a season. Since the complexity to implement the project is high, the main objective was then subdivided into milestones in order to achieve more measurable results and sustainable growth.

The first part of the project focused on analyzing HUUB through an internal perspective and understand its core processes as well as all the synergies currently established with the partners in order to have a full understanding of all the costs that somehow impact the final solution. Although previous iterations have already been made by HUUB, the capacity of splitting Stock Keeping Units through several warehouses, taking advantage of aggregating products or predict potential future scenarios have not yet been done.

The second part is related to the development of the algorithm itself. The goal is to minimize overall cost while dealing with several hard constraints such as the capacity of the warehouses, the flow of products going through a warehouse and the processes' precedences together with the penalty costs of failing SLAs or the necessity of recruiting extra workers.

Finally, the last part of the project, consisted on the integration of this algorithm with the entire Information System currently in place in HUUB. For that, it will be required to connect this Intelligent Module with Application Programming Interface of Spoke, the platform that gathers all stakeholders; Big Query, that will provide the data for the algorithm; and Supply Chain Planning tools that will receive the output generated by the algorithm and take the necessary decisions regarding the next steps.

1.4 Methodology

The Methodology of the project was quite straightforward when analyzing the objectives previously mentioned. The initial steps followed a top-down approach in order to have a general perspective of the business and the main variables involved in a global scale. Together with this reflection, it was taken into account how HUUB is planning to develop its business in the next upcoming years in order to be able to work in the same direction.

A deeper analysis was conducted in the relevant areas that will somehow influence the outcome of the project. To get a more in-depth understanding of the issue, several discussions were raised within the Supply Chain teams (upstream and downstream), Marketing & Sales, Product Managers and within the team where the project was developed - Business & Artificial Intelligence team.

After having an overview of the main tasks and responsibilities of each team, a careful literature review was conducted to become aware of the state-of-the-art and collect the best practices currently being done in the industry. Later on, with the knowledge of how practical implementations of theoretical content are being done in similar projects, a more specific study of all the costs and important variables was carried on executed to ensure more sustained future decisions.

To conclude, in order to guarantee the consistency of the output and its advantages, an algorithm was developed to have a basis to frame the improvements realistically.

1.5 Thesis Outline

This current chapter aims to emphasize the reasoning behind the creation of HUUB and what it aims to be. As a technological start-up, the need for innovation and strive for growth is constant, being this project a perfect example of this.

Afterwards, the dissertation is divided into five more chapters. The second chapter, "Literature Review", compiles all of the relevant information regarding the concepts addressed throughout the project, as well as an analysis of the state-of-the-art that provides input into the resolution of the problem. It is composed of academical content and practical implementations.

In Chapter 3, the structure of HUUB, its main processes and flows are thoroughly analyzed. It is also addressed in detail the characteristics associated with the problem. Lastly, the variables and their correlations are presented as well as the cost structure.

Chapter 4 starts by characterizing a first model that aims to complement the main optimization model, defines the parameters and costs, the objective function, the decision variables and constraints in which the algorithm will focus upon.

The application of the algorithm is illustrated in Chapter 5, "Implementation and Results", where multiple case studies will be considered, characterized by different peaks of a season together with a sensitivity analysis.

Chapter 6 focuses on the comparison of the results and its critical analysis. A reflection is made of the goals of the dissertation and a discussion is raised regarding future work that must be addressed afterwards in order to increase its impact in the future.

Chapter 2

Literature Review

This chapter provides a scientific overview of the state of the art present in the areas the project is focusing upon. After a first introduction to dynamic stock allocation and to both supply chain and its management, a deeper analysis is conducted regarding both the Warehousing and Distribution partitions of the SC, as these are the ones that will mainly influence the project as a whole. Afterwards, there is a review regarding the costs of a SC as well as the benefits and synergies from higher volume of products being linked together with a costing system to classify such products. As there is a certain degree of unpredictability associated with the amount of orders to expect, there is also a statistical background analysis in order to perform more sustained decisions in a future allocation. An introduction to optimization models is described, with a special focus on Mixed Integer Linear Programming Models as these will work as a basis for the development of the main algorithm of this dissertation. Finally a focus in meta-heuristics, namely Particle Swarm Optimization (PSO), and in a deeper level, Self-Learning PSO, is also conducted to consider as potential future work.

2.1 Introduction to Dynamic Stock Allocation

The current business environment has become widely unpredictable, making the Supply Chain Management a key issue in the success of a company (Gebennini et al., 2009). Certain questions arise such as the country where it is more profitable to centralize the activities, the transportation mode to better fulfill a certain Service Level Agreement with customers or the optimum storage capacity of each warehouse in the network.

To tackle all these questions, this dissertation aims to provide a decision-making solution to decide where to allocate each SKU based upon multiple variables such as the location of both the supplier and end-customer, the point of the season or the warehousing costs for each product.

This solution, composed of a multi-production, multi-warehouse and multi-period model, belongs to the NP-hard complexity class of decision problems, using a mixed integer linear programming solver to find solutions in complex industrial applications (Manzini and Gebennini, 2008).

2.2 Supply Chain & Supply Chain Management

Supply Chains have become more sophisticated over time mainly due to the globalization which results in many organizations experiencing market pressures that are forcing a fundamental rethinking of the way business is managed. Trade-offs between labor, transportation or inventory costs and response time to the customer are becoming increasingly complex (Wilding, 2006). This complexity is managed by a successful integration of all the organizations involved in upstream and downstream flows of products, services, finances and information.

The Supply Chain Management needs to be addressed as a systemic, strategic coordination of traditional business functions and tactics within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (Holcomb, 1992).

According to Ayers B. (2006), a supply chain encompasses the following activities: manufacturing, procurement, distribution, marketing & sales, product design, and information technology. Since the SC being analyzed works as an orchestrator for its clients, both product design and marketing & sales are not considered for this analysis since are handled by the clients.

2.2.1 Warehousing

Inventories exist throughout the SC in various forms and to serve multiple purposes. They exist at the distribution warehouses and they exist in-transit, or "in the pipeline", on each path linking these facilities (Ganeshan, 1999).

In an environment that is controlled at a certain level by uncertainty, it is crucial that an efficient warehousing system is run in order to ensure the stability of the flow of products as well as maintaining the costs low.

According to Billington and Lee (1992), uncertainties such as supplier lead time, delivery performance, quality of products, transit time and demand need to be accounted for *a priori*.

Since a supply chain consists of several levels of echelons, and while accounting with a push philosophy, there needs to be a central decision-maker, who possesses continuously or periodically updated information about all inventories of all products at all the facilities (Federgruen, 1993).

Warehousing Activities

Goods are delivered by trucks, which are unloaded at the receiving docks. Here quantities are verified and quality checks are performed. Subsequently, the loads are prepared for transportation to the storage area. A label is attached to the load and transported to a location in the storage area.

Whenever a product is requested, it must be retrieved from storage. The process is called *order picking*. An order lists the products and quantities requested by a customer. When an order contains multiple SKUs, these must be accumulated and sorted before being transported to the shipping area (Berg and Zijm, 1999).

As an overall, warehousing comprises six major throughput activities that must be done in the order represented in Figure 2.1:

1. Receiving;
2. Transfer;
3. Handling;
4. Storage;
5. Packing;
6. Expediting.

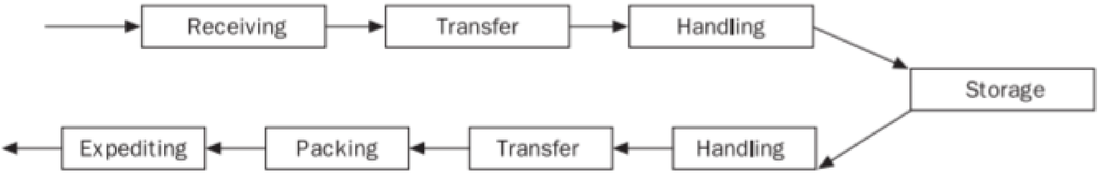

Figure 2.1: Warehouse Activities

2.2.2 Distribution

One of the most critical decisions in a supply chain is the transportation function of the goods, as it correlates with almost every other function within the SC. Vidal and Goetschalckx (1997) consider that different types of decisions need to be taken into consideration such as strategical, tactical and operational ones. This can be represented by choosing the transportation mode, determining the volume size or the number of vehicles, respectively. The difficulty increases due to the complex design of the supply chain as well as the internationalization of clients (Mattsson, 2006).

Regarding this topic, different concepts need to be brought up in order to have a full scope of all the variables involved and their dependency, such as:

Transshipments

Physical pooling of inventories has been widely used in practice to reduce costs and improve customer service. The practice of transshipment, the monitored movement of material between locations at the same echelon (e.g. among warehouses), may entail the sharing of stock through enhanced visibility. According to Taylor et al. (2006), a supply chain, composed by several suppliers, warehouses and retailers, that differ in terms of costs and demand parameters, may be coordinated through replenishment strategies and transshipments, that is, movement of a product among the locations at the same echelon level.

Cross-Docking

Cross-docking is a logistics strategy where each freight is unloaded from inbound vehicles and (almost) directly loaded into outbound vehicles, with no storage in between (Belle et al., 2012).

Considering that a part of the company's costs originates from warehousing costs, namely storage costs, even more when considering outsourced warehouses, the activity of cross-docking, according to Apte and Viswanathan (2010) brings substantial reductions in the transportation cost without increasing the inventories while simultaneously maintaining the level of customer service. Cross-docking can also lead to the reduction of order cycle time, thereby improving the flexibility and responsiveness of the distribution network.

Stock-Transfer

A stock transfer aims to shift the same SKU between warehouses according to the stochastic demand of each. This can be mainly done when the demand is high when in comparison with the storage capacity available (T. W. et al., 1997). From another perspective, it also allows to store the excess inventory in a further warehouse with lower costs and aggregate with other types of stock, and transfer it in bulk rather than in small quantities (Hill, 2006).

Bulk-Shipment

In an environment strongly influenced by uncertain demand, supply and transportation lead times (Acar et al., 2009), it is crucial to find synergies to merge the different types of products that have similar decision variables. This said, the bulk shipment aims to aggregate a large number of goods with the goal of reducing the overall costs (Bilgen and Ozkarahan, 2007).

Last-Mile Delivery

Within the several distribution costs, the last-mile delivery in a B2C environment is the most expensive one, the least efficient and most polluting section of the entire logistics chain (Gevaers et al., 2014). Although the effects are not felt that significantly in a B2B environment, the need to deal with the issue remains. The complexity of the problem is in the difficulty of combining profitability and high service level (Punakivi et al., 2007). It becomes critical to take advantage of movements such as cross-docking or stock transfers as an attempt to decrease this section.

2.2.3 Management System

A management system is a set of processes, interactions and procedures used in a company to fulfill all the tasks. In a supply chain, several of these systems must be connected as they depend on each other for its success.

Warehouse Management System

A Warehouse Management System (WMS) is responsible mainly for the daily activities of a warehouse. The scope is restricted to operational decisions such as route definition, resource allocation or inventory control for example. A WMS is an integrated management system of warehouses, that optimizes all the activities and information flows within the storage process. By integrating different functions such as receiving, stocking, loading, among many others, it ensures the logistical needs of the firm as it maximizes the resources.

Transportation Management System

A Transportation Management System (TMS) is a subset of the supply chain and it usually involves a scenario with procurement and shipping orders and offers various suggested routing solutions. In general, a TMS belongs between an Enterprise Resource Planning (ERP) and a warehouse module. A successful supply chain needs to have a WMS and TMS working together to reduce the overall costs, lead times and increase reliability (Mason et al., 2003). For this to happen, there needs to be a process analysis regarding inventory levels, production schedules, demand and available resources.

2.3 Costs

In a supply chain environment, a major cost element in the logistics of distributed warehousing is the transportation cost. In most practical systems, the transportation costs are volume-dependent. The unit transportation costs is usually determined differentially among intervals of shipment volumes. While the unit cost is constant over an interval, it follows a step-wise declining pattern from an interval to the next higher interval of shipment volumes. This structure is analogous to that of quantity discounted inventory systems (Vroblefski et al., 2000).

In the same line of thought as the transportation cost, in a SC, the warehousing costs also need to be handled carefully as it can have major impacts on the overall costs. For this, the company needs to focus on characteristics such as inventory turnover rate, available space and shipping routes (Krittanathip et al., 2013). The trade-off of the Economic Order Quantity (EOQ) between ordering and storage costs while choosing the quantity to use in replenishing item inventories also needs to be taken into consideration.

Marginal Costs

Marginal Cost is an estimate of how the economic cost would change if output changed. The main focus is the per unit change that will occur based on the change of future output (Turvey, 2000). As the price settled is previously agreed upon, the aggregation of different goods in the same shipment will contribute to a decrease in the marginal costs based rates (Joskow, 2014). The marginalization of these costs makes it crucial when defining the decision variables in order to maximize the synergies that derive from this.

Economies of Scale

Working as an orchestrator is especially advantageous when it allows for the merge of different goods as one. The theory of economies of scale is the theory of the relationship between the scale of use of a properly chosen combination of all productive services and the rate of output of the enterprise. HUUB achieves this by combining the products from all of its brands, being therefore able to offer smaller distribution prices that each individual fashion brand wouldn't be able to achieve on its own.

Activity-Based Costing

Companies need to effectively measure costs involved throughout the supply chain to identify room for improvement and thus to reduce costs. Therefore, costing control is a valuable input to decision making regarding cost effectiveness. Activity-based costing (ABC) has helped many companies identifying important cost-and-profit enhancement opportunities through process improvements on the shop floor, lower-cost product designs and rationalized product variety (Kaplan and Anderson, 2019). This technique aggregates different tasks, events or units of work that cause resource consumption in activities and then accumulate these costs in activity cost centers.

2.4 Sustainability in Fashion

The awareness of the urgent need for sustainability in everyday life has recently become one of the most important topics to address.

Sui and Rejeski (2003) predict that the energy spent fulfilling e-commerce orders in the United States in one year is enough to run the entire British economy for six months, with the business-to-consumer transactions representing approximately 20%, where the remaining 80% are in business-to-business e-commerce. The pattern is followed by the fashion industry in a similar way, representing high expenditures and consequently bringing higher awareness for the population.

In order to decrease the environmental impact that commerce is inducing in the world, the first and main linkage is to develop a sustainable supply chain (Shen, 2014). For the SC, different variables need to be taken into account, such as the carbon emissions or environmental concerns from each carrier, a stock distribution based on the human well-being of the country, or even ensuring the "Triple Bottom Line" when closing an agreement, which consists of making a decision based on the social, environmental and economical performance aspects (Elkington, 2004).

The fast-fashion model driven by drastically reducing the turnaround time, working with smaller batches and rapid prototyping, together with the reduction of manufacturing and labor costs, would end up with lower prices and consequently higher volume, is proving to be unbearable and causing a too drastic impact that is no longer sustainable (Joy et al., 2015).

Therefore, in order for a supply chain to be more environmental friendly, different drivers should be considered. The internal drivers focus mainly in the commitment of the company to reach sustainable objectives, the focus on strategic leverage rather than cost reduction and an increase in the efficiency of the supply chain management (Caniato et al., 2012). The environmental sustainability performance can be traced by the type of materials used, the emissions and waste produced, energy spent and the business integration with environmental certifications.

These principles must be integrated in the mindset of a company and it must be accounted responsible for the decisions it makes and its contribution to the environment.

2.5 Optimization Models

Optimization is currently present in every daily activity, where the goal is usually the maximization of profit or quality and the minimization of costs (Yang, 2014).

$$\begin{gathered}\text{minimize} f_i(x), \quad (i = 1,2,...,M),\\ \text{subject to } h_j(x) = 0, \quad (j = 1,2,...,J),\\ g_k(x), \leq 0 \quad (k = 1,2,...,K),\end{gathered}$$

where $f_i(\mathbf{x})$, $h_j(\mathbf{x})$ and $g_k(\mathbf{x})$ are functions of the design vector.

$$\mathbf{x} = (x_1, x_2, ..., x_n)^T$$

Here the components x_i of $\mathbf{x}$ are decision variables and can be either continuous, discrete or both.

The functions $f_i(x)$ where i = 1 , 2, ... , M are called the objective function. Space spanned by the decision variables is called the design space or search space $\mathbf{R}^n$, while the space formed by the objective function values is called the solution space. The equalities for h_j and inequalities g_k are called constraints.

In the recent past, there has been a growing attempt in using such mathematical models from engineering and economics in interpreting the diversity of life (Smith, 1978). The main goal is to interpret the complex structures and behaviors in evolution and their contribution to the survival and reproduction of their possessors.

2.6 Mixed-Integer Linear Programming Model (MILP)

Many real-life problems contain a mixture of discrete decisions and continuous phenomena. According to Margot (2010), to solve complex problems it is needed to tackle it from two sides, the primal and the dual. On the primal side, we aim at finding feasible solutions quickly by using meta-heuristics. These methods have demonstrated their ability to find solutions in a short time. However, in principle, it is not possible to guarantee their optimality. If a feasible solution is returned by such heuristic we denote its objective function value by z^{primal}. The dual side deals with relaxations to be able to solve something efficiently. Relaxation means that some parts of the problem are dropped, typically those that prevent us from solving the problem to optimality in the first place. Thereafter the relaxed parts are iteratively re-introduced into the problem formulation, in such a way that it remains solvable.

$$z^{MILP} = \min \quad c^T x \ ,$$

$$\text{subject to} \quad Ax \leq b \ ,$$

$$x \in \mathbb{R}^n \ ,$$

The problem can now be solved efficiently with any linear programming algorithm, as mentioned by Dantzig (1947). By the nature of Dantzig's simplex algorithm, it returns a basic solution, i.e., a solution in a "corner" of the polyhedron, that is, an extremal point of the convex hull H. Since all feasible solutions of (1) are also feasible solutions for (2), we have that $z^{dual} \leq z^{MILP}$. Hence the solution value of the LP relaxation is a lower bound that can easily be obtained on the optimal solution of the MILP, which is difficult to obtain. When also a primal solution is available, one can define the optimality gap as follows:

$$Gap = \frac{z^{primal} - z^{dual}}{z^{dual}}$$

In order to improve the dual bound one has to re-introduce the integrality condition back into the formulation. This can be done either by cutting planes (Kelley, 1960) or by re-introducing the relaxed integrality constraints of the variables it is branching (Achterberg et al., 2005).

2.7 Statistical Analysis

2.7.1 Coefficient of Determination

According to Reisinger (1997), the linear regression model is the procedure for analyzing dependencies between variables measured on a metric scale. In the course of model estimation, it is common practice to assess the appropriateness of a single descriptive model for the problem under study with the help of the coefficient of determination, R^2.

As explained by Abdi (2007), in empirical studies, R-Squared (R^2) is a statistic that explains the amount of variance accounted for in the relation between two (or more) variables. Given paired variables (X_i, Y_i), a linear model that explains the relationship between the variables is given by:

$$Y = \beta_0 + \beta_1 X + e, \qquad \text{where } e \text{ is a mean zero error}$$

The parameters of the linear model can be estimated using the least squares method and denoted by $\hat{\beta}_0$ and $\hat{\beta}_1$. The parameters are estimated by minimizing the sum of squared residuals between variable Y_i and the model $\beta_0 + \beta_1 X_i$, that is, ($\hat{\beta}_0$, $\hat{\beta}_1$) = argmin $(Y_i - \beta_0 + \beta_1 X_i)^2$.

$$\hat{\beta}_0 = \bar{Y} - \bar{X}\frac{S_{xy}}{S_{xx}} \text{ and } \hat{\beta}_1 = \frac{S_{xy}}{S_{xx}}, \qquad \text{where } S_{xy} = \frac{1}{n}\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y}) = \overline{XY} - \bar{X}\bar{Y}$$

The estimated denoted model is denoted as: $\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X$

With the above notations, the sum of squared errors (SSE), or the sum of squared residuals, and the total sum of squares (SST), or total variation in the Y variable are given by

$$SSE = \sum_{i=1}^{n}(Y_i - \hat{\beta}_i)^2 \text{ and } SST = \sum_{i=1}^{n}(Y_i - \bar{Y})^2$$

Finally, the coefficient of determination (R^2) is defined as the following ratio: $R^2 = \dfrac{SST - SSE}{SSE}$

2.7.2 Poisson's Distribution

The Poisson distribution is a probability distribution of a discrete random variable that stands for the number of statistically independent events, occurring within a unit of time or space (Letkowski, 2014). Given the expected value, μ, of the Poisson variable, X, the probability function is:

$$f(n) = P(X = n) = \frac{e^{-\mu}\mu^n}{n!}, \qquad F(n) = \sum_{k=0}^{k=n} f(k), \quad n = 0, 1, 2, \ldots$$

As the Poisson random variable can be "stretched" over longer or shorter time intervals, therefore μ is the expected number of events per one unit of time or space, μt will be such a number per t units. One has to make sure that process N(t) is stationary within time interval (0,T):

$$f(t,n) = PN(t) = n = \frac{e^{-\mu t}(t\mu)^n}{n!}, \qquad F(t,n) = PN(t) \leq n = \sum_{k=0}^{k=n} f(t,k), \quad n = 0, 1, 2, \ldots$$

2.8 Meta-heuristics

Meta-heuristics are generic strategies that define algorithmic frameworks for designing a set of techniques able to efficiently and accurately find approximate solutions for search, optimization, and machine learning problems (Glover, 1986). This way, meta-heuristics are not specifically focused on solving any kind of problem, but they propose simple ideas with high applicability to a wide number of problems. These simple procedures are usually based on emulating natural or physical phenomena, such as the behavior of flocks of birds and insects, cooling procedures in metals or natural evolution (Nesmachnow, 2014).

2.8.1 Particle Swarm Optimization

The theory of Particle Swarm Optimization has roots in two main component methodologies. Perhaps more obvious are its ties to artificial life and swarming theory (Kennedy and Eberhart, 1995).

According to Zeugmann (2011), the particle swarm is a population-based stochastic algorithm for optimization which is based on social-psychological principles. The swarm does not use selection; all members survive from the beginning of a trial until the end. Their interactions result in iterative improvement of the quality of problem solutions over time.

The intent is to graphically simulate the graceful but unpredictable choreography of a bird flock. PSO is similar to a Genetic Algorithm in that the system is initialized with a population of random solutions. Each potential solution is also assigned a randomized velocity, and the potential solutions, called *particles*, are then "flown" through space.

Each particle keeps track of its coordinates in the problem space which is associated with the best solution it has achieved so far (Eberhart and Shi, 2001).

The equations to characterize the velocity and position of each particle are:

$$V_i^{d+1} \leftarrow w * V_i^d + c_1 * rand_i^d * \left(pbest_i^d - X_i^d\right) + c_2 * rand_i^d * \left(gbest^d - X_i^d\right)$$

$$X_i^{d+1} \leftarrow x_i^d + V_i^d$$

where V_i^d and X_i^d correspond to the particle's velocity and position, respectively. The velocity of the particle is guiding it partially towards its local best position (*pbest*) and partially towards its global best position (*gbest*); $w \in (0,1)$ is the inertia weight that decides velocity preservation criterion from the previous iteration; $rand_i^d$ is a random number generated uniformly from the interval [0,1]; and c_1 and c_2 are two acceleration coefficients.

2.8.2 Self-Learning Particle Swarm Optimization

Although the original PSO has a very good convergence ability, it also suffers the demerit of premature convergence, due to the loss of diversity, having the risk of shrinking to a local optima (Zhao et al., 2009). Furthermore, the updating of the velocity V_i^d is heavily dependent on previous experiences, i.e., *pbest* and *gbest*.

Self Learning Particle Swarm Optimization is based on swarm intelligence that finds the near optimal solution to the problem. Wang et al. (2011) proposed four operators to update the velocity and position vectors. The operators correspond to the four learning equations, as:

$$v_p^{upd} = w * v_p + \eta * r_p * (pbest - x_p) \tag{2.1}$$

$$x_p^{upd} = x_p + v_{avg} * N(0,1) \tag{2.2}$$

$$v_p^{upd} = w * v_p + \eta * r_p * (pbest_{rand} - x_p) \tag{2.3}$$

$$v_p^{upd} = w * v_p + \eta * r_p * (abest - x_p) \tag{2.4}$$

where p represents the pth particle; x_p^{upd} and x_p represent the current and the previous position vectors of the particle p, respectively; v_p^{upd} and v_p are the velocity vectors of the current and the previous iterations; η is the acceleration coefficient; r_p is a random number generated uniformly from the interval [0, 1]; $pbest_{rand}$ is the $pbest$ of a random particle that is better than to $pbest_p$; *abest* is the archived position of the global best (*gbest*) particle so far; N(0, 1) generates a random number from the standard normal distribution with mean 0 and variance 1; and $v_{avg} = \sum_{p=1}^{N} \frac{|v_p|}{N}$ is the average speed of all particles, where N is the population size.

Operator 2.1 exploits the local optimum solution; Operator 2.2 has a mutation operator used to escape the local optima; Operator 2.3 enables a particle to explore the non-searched areas with high probability; and Operator 2.4 enables particles to converge to the current global best position.

According to Manatkar et al. (2016), initially, all four operators are given the same percentage in a roulette wheel. As the algorithm progresses, the probabilities of selecting each operator will be updated, aiming to satisfy what the algorithm is in need at the moment.

2.9 Critical Analysis

The expected increase in volume transacted in HUUB's operations and the beginning of the partnership with DAMCO, demands optimization of routes, transshipments and allocation of stock.

This said, the analysis of the Warehousing and Distribution activities are crucial to the successful development of an optimization model as well as the ABC system used to classify these same activities. Furthermore, HUUB needs to take into consideration the environmental impact that is creating and be accountable for it based on the decisions it decides to make.

The optimization model was based on mixed integer linear programming that must be run every day and planning for the upcoming three weeks, deciding what storage to maintain in each warehouse, the transshipments to be made between warehouses and where to ship an order from. The model is mainly deterministic with only a small part being considered as stochastic, which is based on statistical analysis to provide accurate results.

As it is expected that an optimization model might become too complex to find an optimal solution in the future, other perspectives are also analyzed such as meta-heuristics, namely PSO, to provide a near-optimal solution in a shorter period of time.

Chapter 3

Problem Context & Description

The current chapter is divided into two main sections. The first part aims to provide a detailed context for the project, by a detailed description of the company's core business, structure and main operations; the second part is related to the HUUB's current situation, the activities taken by each team and the need for the work done in this dissertation.

The project was developed in an industrial environment, the start-up HUUB, whose operations deal with different stakeholders that impact its several teams and inbounds, outbounds and flows within the storage management of the warehouses.

After the introduction to HUUB's business model and its value proposition, a deeper analysis of its internal and external structure is conducted and the different sales channels where HUUB is operating in and the current international expansion plans are presented. Furthermore, an analysis of the operations of the company AS-IS is made as well as the expected TO-BE after this project.

3.1 HUUB's Value Proposition

Supply Chain is the backbone of international commerce. However, it is not designed to support the ongoing digital transformation of fashion brands, as they are not collaborative, too complex and provide with reduced visibility.

HUUB was born with the goal of reshaping the supply chain, by creating an integrated logistics platform for fashion brands. As it can be seen in Figure 3.1, the scope in value proposition goes from the suppliers to the end-customers (B2B or B2C), managing the physical and data flows, orchestrating different subcontracted partners.

HUUB's strategy focused upon the development of one platform that is able to manage the entire supply chain, a network of warehouses that increase the flexibility of the company, an end-to-end visibility to the fashion brands, allowing them to (i) have a full tracking feature over their products, (ii) amplify each brand's market and reach broader audiences, (iii) establish a price per item transacted, (iv) allowing the clients to have a better overview of their cost structure.

Furthermore, as a technological start-up, HUUB also optimizes its network through the development of Artificial Intelligence algorithms that have the ultimate goal of optimized planning and greater customer satisfaction.

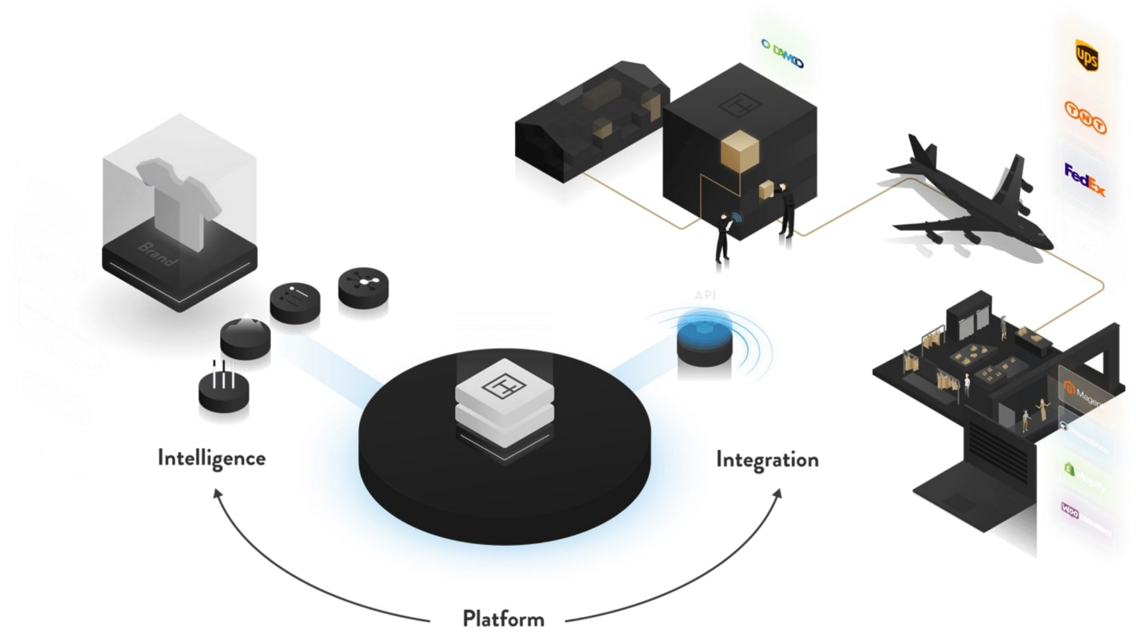

Figure 3.1: HUUB's Integrated Vision

3.2 Internal Structure

The company, although still a start-up, works in a conventional way, currently having 7 different teams: Account Management, Business Intelligence & Artificial Intelligence, Information & Technology, Marketing & Sales, Financial & HR, Operations and Supply Chain Solutions.

Account Management

This team is responsible to establish a link between HUUB and its brands. Since part of HUUB's value is built upon leveraging Software as a Service, after a first onboarding process, part of this team's responsibilities relies in ensuring the brands that are joining HUUB know how to use Spoke, the all-in-one supply chain management platform developed by HUUB with the purpose of allowing brands to have a full overview of their supply chain. After this first process is concluded, it will be their responsibility throughout time to advise the brands on how to proceed in the future, that is, how to use HUUB's potentialities to their best advantage and provide business insights regarding future strategical decisions of the brand. Since a fixed fee per item is charged to the brands, it is in the best interest of HUUB to help the brands to grow and increase the number of products commercialized as that will indirectly contribute to HUUB's growth as well.

Business Intelligence & Artificial Intelligence (BI & AI)

This team is mainly focused on gathering all the data that is generated from all the internal functions as well as every *order* that is managed throughout HUUB's system. From this collection, the data is later analyzed and business insights collected from it. Furthermore, this team is also responsible for the development of several algorithms, such as optimization or machine learning models, that aim to enhance different functions of the company. All of the responsibilities of this team can, therefore, be grouped into the descriptive, predictive and prescriptive analysis.

Information & Technology (IT)

The main responsibility is the maintenance and development of HUUB's product, Spoke, as well as every other system that is crucial for the maintenance of the business such as Warehouse Management System (WMS), Inventory Management System (IMS), Operations Management System (OMS) and Distribution Management System (DMS). Spoke is more concretely a web-based platform that is the HUUB's backbone and aims to connect every stakeholder of the company. It is crucial to maintain and improve it as it is a significant part of HUUB's value proposition to the brands.

Marketing & Sales

It is mainly responsible for the acquisition of new brands and establishing relationships with clients, sharing the company's services with every potential stakeholder and promote to other clients. At the moment, the most chosen method is to share it in fairs which is simultaneously more effective as it is also more expensive.

Financial & HR

The financial team is responsible to keep track of all the company's finances and ensure all of the transactions follow certain procedures. Again, as part of the company's strategy, it is also their responsibility to establish key performance indicators to have better insights regarding expected costs for the future.

Operations

This team is responsible for all the warehousing activities (such as receptions of items to stock, picking items to ship, among many others). These activities only take place in the warehouse in Portugal, as the one in the Netherlands is outsourced. For the latter case, the amount of volume is communicated beforehand and the warehouse will allocate the necessary resources to handle that operation, making this another reason for the importance of the development of this thesis project. Following HUUB's mindset, this team also follows a continuous improvement methodology with the aim of increasing its efficiency, keeping regular track of its performance indicators.

Supply Chain Solutions

Last but not least, in a company that provides value by being an orchestrator of its clients' supply chain, this department is crucial to ensure a correct flow of processes and contact all the responsible parties that directly or indirectly affect its performance. The team is divided into the downstream team that contacts all the carriers and customers to define delivery dates and quantities and the upstream team that contacts all the suppliers regarding the transportation and its destination. Finally, there is also a general Supply Chain team that coordinates the agreements between HUUB and the brands and works in the development of the network while guaranteeing the fulfillment of SLAs or allocating stock to different warehouses of the network.

3.3 External Partners

As a company that mainly works as an orchestrator between several parties, the relationships established with each one of these is crucial for the company's successful development and growth. It is therefore required that a contextualization related to the main stakeholders is held to further explain their impact and importance in the SC. The main stakeholders are Brands, Suppliers, Carriers and End-Customers and its flow is represented in Figure 3.2.

Brands

These are HUUB's main target group and the ones that provide revenues to the company. The majority of transactions happen between customers and brands where customers acquire a certain quantity of products from the brands, having the products' delivery managed by HUUB. All of this transactions will be transformed into a high volume of data, such as Purchase or Sales Orders, Stock Availability per SKU and Distribution through all the Sales Channels that can be later on analyzed and valuable input provided for these stakeholders such as the expected demand and the process on how to handle it more efficiently.

Suppliers

Their main responsibility is to guarantee the requests of their brands and produce the required amount of each product to be delivered in a specific date. After the production, there is an agreement with HUUB regarding the collection procedure and the transportation mode to the warehouse. At the moment, the contact is mainly handled manually and the dates agreed upon between HUUB and each supplier. Although the complexity of this process is not high, the fulfillment of the agreement is crucial as all the following steps of the SC will depend upon this one step.

Carriers

This stakeholder is responsible for ensuring the transportation of the shipment process. As the most expensive cost of the supply chain relies on the last-mile delivery, guaranteeing the cheaper possible option is crucial to reduce costs for our customers and brands. The work developed in this dissertation will, therefore, emphasize on this topic as a crucial point that needs to be optimized. The flow, in this case, besides naturally a physical one, also carries an informational one that will provide certain data regarding the transportation itself, such as the invoices, billings, among many others.

End-Customers

Although they are not aware of any of the aforementioned processes, expecting to receive their orders on a certain date, a failure in any of these processes will be denoted by the customers which might result in a complaint. In this field, the fulfillment of the Service Level Agreements takes special importance as the satisfaction of the clients is part of the value proposition offered by HUUB. The end-customers are represented can either be stores or individual customers.

Figure 3.2: Stakeholders functions and flow of activities

3.4 Sales Channels

HUUB is currently mainly working with two types of Sales Channels. The one that represents the major part of volume transported is wholesale, where the company is responsible to supply the end-customers, either own-stores or brand branches, with the collection for the upcoming season. A higher number of items in each transaction decreases transportation cost per item, as the cost of the shipment will be distributed by a higher number of pieces. Usually, as the stores do not have the possibility to store an entire collection in its own storage facility, an order is decomposed into *drops* that correspond to a part of the initial order and will be solicited throughout the whole season. These *drops* usually follow a pattern where the first delivery is sent before the beginning of the season to prepare for the launch of the collection, a second delivery happens after the launch of the season to refill the stock and a third delivery happens closer to the end of the season to the sell the remaining stock. Nevertheless, when sales do not go as planned if for example, these sales are higher than expected, the clients can also order new items from the brands, which will involve more *drops* throughout the season.

The second channel is e-commerce; this is usually launched after the beginning of the season and is associated with the brand's website and the end-customers are usually individual customers interested in acquiring a certain item. In this case, the transportation cost will be higher as the volume is naturally lower. The e-commerce is launched after the beginning of the season to be able to provide the initial hype to the stores and only then allow the purchases to be made online. Usually, at the end of the season, if there is still stock remaining sent by the brand to the warehouse, it can be only be sold by e-commerce as part of leftover stock as it is no longer part of the season being currently commercialized at stores.

Furthermore, as the wholesale orders are agreed upon before the beginning of the season between the brand and the end-customer, HUUB will already be aware beforehand what amount of volume to expect, the deadlines and the locations of the shipments. This is an opportunity that will require a higher level of planning and since the time frame available to deliver these *orders* will be higher and easier to find at the lowest cost possible. Such situation does not occur with e-commerce, where the brand will send to the warehouse an estimate of sales through this channel to be sold throughout the season. Such estimates are often inaccurate and without an expected flow during the season, making the planning process more complicated to deal with. When these orders occur, both the lead time and HUUB's margin are considerably lower, meaning the prediction of sales a crucial topic for the reduction of overall costs.

3.5 International Expansion

As part of every supply chain, timing is a key factor that needs to be handled in a way not to compromise the smooth flow of all the processes throughout the whole chain and, at the same time, ensure the flexibility and speed to remain competitive. HUUB is no exception in this field, and the fulfillment of orders' deadlines constitutes one of the main restrictions to overcome. As all processes are linked together in the SC, a mistake or failure in a small section may compromise the entire flow.

At the moment, there are two different warehouses in HUUB's network. The original one, located in Porto, Portugal, and one outsourced from DAMCO, located in Eindhoven, Netherlands.

From Porto's warehouse, the SLAs from the warehouse are standard for all the receptions from suppliers and shipments to customers, with a lead time of three days for inbounds and a lead time of one day for outbounds. The SLA for the transit time will differ based on the country where the items are being shipped to and combined with the service level chosen by the customer.

The partnership established with DAMCO has strong reasoning in the timing factor, as it is expected the transit time from this warehouse to the end-customers be considerably lower than the one found in HUUB's warehouse, as the majority of the customers are international. Nevertheless, although the transit time is indeed shorter, the planning needs to be made earlier in order to allow the time needed for the items to be shipped from one warehouse to another. A package, when being transshipped between warehouses, has two different options - it can be cross-docked - where it is not stocked and has a transit time of three days to reach the warehouse and can be sent to the end-customer in the next day - or it can recur to a stock-transfer where the items have the same three days transit time with an increase of two extra days for inbound processes and will then be considered as part of the stock. As mentioned before, the downside of having items moved is the time it requires for the action to be completed. Therefore, if the time for the transshipment together with the time to reach the end-customer is higher than the one agreed upon, such action cannot happen. A more detailed analysis of the times associated with each task can be found in Figure 3.3. To conclude, the main objective with the transshipments is to find synergies between items not correlated but that can be grouped together in order to decrease the price per item of the fixed cost of shipping one pallet, finding this way potential economies of scale.

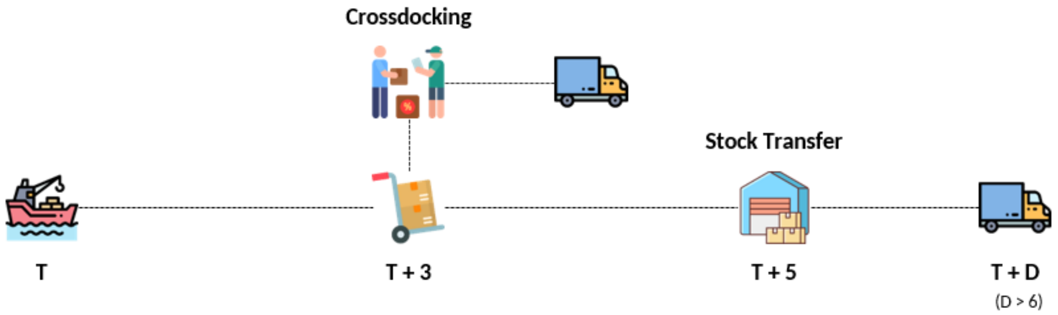

Figure 3.3: Transshipments processes and transit times

3.6 AS-IS Situation

Since HUUB's clients lie in the fashion industry companies, the organization of all the processes is structured according to the two seasons that happen in a year, Autumn/Winter and Spring/Summer, with an approximate duration of six months each.

The preparations, nevertheless, start long before the launch of the season, with the presence of the Marketing & Sales team in fairs to present HUUB's proposal next to the brands and acquire them for the portfolio of clients being managed. In case of a successful acquisition, the IT team will follow the process by including them in Spoke and register all the necessary information such as their details, different products, the upcoming purchase and sales orders, among others. The next step in the process is the allocation of an Account Manager to the brand that will be responsible for interacting directly with them, clarify any doubts or, later on, advise them on decisions for future collections based on the analytics collected, while the IT team facilitates the integration of the brand's information system with Spoke.

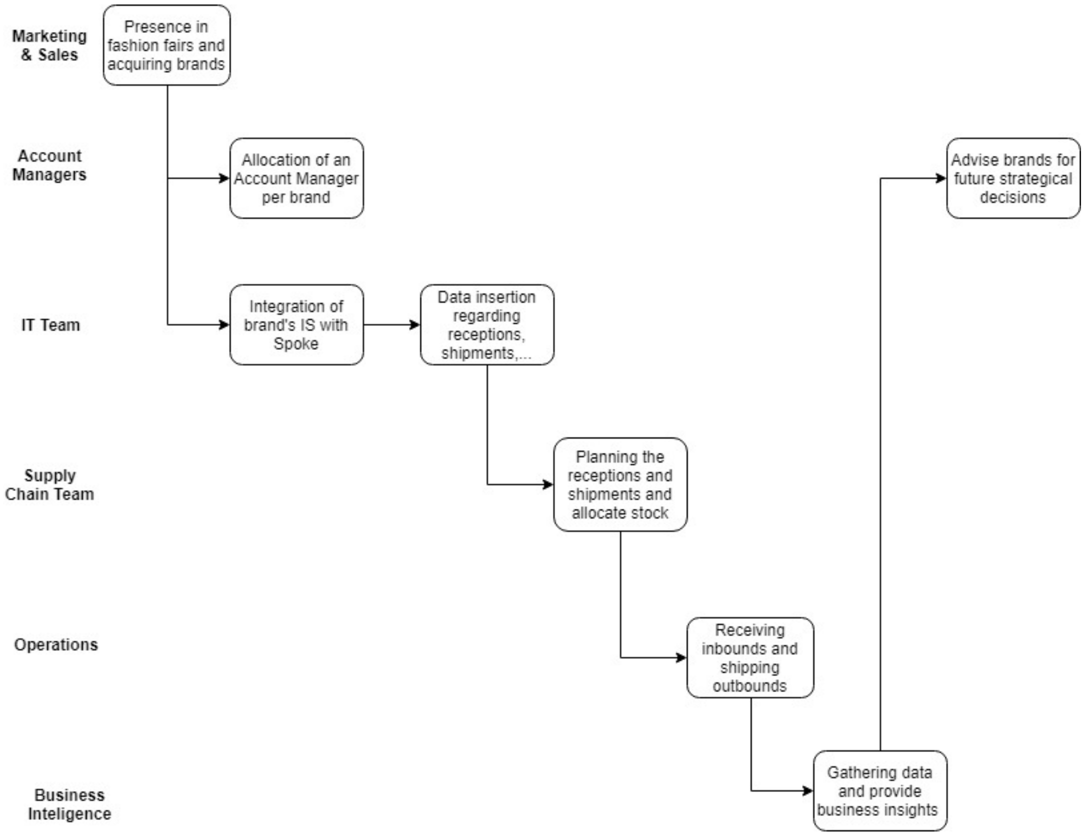

Figure 3.4: HUUB's main process flow

3.6.1 Data Management

Although this topic does not fall under the scope of this dissertation, the procedure used is fundamental to its success as the algorithm depends on the data provided. At the moment, the brands provide the information to the account managers directly, which are responsible to insert the information into the data warehouse. As it was aforementioned, time is one of the most crucial topics in this field, meaning that it needs to be as automated and mistake-proof in order to not compromise future actions. With this in mind, the platform developed by HUUB already has some functionalities embedded that allow some automatization, even though it is still not ideal.

When a purchase or sales order is introduced, certain procedures must be followed such as ensuring mandatory fields to be filled, guaranteeing this way the necessary information for all upcoming processes that will depend on the data being introduced. As the details from every reception are provided fully by the brand, the information must be defined by the brands together with the supplier and HUUB will only be responsible to follow strict deadlines and procedures, whereas in the shipments the only information required is the quantity, estimated date with a certain service level and the final destination, giving HUUB more flexibility to rearrange the processes in the way it seems more appropriate.

Several algorithms have been being developed in HUUB and one application programming interface (API) is especially helpful for this dissertation, as it allows us to go through several items of a shipment and predict what is the weight and the volume of each item. This information, usually not provided neither by the brand nor the supplier, is crucial to determine both the shipping cost together with the carrier and the number of pallets needed to send to the Netherlands based on the volume of items to be shipped.

3.6.2 Supply Chain Activities

When the onboarding process is completed, the Supply Chain team will be responsible from then on to schedule all the receptions in the warehouse from the respective suppliers, planning transshipments, such as stock-transfers or cross-dockings, and ship all the orders to the end-customers. As it can be seen in Figure 3.2, at the moment, due to restrictions regarding contracts with the suppliers, all receptions need to be received in HUUB's warehouse, processed to stock and only then incur in another activity such as being transshipped or sent directly to the end-customer. This restriction mainly influences the lead time, taking into consideration that it needs to be inbounded and outbounded in HUUB's warehouse and both of these processes have a time associated that may delay the arrival date of such items to the end-customer. This happens since the transportation cost from the supplier to the warehouse is not guaranteed by HUUB, but being however planned by the company and afterwards charged to the brand. As the suppliers are almost entirely from Portugal, the prices established between these and HUUB are only related to HUUB's warehouse in order to keep the transportation cost low. Finally, it is also not possible to ship directly from suppliers to an end-customer since usually the storage space available of the end-customer is not enough to accommodate an entire reception from the supplier.

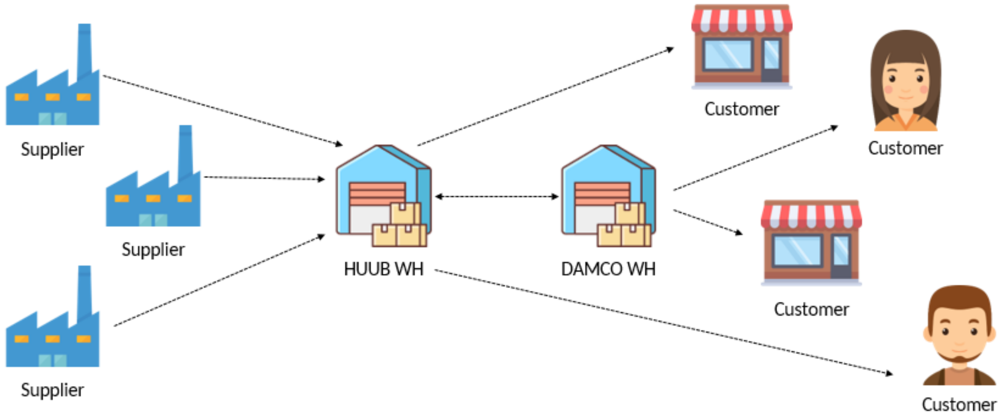

Figure 3.5: AS-IS flow of the Supply Chain

3.6.3 Stock Allocation

HUUB works from its own warehouse located in Porto since its creation and every order had to be received from the supplier before being shipped to the end-customer. This created additional costs as there had to be more traveling costs even if the warehouse was further away to the end-customer than the supplier. With this in mind, HUUB expanded to the Netherlands by outsourcing warehousing tasks to DAMCO and finding synergies between the orders to decrease the costs. At this moment, the orders being sent are still selected manually and tests are being made regarding different scenarios. In spite of the efforts made, the number of products being sent to the warehouse is still considerably low taking into consideration the total amount of distinct SKUs currently in HUUB's data warehouse.

Table 3.1: Comparison between the usage of warehouses of the network

Warehouse	**Distinct SKUs**	**Stock**
HUUB	97,99%	83,10%
DAMCO	2,01%	17,90%

As it is represented in Table 3.1, only approximately 2% of all the SKU from the current season are present in DAMCO while the remaining percentage is only stored in HUUB's warehouse.

The allocation of stock in DAMCO can serve two different purposes: either cross-docking or stock-transfer. In case it is for cross-docking, there is a fee per box received and a storage cost in case the shipment does not leave on the same day. As the order will not be changed, there are no inbound processes and the order will remain in temporary storage space. When is ready to be shipped, there will be the standard outbound processes associated with it. Regarding the outbound, the cost varies depending on if it applies to a B2B or B2C destination. For the former, the cost is reflected in the number of boxes, whereas for the latter there is an additional fee for the number of items. The second case is when a stock transfer is executed and the items will go from the storage of one warehouse to the storage of another. In this case, both the inbound and outbound processes will be executed and a standard fee will be applied per item.

There has been some improvements regarding the testing of different scenarios such as sending the whole collection of a specific brand to the warehouse in the beginning of the season and having it there until the end, sending it in the beginning and shipping it back to HUUB's warehouse when the storage cost overcomes the reduction in the last-mile delivery or having it in HUUB's warehouse in the whole season.

However, these tests have only been made for a combination of one brand and a specific sales channel, not considering the possibilities of sending only parts of collections from several brands together. The main reasoning falls under the fact that it is not possible to split one reception in the supplier stage into several smaller receptions in where each one of them would fulfill a different warehouse, representing this way a hard constraint to the problem.

3.6.4 Warehousing Operations

From the warehousing perspective, the only process fully controlled by HUUB is its own warehouse, outsourcing everything else without any ability to interfere besides planning according to the SLAs agreed upon with DAMCO's warehouse.

At the moment, regarding receptions, the items are picked from the supplier's delivery, which will require a verification of the amount delivered in comparison with the expected amount to receive and only then collected to stock even if the same items will have to be shipped in the near future to an intermediate or final location. In case the amount received does not match with the expected amount, both the supplier and the brand will receive a warning related to the inconsistency.

Simultaneously, the warehouse is also responsible to fulfill every sales order that needs to take place on that day. For that, the corresponding items are picked from stock, which is placed in a layout that privileges SKUs with a higher rotation closer to the shipping station to decrease the picking time, together with the associated packs and the order is prepared accordingly. In the end, both the items and packs are double-checked, the weight is measured and a label is associated with the shipment. This shipment can be associated with a sales order to an end-customer or as a transshipment to DAMCO's warehouse. The flow is completed when the items are given to the carrier. The flow of such processes can be found below in Figure 3.6

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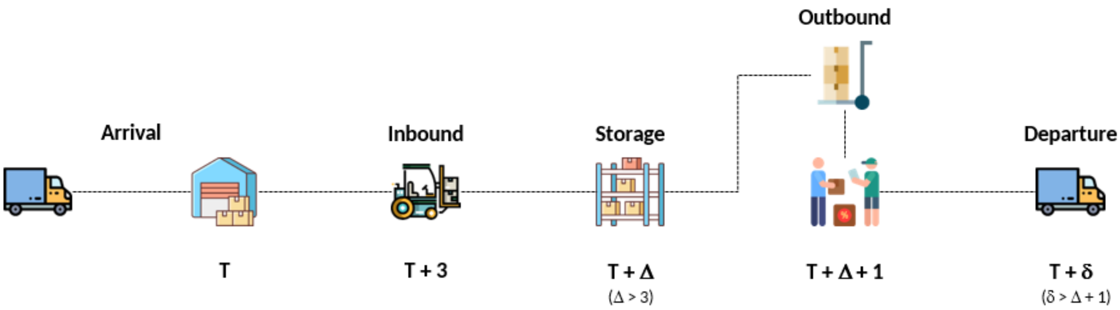

Figure 3.6: Warehousing processes and transit times

3.6.5 Business Intelligence

This team is responsible for optimizing all the logistic flows, such as the selection of packs that best fit the items of a certain order, prioritization of orders to be prepared throughout the day to meet the time the carriers pass in the warehouse to pick up the orders, and a grounded reasoning regarding the allocation of stock in order to decrease the overall costs. It is therefore easily understandable the need of developing an algorithm to allocate stock derived from the analysis of the savings in last-mile delivery costs acquired by sending from DAMCO's warehouse and the need of finding synergies between different orders to make it profitable to choose such option.

The 10 most common countries where shipments are delivered to can be found in Table 3.2. The correlation USA with Service Level 2 and Japan with Service Level 2 were removed as DAMCO's warehouse does not provide that possibility. Table 3.2 demonstrates that the potential in DAMCO's warehouse although the operations in HUUB should still remain as there are still some destinations from where it is more profitable to ship directly to the end-customer.

Table 3.2: Best shipping rates for the 10 most common destinations

Country	**Service Level**	**Best Option**	**Avg. Savings per Delivery**
USA	1	HUUB	-
Germany	1	DAMCO	1.17€
Germany	2	DAMCO	4.80€
United Kingdom	1	DAMCO	0.87€
United Kingdom	2	DAMCO	1.39€
Denmark	1	HUUB	-
Denmark	2	HUUB	-
France	1	DAMCO	1.03€
France	2	DAMCO	0.82€
Portugal	1	DAMCO	4.30€
Portugal	2	HUUB	-
Japan	1	DAMCO	8.00€
Netherlands	1	DAMCO	18.91€
Netherlands	2	DAMCO	5.50€
Switzerland	1	HUUB	-
Switzerland	2	DAMCO	6.08€
Italy	1	DAMCO	0.80€
Italy	2	HUUB	-

3.7 TO-BE Situation

In order to make the operations of the supply chain the most agnostic possible, that is, to not be dependent on human interference, it is expected to find the optimal flow of each SKU individually throughout the entire SC, taking advantage of its characteristics. This said, it is expected that a shipment from a supplier can go either to any warehouse of the network or directly to the end-customer, depending on the capacity each one of these points has available.

Within the warehouse, the item can either be received into the storage, losing its attachment with the reception it was received from, or remain in cross-docking where it will as soon as possible be shipped to the end-customer, not being introduced to the system as stock but remaining temporarily in the warehouse.

When an item is in stock, it will either remain in the storage of that warehouse, undergo the outbound process to fulfill an order to and end-customer or be transshipped between warehouses together with other items that will lead to a reduction in the overall costs of the SC.

These decisions will, therefore, be taken based on an optimization algorithm that will receive the input from the database and provide the output to the upstream and downstream teams which will then schedule the transportation with the suppliers and carriers respectively.

It is expected in the future, that a product can be shipped from a vendor either to HUUB's warehouse, any other warehouse in the network or directly to the end-customer, in case the storage space is enough to accommodate the entire reception. In case it goes to a warehouse, the SKU becomes agnostic as part of the stock and can be transferred between the warehouse of the network if that represents the less costly decision to make. Finally, each warehouse will be allowed to ship an item to an end-customer, no matter the type. The future flow of the SKU through the supply chain is also represented in Figure 3.7.

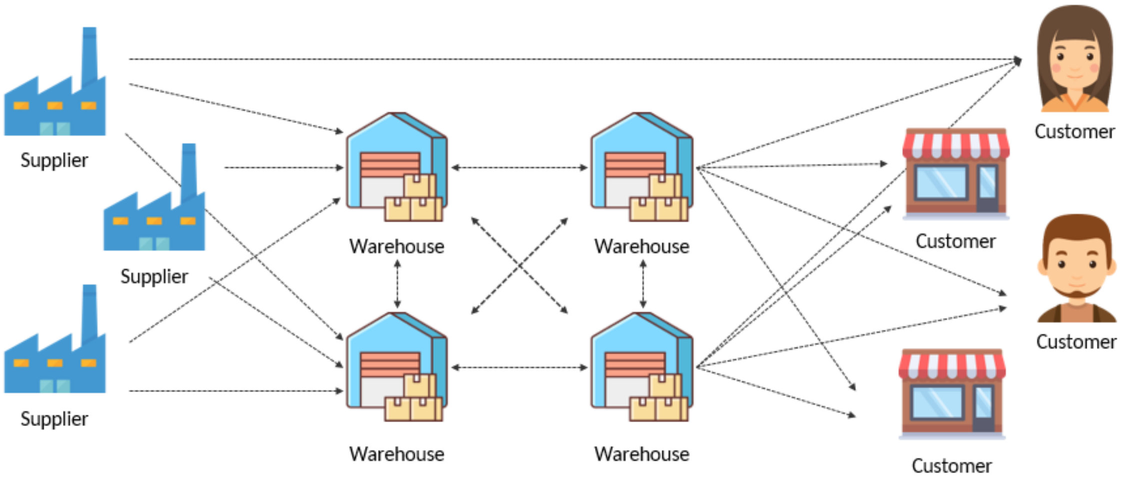

Figure 3.7: TO-BE flow of the Supply Chain

3.7.1 Expected Benefits

The main advantage expected to find is an increased number of possibilities to choose how to move stock, that is, a broader scope of possibilities choosing the one that will ultimately provide the less costly option. Another benefit will be to find synergies between unrelated SKUs that have similar characteristics (such as a similar estimated due date) and aggregating them if it proves beneficial. Finally, on one hand, the increased number of options will make it easier to find feasible solutions and focusing the goal in the optimality and, on the other hand, allows to create harder constraints which will provide more accurate results.

Chapter 4

Methodology

In order to solve the problems exposed before, the solution found was the development of an algorithm as a linear programming model that aims to take all variables into consideration and make a grounded decision regarding the minimization of the overall costs. As a standard linear programming model, the algorithm will receive the input available at a given time and prescribe a solution based upon this information. However, due to the fact that both the brands and stores are not specialized in the prediction of sales, more orders may arise within the time horizon that the model is trying to optimize but will not take into consideration as they are not present in the moment the model collects the data. This said, another model was developed by analyzing re-orders from past seasons and predict unexpected demand for the model as input.

In this chapter, prior to the development of the unexpected demand model and the formulation of the linear programming one, an introduction is made regarding the necessary inputs and consequent outputs, parameters gathered beforehand and subsequent quantification of the costs associated with each activity as well as timings for all the warehousing actions.

4.1 Inputs and Outputs

The algorithm was developed as an LP model and takes different types of input such as the estimated due date to expect a reception or the date for a shipment to arrive at the end-customer, the stock availability of each SKU in each warehouse as well as its capacity. The output provided will be related to the allocation of stock to the warehouses of the network considering the estimated dates of arrival to the warehouse and to the end-customer and the origin of the receptions and the destination of shipments. Since the flow of information is continuous and may influence a previously calculated output, the algorithm will run daily and provide the SC team with the decisions to make each day. In order for the scope to be broad, the algorithm will take into consideration a time horizon of three weeks to understand when it is best to ship each order and from where. Furthermore, since the transshipments, due to restrictions from DAMCO, can only occur on a Tuesday or Friday, the model will take into consideration only the SKUs that will be involved in a reception or a shipment in the upcoming four weeks. The reasoning was to find a trade-off in maintaining the model's flexibility and consider a broad scope of SKUs as possibilities for transshipments.

4.2 Data Parameters

For the prediction model, there was a need to acquire information with the Account Managers related to the percentage of re-orders from each store in comparison with their total amount acquired in that season. It was also gathered data regarding the flow of leftover stock from previous seasons to use in predictive analysis for the storage costs of such products.

The collection of data for the linear programming model is divided into two different steps. The first one is acquiring from the database certain parameters that will be important while building the model itself. As examples of such parameters, it will be needed to know which warehouses to consider in the analysis, the capacity of such warehouses and the different SKUs that will be accounted within the model. The second step, due to the lack of necessary information provided by the brands and suppliers, will consist in gathering the remaining data by connecting to an application programming interface that will deliver the volume and weight of each SKU as these are crucial to the output of the model, regarding the cost of transportation and the number of pallets needed for a transshipment, respectively.

4.3 Cost and Time Quantification

The different costs considered are transportation, warehousing, storage, penalties and labor.

The transportation cost is based on the rates proposed by all the carriers. The prices differ from each warehouse, as both the distance between the suppliers and end-customers together with the service level chosen varies accordingly. The rates are then proposed by the carriers and HUUB is responsible to choose the cheaper option. Although the brands have different costs for different intervals of weight, either between 0,5kg for lower weights or between 1kg for higher ones, an approximation was made to linear regression with all the equations presenting an R^2 higher than 96%, guaranteeing a small error. Furthermore, carriers measure both the weight of the order and the volumetric weight, charging the highest; therefore, both the total volume of each order and its volumetric weight were calculated. It is important to denote the volumetric weight was calculated by choosing the first pack with a volume higher than the total volume of its products. The costs for the warehousing activities are calculated differently for HUUB and DAMCO. For HUUB's warehouse, the cost is calculated based on the time spent on each activity taking into consideration the average wage of the workers. For DAMCO the fees per product are fixed and independent from the type or size of the product.

The storage costs are again different for both warehouses. HUUB only has fixed costs in its own warehouse since this is independent of the number of products inside of the warehouse at any given moment. For DAMCO the price is charged as a standard fee per item per day. Finally, the labor costs only exist in HUUB since the activities in DAMCO are outsourced. There is a standard cost for the regular workers currently working in HUUB, and an extra cost per every extra worker required to hire temporarily, entailing a higher fee as the need is not planned.

4.4 Reorders and Leftover Stock

As the linear optimization model will have to predict the minimization of the overall costs taking into consideration the receptions and shipments of the upcoming three weeks, new orders may appear within that time horizon that may influence the output and will not be considered as they are not yet introduced in the database. As such, there is a need to predict these orders and input their predictions as an external source to the main model.

The analysis was conducted by gathering the data from previous seasons (both Autumn-Winter and Spring-Summer) from the years of 2017 and 2018. The data consisted of the percentage of reorders that each brand has made throughout the season and compiled as the total expected average of products to be reorder every month. A partition was also made between new brands and brands already in contract with HUUB before, with the reasoning that the team of Account Managers advises the brands regarding the number of products to order based on an analysis from previous seasons and turnover of each one of them, ensuring a better accuracy for upcoming seasons, causing a lower reorder percentage throughout time. A final prediction was made considering the number of brands already being managed and the new ones for the 2019 seasons. To simplify the calculations, an approximation was made based on the assumption that the percentage of reordering of each SKU would follow the same pattern as the total percentage of reorders. This value is then used as input to the LP model, considering which time of the season is being planned.

As it can be seen in Figure 4.1, the Autumn-Winter season follows a trend inversely proportional to the usual demand a store faces during the season, that is, it is low in the beginning as the stores have been stocked, increases by the middle of the season where the first flow of stock is already over and decreases to the end as it is mainly located in seasoned sales and the objective is to finish the season without stock. Figure 4.2 shows that Spring-Summer Season has a more complex pattern since the amount of reorders is oddly high in the beginning and has a late mid-season. The reasoning lays in the number of products ordered by each brand in the beginning, which tends to be lower in the Spring-Summer when in comparison with the Autumn-Winter which will require an earlier reorder in order to prevent a potential stock-out.

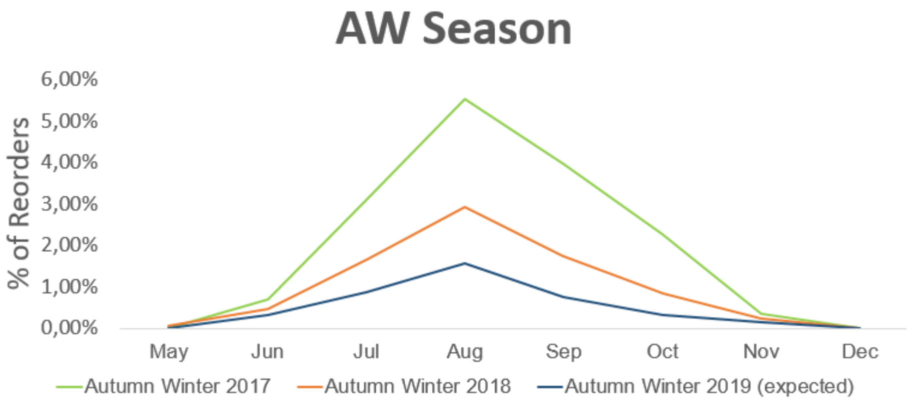

Figure 4.1: Autumn-Winter Season

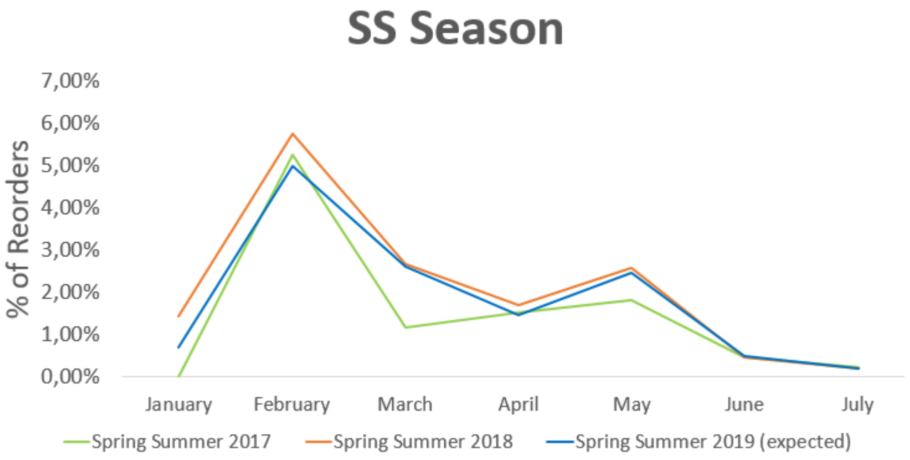

Figure 4.2: Spring-Summer Season

Following the same line of thought, some brands might not be able to drain all of the stock of each season in the time frame of each corresponding one, ending up with leftover stock the stores are no longer interested in acquiring. For this type of stock, there are two possibilities that are usually handled by the brand: selling through e-commerce or including as part of a deal when closing an agreement with multi-brand stores. Therefore, since these cases are independent of time as they are no longer part of the current season, and it is expected for a certain number of products to be sold in each period of time, it was assumed that these products would follow a Poisson distribution regarding the flow from storage, having this way a more accurate storage cost.

4.5 Linear Optimization Model

The model developed in the scope of this dissertation aims to allocate stock dynamically to each warehouse of the network considering the different timings of a fashion season and the costs associated with that decision. The main variables to be taken into consideration are therefore the warehouse where an order will be received or shipped, together with the products associated with that order and the date chosen for the execution of such order. To find the best trade-off between maximum flexibility of the algorithm and a level of complexity that can be solved by a linear optimization model, the time horizon was of three weeks (21 days), where the planning will be done for the orders that have an estimated date in that horizon. However, as new orders may arise at any given moment, the algorithm should run every day as it may provide new outputs.

4.5.1 Decision Variables

There are three different types of decision variables represented in this problem. The first decision needs to be regarding either the allocation of a certain reception to one warehouse or the warehouse from where a shipment will be sent from, which will be represented by binary variables that will be responsible for establishing this decisions where their meaning translates when they are set to 1; secondly, as each product will have a cost associated with it, either as it is in storage or being transported, the quantities of each SKU also needs to be defined. The third type is related to the number of pallets used in a transshipment, which are independent of the number of products inside and are only charged by the number of these used. The Indices and the all of the Decision Variables of the model can be found in Table 4.1 and Table 4.2 respectively. All of the parameters can be found in Table A.2.

Table 4.1: Indexes of the Linear Optimization Model

Index	**Description**
i	product
j	supplier
k,d	warehouse
l	customer
m	reception
n	shipment outbound
t	period

Table 4.2: Decision Variables

Variable	**Description**
x_{ijkt}^{m}	Quantity of SKU i from supplier j to warehouse k in period t belonging to inbound m
X_{jkt}^{m}	1, if inbound m is received from supplier j in warehouse k during period t and 0 otherwise
w_{ikdt}	Quantity of SKU i transshipped from warehouse k to d during period t
W_{kdt}	Quantity of pallets transshipped from warehouse k to d during period t
z_{iklt}^{n}	Quantity of SKU i from warehouse k to customer l in period t belonging to outbound n
Z_{klt}^{n}	1, if outbound n is shipped from warehouse k to customer l during period t and 0 otherwise
I_{ikt}	Quantity of SKU i in storage in warehouse k in period t
LO_{ikt}	Quantity of SKU i in leftover storage in warehouse k during period t
$NrDays_{n}$	Number of Days shipment n is delayed
$NrDays_{m}$	Number of Days reception m is delayed
$NrWorker_{kt}^{ex}$	Number of extra workers required in warehouse k for period t
$Time_{kt}$	Time available to process products in warehouse k during period t

4.5.2 Objective Function

This optimization model focuses on the reduction of the overall costs of the stock allocation of the different brands throughout the warehouses of the network as well as coordinating the receptions and shipments of the products where it is most beneficial. To achieve these objectives, the objective function is decomposed into several parcels that emphasize the reduction of costs of a specific section of the supply chain.

$$
\begin{aligned}
&\mathit{Sourcing} && \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{t=1}^{T}\mathrm{Cost}^{w}_{jk} * x^{m}_{ijkt} + Cost^{int}_{jk} * X^{m}_{jkt}\\
&\mathit{Transshipments} && \sum_{t=1}^{T} Cost_{kd} * W_{kdt}\\
&\mathit{Last\text{-}Mile\ Delivery} && \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{n=1}^{N}\sum_{t=1}^{T}\mathrm{Cost}^{w}_{kls} * z^{n}_{iklt} * weight_i + Cost^{int}_{kls} * Z^{n}_{klt}
\end{aligned}
\tag{4.1}
$$

$$
\begin{aligned}
&\mathit{InboundCost} && \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{t=1}^{T}(Cost^{inb}_{ik} * (x^{m}_{ijkt} + w_{ikd(t-LT)}))\\
&\mathit{OutboundCost} && \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{n=1}^{N}\sum_{t=1}^{T}(Cost^{out}_{ik} * (z^{n}_{iklt} + w_{ikdt}) + Cost^{out}_{k} * (Z^{n}_{klt} + W_{ikdt})
\end{aligned}
\tag{4.2}
$$

$$
\begin{aligned}
&\mathit{Stock} && \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{t=1}^{T}(\mathrm{Cost}^{stock}_{ik} * \mathrm{I}_{ikt})\\
&\mathit{LeftoverStock} && \sum_{i=1}^{I}\sum_{r=0}^{Max}\sum_{t=1}^{T} Cost^{stock}_{ik} * (1 - P[N(t) = r]) * (LO_{ikt} - r * t)\\
&\text{where} && P[N(t) = R] = \frac{e^{-\lambda t} * \lambda t^{t}}{r!}
\end{aligned}
\tag{4.3}
$$

$$
\begin{aligned}
&\mathit{WarehouseDelay} && \sum_{n=1}^{N} Cost^{delay}_{k} * NrDays_n \quad \forall k\\
&\mathit{SupplierDelay} && \sum_{m=1}^{M} Cost^{delay}_{j} * NrDays_m \quad \forall j
\end{aligned}
\tag{4.4}
$$

$$
\mathit{AdditionalWorkers} \qquad \sum_{k=1}^{K}\sum_{t=1}^{T} Cost^{extra}_{worker} * NrWorker^{ex}_{kt}
\tag{4.5}
$$

The equations in 4.1 of the objective function are related to the transportation of the products which will be divided into three different parcels: the Sourcing is the transportation from a supplier j to a warehouse k and it considers a fixed rate $Cost^{int}_{jk}$ for the transportation X^{m}_{jkt} with an additional cost $Cost^{w}_{jk}$ for the number of products carried x^{m}_{ijkt}; the Transshipment is the stock-transfer or cross-docking between warehouses and where the cost $Cost_{kdt}$ will be reflected based upon the number of pallets W_{kdt} shipped between warehouses and the Last-Mile Delivery is the shipment of the order from a warehouse to an end-customer Z^{n}_{klt} where there is a fixed fee $Cost^{int}_{kls}$ with additional cost $Cost^{w}_{kls}$ considering the weight of the transport which is the sum of all the products in z^{n}_{iklt} multiplied for the weight of each product $weight_i$.

The equations in 4.2 are related to the fulfillment of inbounds m and outbounds n in a warehouse k of the network. For the inbound there if a fixed fee $Cost_{ik}^{inb}$ per item received for the stock, which may derive from a reception of a supplier x_{ijkt}^{m} or a reception from a transshipment of another warehouse $w_{ikd(t-LT)}$. For the outbound, there is, besides the fixed fee $Cost_{ik}^{out}$ for a product that will be sent to a customer z_{iklt}^{n} or transshipped to another warehouse w_{ikdt}, an additional cost $Cost_{k}^{out}$ per shipment that needs to be prepared, both shipments Z_{klt}^{n} or transshipments W_{kdt}.

The equations in 4.3 consider the cost of storage in any warehouse of the network. Although the cost $Cost_{ik}^{stock}$ of storing an SKU is transversal through all products, there is a separation between stock that is currently being commercialized, such as the permanent collections or the season in force I_{ikt}, and the leftover stock, which represents the entire stock from previous seasons that was not sold LO_{ikt}. The latter type of stock will follow a specific distribution since usually the flow of these products derive from agreements between brands and clients and not predicted sales that can be added to the database of Spoke. This said, the total cost of Leftover Stock is the sum of the SKU i in warehouse k in period $t = 0$ times the total number of periods t minus the expected number of items being sold in each period t according to Poisson's distribution.

The equations in 4.4 consider the cost of delay in either receiving the orders $Cost_{j}^{delay}$ or shipping them $Cost_{k}^{delay}$ to the end point. The impact is represented by a cost that will increase by the number of days the order is delayed according to the estimated date, either $NrDays_m$ when it is the supplier's fault or $NrDays_n$ when it is HUUB's fault.

The equation in 4.5 considers the cost, $Cost_{worker}^{extra}$, in a period t in HUUB's warehouse (since DAMCO's warehouse does not account labor) of a certain number of extra workers $NrWorker_{kt}^{ex}$ in case they are needed, since every inbound and outbound will have a processing time associated with it and the number of regular workers will limit its capacity to receive or ship new orders.

4.5.3 Constraints

Warehouse

Throughout the entire period that the algorithm is focusing upon, the balancing of stock, as it is characterized in Figure 4.3, represents one of the most important restrictions in order to ensure the stability of every SKU i present in every warehouse k during every period t or the reasoning behind its change. Therefore, the flow of products that enter a certain warehouse either as reception x_{ijkt}^{m} or as transshipment $w_{ikd(t-LT)}$, together with the products that leave that same warehouse either as a shipment z_{ijkt}^{n} or again as transshipment w_{ikdt} and the variability of stock I_{ikt} and leftover stock LO_{ikt} from a given period t with its prior period $t-1$ need to be equal at all times.

$$I_{ik(t-1)} + LO_{ik(t-1)} + \sum_{m=1}^{M} x_{ijkt}^{m} + \sum_{\substack{k=1 \\ k\neq d}}^{K} w_{idk(t-LT)} = I_{ikt} + LO_{ikt} + \sum_{n=1}^{N} z_{ijkt}^{n} + \sum_{\substack{k=1 \\ k\neq d}}^{K} w_{ikdt} \quad \forall i,k,t \tag{4.6}$$

Furthermore, each warehouse will have a maximum capacity of products cap_k that will differ on its definition: since HUUB's capacity is limited by a fixed amount, the constraint will be a fixed number immutable throughout time; the one in DAMCO, although the storage space can almost be considered as unlimited, the amount must be communicated beforehand if the volume expected is much higher than the one currently being stored, otherwise the flow of products for every period t must be relatively similar to the corresponding previous period $t-1$.

$$\sum_{i=1}^{I} I_{ikt} \leq cap_k \quad \forall k,t \tag{4.7}$$

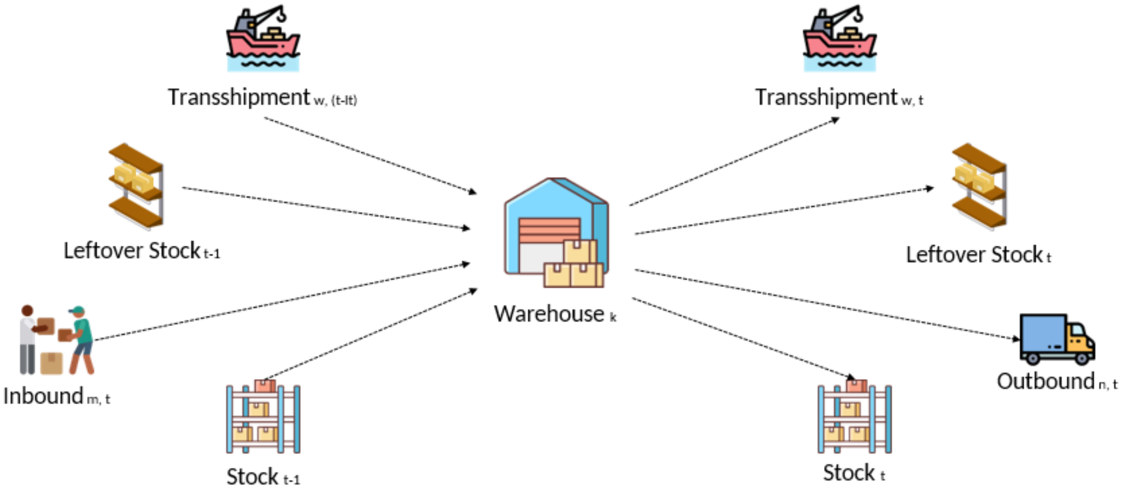

Figure 4.3: Inventory balance

Process Singularity

Every inbound m and outbound n has a certain amount of variables associated with it: the first one is the binary decision in which warehouse k to receive the inbound m or from what warehouse k to ship it. As both inbounds and outbounds need to be received or sent as a whole in or from the same warehouse k respectively at the same period t, the sum of all binary variables containing the same inbound X^m_{jkt} or outbound Z^n_{klt} must be equal to 1.

$$\sum_{k=1}^{K}\sum_{t=1}^{T} X^m_{jkt} = 1 \quad \forall m \tag{4.8}$$

$$\sum_{k=1}^{K}\sum_{t=1}^{T} Z^n_{klt} = 1 \quad \forall n \tag{4.9}$$

Process Restrictions

As mentioned in the previous restrictions, certain restrictions apply due to HUUB's current situation. More concretely, as the brands in contact with HUUB are relatively small, it is not possible to ship directly an order from a supplier to an end-customer, as the stores usually do not have a size large enough to store the entire collection at once and the suppliers are not able to ship only parts of it, being therefore necessary that every reception is received by a warehouse belonging to HUUB's warehouse network. Furthermore, as the agreements for the cost of transportation established with the suppliers are only calculated for deliveries at HUUB, it is mandatory that a reception, for the time being, is received in HUUB's warehouse (k = 1).

$$\sum_{m=1}^{M} X_{ijkt}^{m} = 0 \quad \forall k \neq 1 \tag{4.10}$$

As the Process Singularity restriction forces a reception or a shipment be associated with only one warehouse k, the amount required in the inbound m, $quantity_{ijkt}^{m}$, or outbound n, $quantity_{iklt}^{n}$, must be equal to the decision variable regarding the quantity associated with it, both x_{ijkt}^{m} or z_{iklt}^{n}.

$$x_{ijkt}^{m} = quantity_{ijkt}^{m} * X_{jkt}^{m} \quad \forall m \tag{4.11}$$

$$z_{iklt}^{n} = quantity_{iklt}^{n} * Z_{klt}^{n} \quad \forall n \tag{4.12}$$

Transshipments Restrictions

The only packaging unit allowed to be transshipped between warehouses in the network is a pallet. Each one of these units has a size of 1.2 per 1.8 per 0.8 m^3, where the weight is not relevant for the calculation of the final cost. The cost imputed is indeed entirely based upon the number of pallets transshipped and there is no additional cost per SKU inserted in each pallet. Therefore, the sum of the total vol_i being transshipped in w_{ikdt} cannot be higher than the total volume of the number of pallets W_{ikdt} being used.

$$W_{ikdt} \geq \frac{\sum_{i=1}^{I} w_{ikdt} * vol_i}{1.2 * 1.8 * 0.8 * 10^6} \quad \forall k, d, t \tag{4.13}$$

Service Level Agreement

HUUB currently has several SLAs from each base its rates of quality upon. As some of the SLAs are already involved in daily warehousing operations, such as the maximum inbound and outbound time for a reception or shipment respectively, not needing to be calculated as part of this formulation, the main Service Level Agreement that the company currently holds as the most important SLA when delivering to its customers is the time for last-mile delivery: Transit Time. An outbound has a maximum amount of time since it is shipped from a warehouse until it reaches the final destination, which means that the date when it is shipped must, therefore, be smaller or equal than the date it is expected to arrive taking into consideration the transit time it will take to arrive, which is itself based on the warehouse from where it will departure, the destination's location and the service level chosen.

$$NrDays_n \geq (AD_n - EA_n) * Z^n_{klt} \qquad \forall n \tag{4.14}$$

Throughput Time

As time is a scarce resource in HUUB's warehouse, there is a limited amount of inbound and outbound activities that can be processed in a working day depending on the number of available workers and the longevity of their shift. Each product i has a certain time associated with it depending on if the goal is for inbound PT^m_{ik} or outbound PT^n_{ik}. This said, the time of all the products received in a given period t given from inbounds' receptions x^m_{ijk} or transshipments' receptions $w_{idk(t-LT)}$ together with the outbound of transshipments w_{ikdt} and shipments z^n_{iklt} must be lower than the amount of time available in that warehouse k in that same period t.

$$Time_{kt} \geq \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{q=1}^{Q}(x^m_{ijkt} + w_{idk(t-LT)}) * PT^m_{ik} + \sum_{i=1}^{I}\sum_{q=1}^{Q}\sum_{n=1}^{N}(w_{ijkt} + z^n_{ijkt}) * PT^n_{ik} \quad \forall\text{t, k=1} \tag{4.15}$$

$$Time_{kt} = (NrWorker^{reg}_{kt} + NrWorker^{extra}_{kt}) * WorkingTime \tag{4.16}$$

Since DAMCO's warehouse is outsourced, the time availability is not bounded, such is not considered as a constraint for this problem. However, there is a limit regarding the number of movements allowed for each day that HUUB is allowed to coordinate. More precisely, the number of inbounds x^m_{ijkt} or transshipments $w_{ikd(t-LT)}$ and the number of outbounds z^n_{iklt} or transshipments w_{ikdt} needs to be equal or lower than the SLA agreed upon with the warehouse.

$$Movements_{kt} \leq \sum_{i=1}^{I}\sum_{m=1}^{M} x^m_{ijkt} + \sum_{i=1}^{I} w_{idk(t-LT)} \sum_{i=1}^{I} w_{ikdt} + \sum_{i=1}^{I}\sum_{n=1}^{N} z^n_{iklt} \quad \forall t, k = 2 \tag{4.17}$$

In case there is a need in HUUB's warehouse to acquire more workers in order to fulfill more orders in a certain period t, it is possible to hire temporarily extra workers until a certain number which will carry a higher cost than the normal worker.

$$NrWorker^{extra}_{kt} \leq Max_t \quad \forall k = 1 \tag{4.18}$$

Non-negativity

$$x^m_{ijkt}, w_{ikdt}, W_{kdt}, z^n_{iklt} \geq 0 \tag{4.19}$$

$$I_{ikt}, LO_{ikt}, NrDays_n, NrDays_m, NrWorker^{ex}_{kt}, Time_{kt} \geq 0 \tag{4.20}$$

$$X^m_{jkt}, Z^n_{klt} \in \{0,1\} \tag{4.21}$$

Chapter 5

Implementation and Results

In this chapter, the practical implementation of the model is explained, together with an explanation of all the features used in the development and the reasoning behind the choices made. Furthermore, the parameters given and considered as standard will be changed in order to predict potential impacts on the overall supply chain as well as testing new possibilities for the future. Finally, the model is tested for different scenarios and an analysis regarding the performance of the model is carried out.

5.1 Programming Tools

This project had a rationale focus on two different programming languages, each having a different and specific goal. There was a strong focus in searching for information in HUUB's database management system, PostgreSQL, and through the usage of queries, be able to represent different views of important information for the case in question. Furthermore, as the algorithm is required to achieve a good performance in terms of run-time, it was also developed a connection to BigQuery, powered by Google, in order to get, for example, all the updates of a given table.

The main programming language for the development of the algorithm was Python. The reasoning behind this decision was to follow the same path of previous algorithms already developed in HUUB, the easiness while dealing with large amounts of data and to work as a basis for a potential future improvements into more complex algorithms in the area of Machine Learning. Furthermore, the pre-existing functions that allow for a simpler and smaller code also prove fruitful when developing the model.

As mentioned before, all the information required regarding inbounds and outbounds, transportation times and stock quantities were extracted from the database by programming queries using SQL. The code was inserted directly into the Python code and by intermediary of libraries, it was possible to connect to the database.

Furthermore, both the information that was unavailable from the database as well as the parameters that could be easily modifiable were inserted in a separate file. The main goal is to perform a sensitivity analysis more easily and withdraw conclusions regarding future steps.

The code was also programmed with the support of several libraries provided in Python that proved to be of utmost importance. The first one was Pandas, an open-source, BSD-licensed library that provides high-performance, easy-to-use data structures and data analysis tools. It allowed for the usage of different built-in functions that increase coding efficiency and handiness of data, together with the possibility of using the lambda function, thus leading to a simpler code. The second one was NumPy, the basis when the objective was handling different N-dimensional array objects, sophisticated functions and linear algebra. The third important library was PuLP which consists of an open-source linear programming package equipped with many solvers. Beyond the easiness in defining the decision variables and structuring the linear programming model, PuLP reveals extremely useful when connecting with different solvers not directly related to it. Lastly, the integration between this model and other models through their APIs was done through access to Flask.

Finally, there was the need to integrate the output of the algorithm and allow it to be consulted by the parties that need to implement the results produced. This said, after connecting with Spoke's API and acquiring both the Sales and Purchase Orders, together with the up-to-date information from the SCM Planning API, the algorithm will compute the model and provide the output back to the Supply Chain team and include the results in Spoke to make it visible. The entire flow is depicted in Figure 5.1.

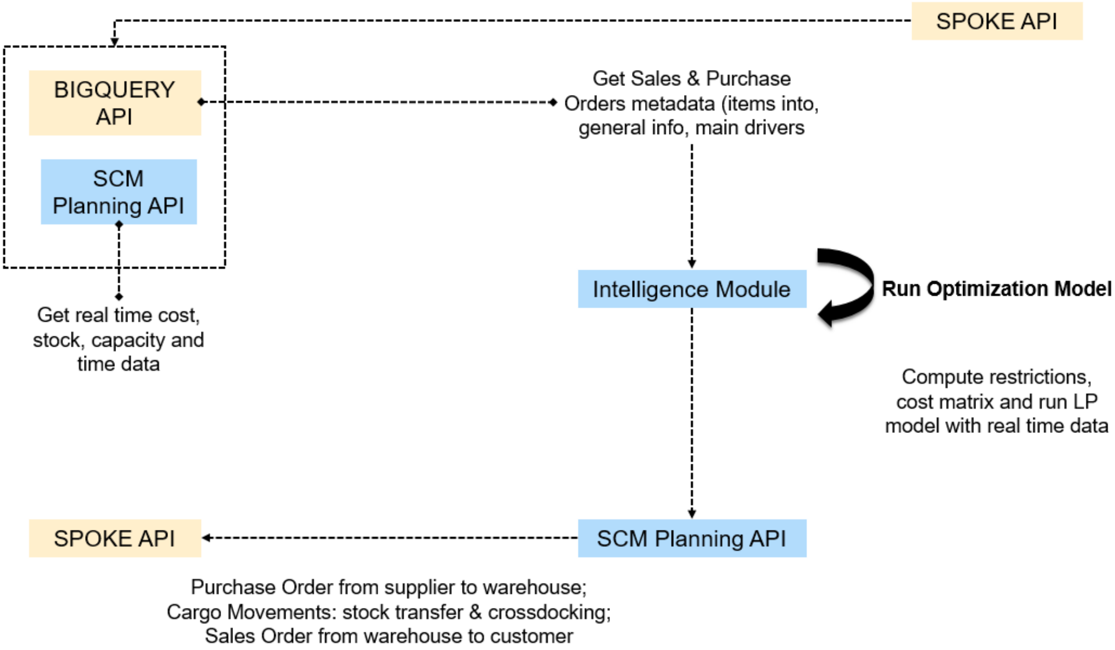

Figure 5.1: Structure of the Model's Integration

5.2 Development of the Model

The first development of the model included all the data that characterizes the AS-IS situation. In this section, all the parameters, times and costs were included as they are currently defined and cost structure as the one currently in place. The different types of data that are inserted into the model, as the parameters, timings and costs, can be found in Tables 5.1, 5.2 and 5.4, respectively. For the model, some assumptions were made in order to be able to test it:

1. It was assumed that all carriers would be available to perform any transportation every business day of the week with the necessary amount of weight;
2. The receptions were completely independent of shipments. A certain amount of products would arrive at the warehouse, always be accounted for stock and from then on be considered as part of the stock and no longer linked to its reception;
3. The cost for a delay from HUUB had a bigger impact than the one from supplier's side since the reputation of HUUB has a bigger impact than an analysis on the performance of the suppliers.
4. The SKUs that would not be involved in any inbound or receptions in the next 28 days would not account for potential transsshipments. It also needs to ensure it does not correlate with the end of a season where the stock should be collected back to HUUB's warehouse.
5. Furthermore, as the costs provided from the carriers were marginally increasing, an approximation was done between the prices provided and a linear equation in order to reduce the complexity. This was done as the R^2 was always above 96%, providing a very accurate approximation. The results for the 10 countries with the biggest amount of orders from the warehouse with the best rate can be found in Table 5.3 whereas the remaining ones can be found in Appendix A.
6. Finally, as the weights and volumes of each SKU are not provided in the database, it is required to connect to an API of Machine Learning that can provide these data by the characteristics of the product, such as its family, the size, the age group, among many others. However, for a large number of different SKUs, the performance decreases significantly, slowing down the entire algorithm. It was, therefore, necessary to calculate the expected weights and volumes for an item, considering its product family (e.g. Top, Bottom...), age group (e.g. Baby, Kid...) and season of the item (e.g. Autumn/Winter and Spring/Summer). After these calculations, the weight and volume of each SKU of the item would be calculated by the combination of these characteristics. The table providing the values can be found in Table A.1.

Table 5.1: Parameter for the Linear Programming Model

Parameter	**Description**
Dates	Time horizon of 14 days
Dates for Transshipment	Twice a week (tuesday and friday)
Warehouses	HUUB and DAMCO
Capacity HUUB	Maximum allowed in the warehouse
Capacity DAMCO	Current storage space available
SKUs	SKUs involved in Inbounds or Outbounds in the next 28 days
Workers	Number of regular workers

Table 5.2: Timings for the Linear Programming Model

Time	**Description**
Reception of Packs	Time to receive an order from the carrier
Reception of Items	Collection of items from an order to stock
Shipment of Items	Collection of items from stock to an order
Shipment of Packs	Grouping of an order's products and ship it to the carrier
Working Schedule	Time available per worker in a day

Table 5.3: Linear Costs for the 10 most used countries

Country	**Warehouse**	**Service Level**	R^2
USA	HUUB	1	98,73%
Germany	DAMCO	1	95,80%
Germany	DAMCO	2	100%
United Kingdom	DAMCO	1	95,80%
United Kingdom	DAMCO	2	100%
Denmark	HUUB	1	99,32%
Denmark	HUUB	2	95,81%
France	DAMCO	1	95,80%
France	DAMCO	2	100%
Portugal	HUUB	1	96,08%
Portugal	DAMCO	2	100%
Japan	DAMCO	1	99,43%
Netherlands	DAMCO	1	100%
Netherlands	DAMCO	2	100%
Switzerland	HUUB	1	99,60%
Switzerland	DAMCO	2	100%
Italy	DAMCO	1	95,80%
Italy	HUUB	2	96,68%

Table 5.4: Costs for the Linear Programming Model

Costs	**Description**
Sourcing Costs	Cost of transporting an order to a warehouse
Transshipment Cost	Cost of transporting stock between warehouses
Last-Mile Delivery	Cost of sending a shipment to an end-customer
Inbound Costs	Cost of receiving an order
Outbound Costs	Cost of shipping an order
Storage Costs	Storage Cost per item per day
Delay Costs	Cost of a reception or a shipment being late
Workers Cost	Cost of hiring extra temporary workers

5.3 Computational Experiments

The model was tested in three different stages:

1. The first one is a point in the season of low demand, which happens before the seasoned sales, where it is expected a relatively small number of re-orders and a high amount of e-commerce. It is characterized by a small number of receptions and shipments of a small number of items.
2. The second one happens in the middle of the season, where the first big demand for the products has already passed. Usually, by this time, the brands make the e-commerce sales available which will increase the shipments of few items per pack. Furthermore, the stores that exceeded sales against the expectation, need to ask for more re-orders in order to prevent stock-out.
3. The last one is in the launch of a season, where it is characterized by a high volume of products being transported through the sales channel of wholesale, with the main goal of the fulfillment of the stores for the upcoming season. It is the point where the number of receptions is high and the number of items shipped is the highest.

These three trials aim to test two different aspects of the linear programming model: the first, and most important one, is the quality of the model by analyzing the output and its feasibility and the benchmark of the overall cost in comparison to the current situation; the second, is the trade-off between the optimality of the algorithm and processing time, which means that the algorithm must produce the output in an amount of time small enough to be able to use its results. The outcomes of these two points will characterize the consistency of the algorithm and its practical feasibility.

The linear programming model was implemented in Intel(R) Core(TM) i7-4702MQ 2.20 GHz processor with 8GB of RAM. An important point to take into consideration is the solver that was chosen to address the problem. As all the variables are only integer and binary, the increasing number of such can drastically increase the complexity and consequently the feasibility of the solution. Therefore, two solvers were chosen in order to compare their potential and strength. The first one was CBC (Coin-or Branch and Cut) solver, which is the default solver from PuLP, the library used to define the decisions variable of the model; the second one is Gurobi 8.1.1 as it has an API integration with Python and PuLP and allows to compare the results with only minor modifications.

An advantage of Gurobi over CBC is that Gurobi, before testing, already has a pre-solving function where is able to eliminate the part of the constraints and decision variables, being then able to solve the entire problem with much less complexity and achieving results much quicker.

Table 5.5: Different Tests with its number of receptions and shipments

Test	Dates	Inbounds	Outbounds	Creating (s)	Solving (s)
1^{st} - CBC	$1^{st}-21^{st}$ May	170	3 743	1 394	951
1^{st} - Gurobi	$1^{st}-21^{st}$ May	170	3 743	471	176
2^{nd} - CBC	$1^{st}-21^{st}$ March	539	3 578	2 431	3 704
2^{nd} - Gurobi	$1^{st}-21^{st}$ March	539	3 578	2 560	207
3^{rd} - Gurobi	$1^{st}-21^{st}$ January	144	4 659	3 675	390

It is important to note that 3600 seconds was defined as the maximum amount of time allowed for a solver to find the optimal solution. The goal is to check its feasibility in case the amount of data grows and the solver is no longer able to provide with an optimal solution within the available time for outputs to be withdrawn.

The first conclusions withdrawn from Table 5.5 sustain what was mentioned earlier.

Test number 1, which matches the low-season demand, shows a low number of both receptions and shipments. It is already observable that CBC shows a lack of strength that will prevent it from being scalable, while the solver from Gurobi presents good results.

The test number 2 is characterized by a peak of receptions, mainly due to re-orders, and a similar number of shipments when comparing with Test 1, most likely associated with the opening of the sales channel of e-commerce, which tends to maintain a steady flow throughout the rest of the season. CBC, although able to provide with an optimal solution, did not fulfill the criteria to achieve a final solution in the time frame provided.

Finally, the third test was only solved with Gurobi and showed a high number of receptions (not the highest since the peak of receptions happen before the beginning of the season) and the highest number of shipments. Although the number is relatively small, as Table 5.6 confirm, the number of SKUs involved is considerably higher.

Another conclusion withdrawn lays in the execution of the algorithm. Even though the solver is able to solve the problem rather fast, the number of the decision variables and constraints raises an issue regarding its feasibility as the number will increase as the company expands its operations.

5.4 Analysis of Results

As previously mentioned, the results obtained were decomposed into its different fractions and analyzed separately. Table 5.6 shows the three tests and the number of products transacted in the period of time selected and the corresponding overall costs.

Table 5.6: Comparison of the values between the Real situations and the Model predictions

Test	Dates	Receptions (SKU)	Shipments (SKU)	Costs (€)
1^{st} - Real	$1^{st} - 21^{st}$ May	4 694	10 827	65 716
1^{st} - Model	$1^{st} - 21^{st}$ May	4 694	11 987	52 394
2^{nd} - Real	$1^{st} - 21^{st}$ March	7 552	13 765	98 804
2^{nd} - Model	$1^{st} - 21^{st}$ March	7 571	14 020	88 711
3^{rd} - Real	$1^{st} - 21^{st}$ January	6 943	59 171	202 903
3^{rd} - Model	$1^{st} - 21^{st}$ January	6 879	63 163	182 323

The first and most important conclusion is provided by Table 5.6 related to the overall costs obtained. It is possible to check those better outcomes were provided in all the three tests, guaranteeing the strength of the algorithm developed.

Naturally, as the model is prescribing an optimal solution for a given time frame, the results regarding the number of receptions and shipments can differ from reality, as the fixed parameter was the dates where the model should optimize. This said, to the volume transacted in that period, the overall costs must be duly compared between the reality and the model.

5.4.1 Cost Framework

A point worth to mention is that, at this moment, the transportation from the suppliers to HUUB's warehouse is either managed directly by the brand or by HUUB which will then charge this extra cost. Therefore, the cost is not accounted for here as the scope of the optimization is based solely upon HUUB's costs. It was with this thought in mind that the time frames chosen for the different examples did not comprise the main receptions as these are not considered.

The goal of the linear optimization model designed was the reduction of the overall costs. However, just a comparison of the total costs is a too simplistic analysis, that does not allow to understand where in the supply chain resides the biggest costs, the biggest chances for improvements, or what are the real margins that the company can obtain in order to establish a price based on more sustained analysis.

With this thought in mind, the company will not only gain better insight for the internal operations and focus upon the sections that can be further improved but also supports more effective negotiation with potential new clients or external stakeholders, once there will be a better knowledge of the impact every decision might have.

Table 5.7: Comparison of the costs between the Real situations and the Model predictions

Test	**Inbounds (€)**	**Outbounds (€)**	**Shipments (€)**	**Trans- -shipments (€)**	**Storage (€)**	**Delays (€)**
1st - Real	1 878	7 054	51 574	0	5 210	-
1^{st} - Model	1 878	9 797	40 108	330	5 281	0
2^{nd} - Real	3 021	6 118	83 615	535	5 515	-
2^{nd} - Model	3 029	8 159	70 837	990	5 696	0
3^{rd} - Real	2 777	11 826	180 374	2 580	5 426	-
3^{rd} - Model	2 752	14 535	152 671	5 280	7 085	0

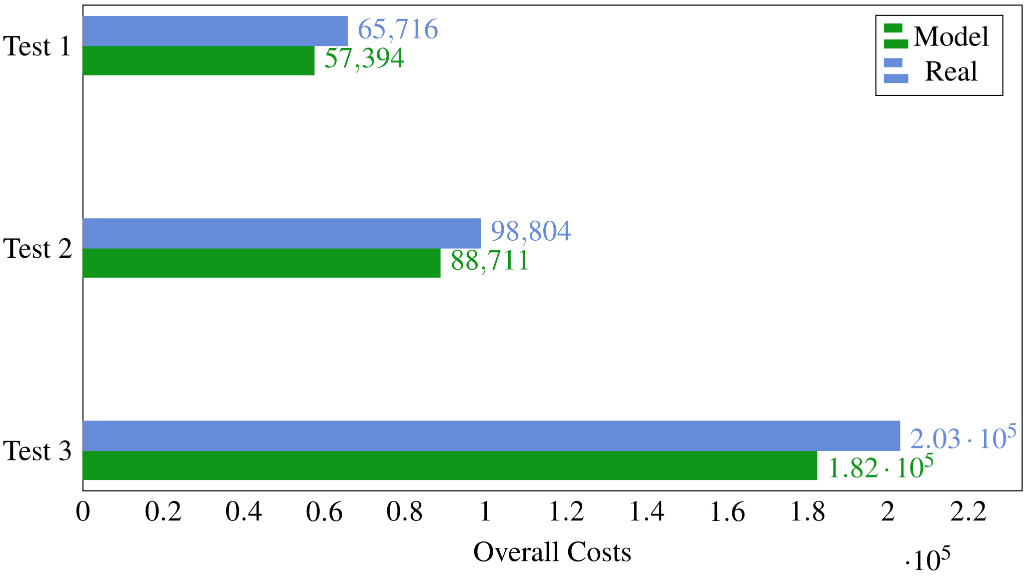

Figure 5.2: Comparison of the Overall Costs between the Real and Model costs

A first note must be regarding the data considered for these tests. Since the different analyses were entirely based upon previous moments, almost all the data was fully available in the database, avoiding the need for predicting unexpected demand. Therefore, for these three tests, the demand and the associated costs were entirely deterministic. Nevertheless, when applying the algorithm with the goal of optimizing the future, stochastic demand will be taken into consideration and translated into guaranteeing enough stock in all the warehouses if unexpected new orders may arise based on the analysis previously made and explained in Section 4.4. Furthermore, the cost of the leftover storage in the objective function will also be calculated as a Poisson's distribution.

The inbounds and outbounds costs are related to the warehousing activities of the receptions and shipments, respectively. Due to a lack of information in the database regarding the true estimated due date to the end-customer, it was impossible to calculate the potential delay costs that HUUB incurred during the time where the tests are being done, therefore assumed as zero.

In general, the model was able to predict a better outcome than the one that took place in the past, providing savings of 12.7%, 10.2% and 10.1% in each test, respectively. The main conclusion withdrawn relies on the benefit that DAMCO's warehouse provide to HUUB's overall SC costs.

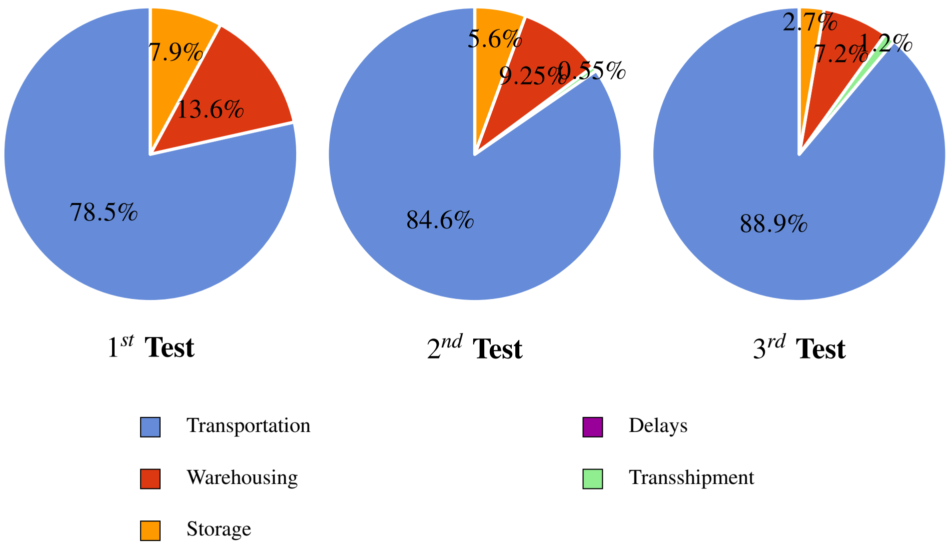

Figure 5.3: Costs Distribution from the Real tests

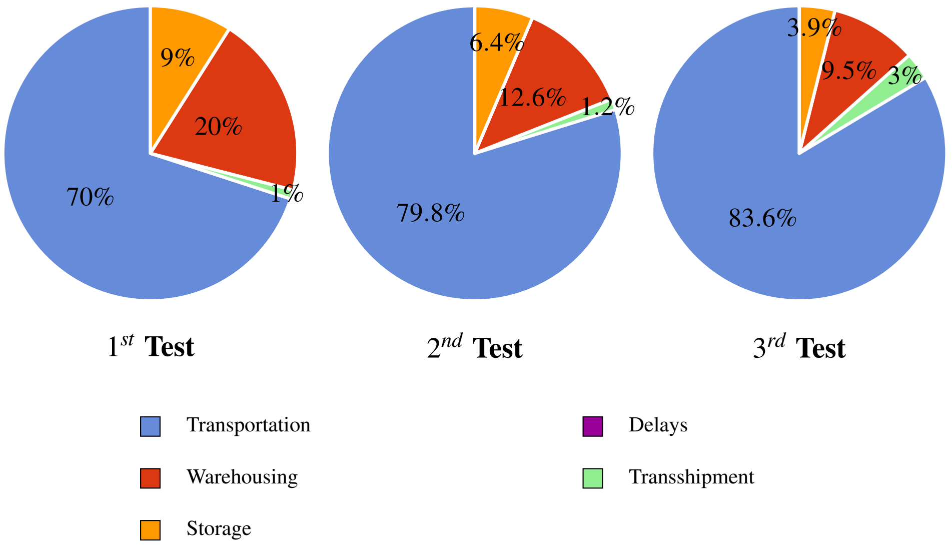

Figure 5.4: Costs Distribution for the Model tests

As can be seen in Figure 5.3 and 5.4, the transportation cost represents the majority of the overall costs, proving the need to optimize this flow. The usage of transshipments, although representing a small part in overall, greatly impacts the total cost of transportation, proving its need.

One conclusion withdrawn from the comparison between the Real and Model tests is that naturally both the storage and warehousing processes are more costly for the Model as outsourcing them is more expensive than doing it at HUUB. It is easily understandable that there is an increase of activity in DAMCO's warehouse as the transshipment costs also gets higher. Nevertheless, although all of these partitions are higher, the impact on the shipments surpasses all of them together, proving it to be beneficial, by reducing the shipment costs in a percentage of 8.5%, 4.8% and 6.3% for each test respectively.

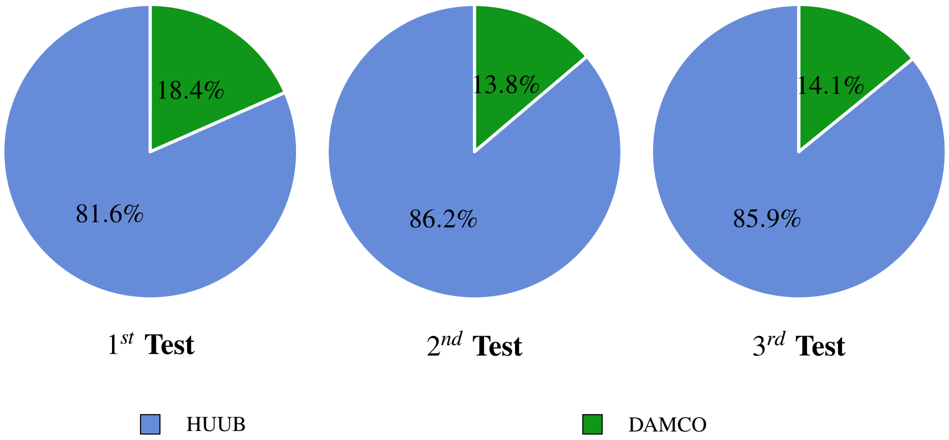

Figure 5.5: Outbound Distribution

An important aspect relies on the usage of DAMCO's warehouse in the totality of shipments. As it can be seen in Figure 5.5, HUUB still manages the majority of shipments, whereas DAMCO only has a relatively small percentage. The reasoning is due to the pricing table provided by DAMCO. Although deliveries to the center and north of Europe, where HUUB's main clients are from, get benefits from being shipped from the Netherlands, for other locations HUUB still does not have prices attractive enough. Furthermore, DAMCO limits the types of Service Level that HUUB can use, providing only the most costly one making HUUB lose flexibility of combining the earlier planning with shipping products with higher transit time and at a reduced cost.

5.5 Sensitivity Analysis

In this section, after getting the initial results, a sensitivity analysis is also performed to study how objective values are affected by the relaxation of certain constraints.

This analysis will focus mainly upon the restrictions that have a higher probability of being modified in the near future. The goal is to predict what changes will occur in the entire supply chain by the relaxation or exclusion of certain restrictions of the optimization model. The tests will be computed for the optimization of the high-season, $1^{st} - 21^{st}$ January, as this is the one that entails bigger expenses and can be optimized with a more significant impact.

This said, the study will perform tests with combinations of the following points:

1. **[Inbound]** Remove the constraint (4.10), allowing the receptions to go directly to another warehouse in the network;

2. **[Relaxation]** Relax the penalty cost of (4.5), incurring in a smaller cost in case a shipment does not arrive in time to the end-customer;

3. **[Deliveries]** Update the constraint (4.8) making it greater or equal to 1, allowing for a reception or a shipment to be associated with more than one warehouse. Consequently, this would also update the constraint (4.12), making the $quantity^n_{iklt}$ equal to the sum of its decision variables Z^n_{klt}. The updated restrictions can be found below.

$$\sum_{k=1}^{K}\sum_{t=1}^{T} Z_{klt}^{n} \geq 1 \quad \forall n$$

$$\sum_{k=1}^{K}\sum_{t=1}^{T} z_{iklt}^{n} * Z_{klt}^{n} = quantity_{iklt}^{n} \quad \forall n$$

Table 5.8: Sensitivity Analysis for different scenarios

Test	**Inbounds (€)**	**Outbounds (€)**	**Transport (€)**	**Storage (€)**	**Delays (€)**	**Total (€)**
Original	2 752	14 535	157 951	7 085	0	182 323
1^{st} - Inbound	2 584	9 523	154 651	2 586	0	169 344
2^{nd} - Relaxation	2 752	14 535	157 951	7 085	0	182 323
3^{rd} - Deliveries	Solver exceeded the maximum amount of time allowed					

Table 5.8 provides the outcomes of the tests realized for the sensitivity analysis and the original cost that occurred with the AS-IS situation. The column "Transportation" aggregates the values from "Shipments" and "Transshipments" from Table 5.7. The main conclusions withdrawn from this sensitivity analysis can already provide valuable input when considering future strategical decisions.

5.5.1 Test 1

The possibility of accepting receptions in DAMCO's warehouse proved to be beneficial in approximately 13 000 € when comparing with the LP model (7.12%). However, as mentioned before, the shipments to HUUB's warehouse currently holds no cost for the company, as this transportation cost is fully charged to the brands. The reasoning behind this decision is the fact that the majority of suppliers operate in Portugal and the shipment to the warehouse is relatively cheap. If a possibility arises of shipping directly to DAMCO's warehouse, since the distance is considerably larger, a cost might be charged to HUUB. However, it is now possible to know the margin where HUUB can negotiate in.

Another point that is needed to be mentioned is the lack of transshipments. As the receptions can now be made in several warehouses, the need to ship products between warehouses fades. Nevertheless, this is the case for the given time frame, not being a conclusion that can be propagated to all situations.

Finally, it is important to refer to the percentage of shipments that were split. From the original 6 879 items received in this time frame, only 699 (10.16%) went directly to DAMCO's warehouse, whereas the remaining 6 180 (89.84%) still went to HUUB's warehouse. This said, the savings of 13 000€ should be associated with the 699 shipments since the remaining ones followed the same path of the baseline solution.

5.5.2 Test 2

This test aimed to relax the constraint related to the failure in fulfilling the established SLA by providing a lower penalty cost in the objective function. The goal was to provide more freedom to the model and allocate orders to other schedules even if that compromised the due date agreed upon. The result proved that it would not affect the final outcome. The costs would be exactly the same since the algorithm has already enough flexibility to allocate the orders to a specific date where it can fulfill the SLA and not incur more costs. The test was realized, as mentioned before, with access to one single instance and therefore, should not be generalized before more tests are conducted in order to withdraw some more valid conclusions.

5.5.3 Test 3

As it is observable, Test 3 was not able to provide with an optimal solution within the time interval provided to the solver. This shows strong evidence regarding the expected potential issue for the future. By allowing the algorithm to be more flexible and compare a drastically larger number of possibilities, it creates an amount of complexity unsolvable through linear programming. This said, new options for the development of the algorithm must be considered if the possibility of fulfilling a client can derive from two or more different warehouses.

Chapter 6

Conclusions

Supply Chain Management has proven to be a key component when increasing the competitiveness advantage against *vis-à-vis* similar companies. Nevertheless, the tools required for an effective management reveal themselves quite complex, even further when considering them within a framework of multiple variables together with internationalization, a necessity of maintaining low costs, increasing the flexibility to new scenarios and ensuring environmental sustainability.

This dissertation, developed on a logistics company providing outsourced services for the fashion industry, aimed to address the lack of sustained reasoning regarding the allocation of stock through the warehouses of the company depending on the demand and costs throughout a season.

Since HUUB mainly works as an orchestrator of its clients' supply chains, the complexity increases even more as the different brands possess different products, with different demands and needs, requiring a specific characterization.

Until the beginning of this dissertation, stock allocation and transport planning were manually handled by HUUB. This was done taking into account the receptions expected in the short-term and combine with the shipments that needed to be done, considering the possibility of transshipping products between warehouses if that proved momentarily profitable. However, due to the natural lack of communication or planning with too little time ahead, the excessive costs due to the lack of synergies were getting too high, together with the unfulfillment of SLAs when the orders arrived in the peak of the season.

The complexity of the status described led to the elaboration and implementation of an LP model with the goal of dynamically allocate stock from several brands to different warehouses in the network, considering factors such as the inbounds and outbounds of each SKU expected, storage cost and location of each warehouse and transit time for the last-mile delivery. From this input, the algorithm predicted where to receive each reception from a supplier, from where to ship an order to an end-customer, what products to maintain in each warehouse and which should be shifted between them, with the goal of minimizing the overall cost that HUUB would entail.

In the end, the algorithm will be responsible for the planning HUUB's operations by, (i) informing the SC team which, when and where each reception and shipment should be allocated, (ii) informing the Warehousing team regarding orders to handle in a certain day, and (iii) provide visibility to HUUB's clients, through Spoke, regarding their stock's location and goods in transit.

6.1 Main Outcomes

The main goal of this dissertation was the development of an algorithm that could optimize the flow of inbounds and outbounds of products through a network of warehouses. The algorithm is meant to run daily in order to predict what must be dealt within that day, but have a scope of three weeks to take into consideration potential movements of stock between warehouses if it proves to be beneficial. This said, the algorithm decomposes into two main sections: the first stage - the collection of data and generation of the decision variables and constraints that derive from it - and the second stage - the optimization of the model and the achievement of one optimal solution. Certain conclusions arise from each stage that should be properly separated:

1. The first stage contains the vast majority of the running time of the algorithm. Even though at the moment it is still possible to obtain results with the amount of data generated, such scenario might not be possible if the number of possibilities drastically increases with the expected growth of the company.

2. The second stage proved that the solver available for free usage does not possess the capabilities to deal with large amounts of data, characterized in the beginning of each season. On the other hand, Gurobi proved to be a solver that can generate a solution and be used for future attempts. Nevertheless, as a commercial solver, there is a cost associated with such a decision that needs to be further analyzed.

In another perspective, both the results obtained from the current situation and an analysis of the impact of future strategical decisions made by HUUB provide some insights to take into consideration, such as:

1. In all tests executed, the algorithm was able to provide a better solution than the decisions made by HUUB, with savings of 12.7% for the low-season, 10.2% for the mid-season and 10.1% for the high-season. This proves HUUB's need for the algorithm if the main goal is based upon the escalation of operations and growth in the amount of volume transacted.

2. The transportation cost is clearly the major cost to take into consideration. Increasing the competitiveness in this field will greatly impact the overall performance of HUUB, even if the other parameters are not affected;

3. The percentage of outbounds from DAMCO's warehouse is still below expectation when compared with the potential its location has. A careful analysis between the prices provided by DAMCO for the HUUB's most used destinations must be done and start by focusing on the reduction of those transportation costs;

4. Regarding the sensitivity analysis, (i) it was proven that receiving a reception in other warehouses besides HUUB's is less costly but must be analyzed case by case as the transportation cost from the supplier to the warehouse is currently not being accounted for, (ii) the model is able to optimize the entire supply chain without incurring in any delays and, (iii) sending parts of the same shipments from different warehouses proves to be beneficial.

6.2 Future Work

Several improvements points arise from the development of this model, both operational as planning wise. As the goal of the model is to be as agnostic as possible, being able to run entirely on its own, all the parameters that are currently being manually defined, need to be gathered in a database, updated when necessary, and directly linked to the model. As an example, it is easy to predict the opening of a new warehouse in HUUB's network, creating a whole set of values, where some can already be available in the database, but others will still not be included, the costs associated with the warehousing activities, the warehousing SLAs, transportation costs, among many others. The digitalization of this data needs to be one of the next steps.

The algorithm as it is designed proved not to be scalable in terms of running time. A hypothesis to be taken into consideration is the implementation of the model in a more powerful machine. A solution lays in employing it in the Amazon Web Services (AWS) servers, which would be able to read the data and prepare the model in a much faster way. Furthemore, AWS grants the possibility of saving each record, allowing a future analysis of the results and the evolution over time.

As has already been mentioned before in this dissertation, the flows in the supply chain need to be more flexible in order to increase the dynamics and the synergies of the products being stored. Creating the flow where receptions are allowed to be received in another warehouse other than HUUB's or creating the possibility of shipping directly from suppliers to the end-customers can drastically reduce the costs as certain steps are no longer needed.

Another restriction that needs to be worked upon in order to increase the strength of the algorithm, is the possibility of allowing partial shipments to depart from different warehouses, where its total is equal to the quantity ordered. This would avoid the need for transshipping products in order to group them and only then send the entire order together.

This model has been developed with the aim of coordinating forward logistics. This said, the majority of actions will be deterministic by default with only a small part being considered as stochastic (such as predicting orders that may arise with less than three weeks of advance or the disposal of leftover products). Nevertheless, an important flow, which has not been considered in the scope of this dissertation, is the inclusion of reverse logistics, allocating potential returns to warehouses and having it in consideration when deciding where to dynamically allocate stock.

Another issue that will arise is regarding the solver used for this dissertation. As it was seen, Gurobi was the solver that produced better results and should, therefore, be adopted as the main solver of the model. However, Gurobi 8.1.1 only has the availability of one academic license for the period of one year to perform the tests, having, therefore, an expiration date and only be performed on this computer. Furthermore, and taking into consideration the growing number of brands under HUUB's control, the opening of new warehouses, together with the potential combinations of transshipments and an increase in its frequency, the complexity of the algorithm might be too high to be solved in its optimality. Therefore, new techniques need to be discussed and potential new implementations developed to sustain this growth. A natural solution focuses on the development of a meta-heuristic that could quickly guarantee the allocation of stock, finding a good balance between the performance of the algorithm and the quality of the solution found.

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Appendix A

Linear Programming Model

A.1 Approximate Weight and Volume of each Product

Table A.1: Weights and Volume per Product Family and Age Group

Product Family	**Product Age Group**	**Weight** (kg)	**Volume** (cm_3)
Bags & Wallets	Adult	0.406	4549
Bags & Wallets	Kid	0.667	1430
Bedroom	Baby	0.329	759
Bottom	Adult	0.327	3766
Bottom	Baby	0.197	643
Bottom	Kid	0.192	1213
Flat	Kid	0.990	1470
Hair Accessories	Adult	0.299	3373
Hair Accessories	Kid	0.344	496
Nightwear	Baby	0.265	390
Nontextile	Adult	0.346	4501
Nontextile	Kid	0.240	1430
Other	Baby	0.384	727
Overall	Adult	0.266	2003
Overall	Baby	0.245	642
Overall	Kid	0.259	1046
Paper	Kid	0.444	62
Swimwear	Baby	0.228	423
Swimwear	Kid	0.240	447
Textile	Adult	0.365	4473
Textile	Baby	0.252	224
Textile	Kid	0.162	427
Top	Adult	0.459	3338
Top	All	0.240	1824
Top	Baby	0.242	600
Top	Kid	0.295	1054

A.2 Parameters

Table A.2: Parameters of the Linear Optimization Model

Parameter	Description
I	Last Product
J	Last Supplier
K	Last Warehouse
L	Last Customer
M	Last Reception
N	Last Shipment
T	Last Period
$Cost_{jk}^{w}$	Cost per kg for transporting from supplier j to warehouse k
$Cost_{jk}^{int}$	Fixed Cost for a transport from supplier j to warehouse k
$Cost_{kd}$	Cost of transporting one pallet from warehouse k to warehouse d
$Cost_{kls}^{w}$	Cost per kg for transporting from warehouse k to customer l on SL s
$weight_i$	Weight of product i
$Cost_{kls}^{int}$	Fixed Cost for a transport from warehouse k to customer l with SL s
$Cost_{ik}^{inb}$	Cost of receiving a product i in warehouse k
$Cost_{ik}^{out}$	Cost of shipping a product i in warehouse k
$Cost_{k}^{out}$	Cost of shipping an order in warehouse k
$Cost_{ik}^{stock}$	Cost of storing a product k in warehouse k
$P[N(t) = r]$	Probability of dispatching r products in period t
λ	Expected number of occurrences
$Cost_{k}^{delay}$	Cost for a delayed shipment in warehouse k
$NrDays_n$	Number of days that shipment n was delayed
$Cost_{j}^{delay}$	Cost for a delayed reception from supplier j
$NrDays_m$	Number of days that reception m was delayed
$Cost_{worker}^{extra}$	Cost of hiring a temporary extra worker
$NrWorker_{kt}^{reg}$	Number of regular workers required for warehouse k during period t
$NrWorker_{kt}^{ex}$	Number of extra workers required for warehouse k during period t
$WorkingTime$	Daily amount of time available per worker
cap_k	Maximum storage capacity for warehouse k
$quantity_{iklt}^{m}$	Quantity of product i in inbound m
$quantity_{iklt}^{n}$	Quantity of product i in outbound n
vol_i	Volume of product i
AD_n	Date of arrival of shipment n considering the date it is dispatched and the lead time it will to take to arrive to the end-customer
EA_n	Expected Arrival to end-customer of shipment n
PT_{ik}^{m}	Processing time for a product i in warehouse k related to a reception m
PT_{ik}^{n}	Processing time for a product i in warehouse k related to a shipment n
$Movements_{kt}$	Maximum number of items processed in warehouse k during period t
Max_t	Maximum amount of extra workers during period t