Analysis and optimization of JMD’s distribution chain

The Case Study of JMD

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Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Abstract

The concepts of supply chain (SC) and its management have been studied and improved, recognizing their crucial role in delivering goods to the right locations with the right quantity at the right time. Furthermore, the literature shows a growing emphasis on sustainability within SC, evident in strategies such as the Triple Bottom Line approach in the designing and planning of SCs network. This work focuses on analyzing the SC of JMD, a leading food distributor in Portugal, responsible for the presence and distribution of several food and beverages brands in the different Portuguese retail shops and other channels. This work aims to design and plan a SC network, presenting recommendations as the number of warehouses needed and their locations, through a strategical approach. Taking the inbound and outbound operations of JMD’s SC, contemplating suppliers, warehouses, and the different clients, an optimization tool is developed based on da Silva et al., (2020) to support decisions regarding the configuration network. The findings propose a reconfiguration of the network to enhance resilience against unforeseen circumstances. It is recommended the addition of one warehouse in Gaia to the already existent one in Azambuja, aiming to reduce costs and environmental impact. A scenario that considers flows between warehouses and the operation of three warehouses (Azambuja, Gaia and Madrid) with lower transportation costs reveals to be even more financially advantageous. Both scenarios should be weighted and aligned with JMD’s strategic goals and operational efficiency. Regular monitoring of transportation costs will be essential for ongoing operations.

Key Words: Distribution Supply Chain, Supply Chain Design, Configuration Network, Sustainability, Optimization, Retail

Resumo

Os conceitos de cadeia de abastecimento e sua gestão têm sido estudados e melhorados, reconhecendo o seu papel crucial na entrega de bens nos locais, quantidade e momento certos. Além disso, a literatura revela ênfase crescente na sustentabilidade nas cadeias de abastecimento, evidente em estratégias como a abordagem Triple Bottom Line no desenho e planeamento da rede. Este trabalho centra-se na análise da cadeia de distribuição da JMD, empresa líder na distribuição de produtos alimentares em Portugal, responsável pela distribuição de várias marcas de alimentos e bebidas nas diferentes lojas de retalho portuguesas e noutros canais. Este trabalho tem como objetivo desenhar e planear a configuração da rede, apresentando recomendações como o número de armazéns necessários e respetivas localizações, através de uma abordagem estratégica. Considerando as operações de entrada e saída da cadeia da JMD, fornecedores, armazéns e clientes, desenvolveu-se uma ferramenta de otimização baseada em da Silva et al., (2020) para apoiar decisões relativas à configuração da rede. Os resultados propõem uma reconfiguração para aumentar a resiliência face a circunstâncias imprevistas. Recomenda-se adicionar um armazém em Gaia ao já existente na Azambuja, objetivando reduzir custos e o impacto ambiental. Um cenário que considere os fluxos entre armazéns e a operação de três armazéns (Azambuja, Gaia e Madrid) com menores custos de transporte revela-se financeiramente ainda mais vantajoso. Ambos os cenários devem ser ponderados e alinhados com os objetivos estratégicos e de eficiência operacional da JMD. A monitorização regular dos custos de transporte será essencial para a continuidade da operação.

Palavras-chave: Cadeia de Abastecimento de Distribuição, Desenho de Cadeia de Abastecimento, Configuração da Rede, Sustentabilidade, Otimização, Retalho

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List of Abbreviations and Acronyms

ATO	Ant Colonization Optimization
CVaR	Conditional Value-at-Risk
DDP	Delivered Duty Paid
FEFO	First Expire, First Out
FIFO	First In, First Out
IT	Information Technology
KPI	Key Performance Indicators
LCA	Life Cycle Assessment
LS	Luís Simões
OoH	Out of Home
SC	Supply Chain
SCM	Supply Chain Management
SKU	Stock-Keeping Unit
SSC	Sustainable Supply Chain
TBL	Triple Bottom Line
3PL	Third-Party Logistics

Chapter 1 – Introduction

1.1 Problem Contextualization

Over the years, the concepts of supply chain (SC) and supply chain management (SCM) have been studied and improved, due to the extreme importance of SC since they are responsible for delivering of goods in the right locations with the right quantity at the right time. In this line of thought, managing a supply chain presents some challenges and the objectives should be clear to support the decisions made. These objectives, generically, stands for the improvement at, at least, one of these dimensions: cost, dependability, speed, quality, and flexibility (Slack, N, Brandon-Jones, A, Johnston, R & Betts, 2012).

Furthermore, the literature shows that the sustainability has gaining importance in supply chains and in its management, with the increase of society pressure for a wealth environment (Barbosa-Póvoa et al., 2018) (da Silva et al., 2020). Nowadays, sustainability has being seen as a business opportunity, enabling the company to seek for a market position (Mota et al., 2018). With this growing significance, the Tripple Bottom Line concept appeared, establishing the alignment between the three different dimensions of sustainability: economic, social and environmental (Rajasekaran, 2013).

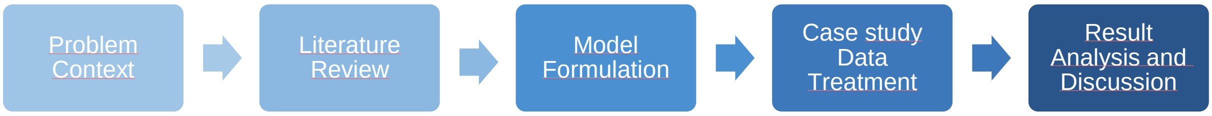
The supply chains have become even more complex systems with the incorporation of the globalization and sustainability. Therefore, designing, planning, and managing a supply chain presents many challenges and decisions to approach, and should existing an effort to consider the three pillars. Depending on the decision level where the problem is being assessed, there is the strategical, tactical and operation level, each one of them narrower than the previous (Mota et al., 2018).

This work focuses on JMD's case study. JMD is the leading food distributor in Portugal with a history of more than 100 years and being responsible for the presence and distribution of several food and beverages brands in Portugal in the different retail shops and other channels. Aiming to improve its service level and the satisfaction of their partners and customers, JMD supply chain will be studied. Through a strategical approach, the goal of this dissertation is to design and plan a supply chain network, presenting recommendations as the number of warehouses needed and their locations. It should be noted that an optimal supply chain design should reflect the best possible configuration and operation of all elements that are part of the supply chain, such as suppliers, manufacturers, and distributors (Garcia & You, 2015).

Taking the inbound and outbound operations of JMD's supply chain, starting in the suppliers, going through the warehouses, and ending in the different Portuguese clients (the retail network), an optimization tool is developed based on "Environmental monetization and risk assessment in supply chain design and planning" (da Silva et al., 2020) to support decisions regarding the configuration network.

1.2 Objectives and Methodology

This dissertation aims to study the restructuration of JMD supply chain, at a strategical level, analyzing the different solutions considered by the company, through an optimization model applied to JMD case study. For this study, the following methodology was used:



1. **Problem context:** The first step aims to present the case study approached, as well as giving the context of the company operations. It is important in this step to have insights regarding its supply chain, the activities and entities involved in both inbound and outbound operations, presenting the problem to be studied.
2. **Literature review:** To assess the problem, the next step is to conduct a literature review in order to highlight important concepts regarding the supply chain management and the inclusion of sustainability in this process. Furthermore, this literature review should include a research on the optimization models tools developed for the design and planning of a supply chain network.
3. **Model formulation:** This step aims to develop a mathematical model considering the case study presented. This model is, then, implemented in an adequate software to enable the comparison between different scenarios, as well as its analysis.
4. **Case study Data Treatment:** For the implementation of the model, it is necessary to collect and process the data applied to the case study. Data regarding the operations, flows, entities, costs and environmental impact should be assessed and treated.
5. **Results Analysis and Discussion:** The final step aims to present the results taken from the implementation of the developed model, as well as compare the different scenarios. A discussion of the results should be conducted, proposing a final recommendation to be discussed with the company.

1.3 Dissertation's Structure

The Dissertation Project consists of the following seven chapters:

- **Chapter 1 – Introduction:** This is the present chapter, which briefly describes the problem, highlighting the context and motivations for the development of the Dissertation Project. Also, the main goals of this study are presented, as well as the methodology followed and the structure of the dissertation.

- **Chapter 2 – Case Study:** In this chapter the company is introduced, giving some context to its operations and activities, the demographic background where JMD is inserted, and the market where it operates. The JMD supply chain is presented, describing the main activities and entities regarding the inbound and outbound operations, as well as the challenges among the supply chain. Giving the company context, the problem studied is then generally assessed.
- **Chapter 3 – Literature Review:** The literature review chapter aims to study the theoretical basis that underlies this dissertation. In this line of thought, concepts related with supply chain, supply chain management and sustainability, such as the Triple Bottom Line and Reverse Logistics, are defined according to the existing literature. At the same time, the process of designing and planning a supply chain network is assessed, researching on existing optimization models.
- **Chapter 4 – Model Formulation:** In the fourth chapter, the model is characterized, and a mathematical formulation is presented, with the objective functions and constraints.
- **Chapter 5 – Data Collection and Treatment:** This chapter presents the data collected, essentially provided by the company, and the treatment process, as well as the simplifications and assumptions made to deal with the complexity of the problem.
- **Chapter 6 – Results:** In this chapter, the results for the different scenarios are presented in a single optimization objective approach, considering two dimensions of sustainability, and establishing a comparison between them. A sensibility analysis to cost parameters is conducted, evaluating its impact on the recommended solution.
- **Chapter 7 – Conclusion:** The final chapter aims to draw a conclusion of the dissertation, highlighting the beneficial solutions for the company and the limitations of the work to be considered in future studies.

Chapter 2 – Case Study

This chapter introduces the case study, presenting the JMD company and is divided into five sub-chapters. The first subchapter (section 2.1), subdivided into three sections, seeks to describe the company and its business area, as well as its strategy. The company's internal structure is also presented, specifying the activities of some of the most relevant departments to the study. Finally, in this subchapter, the company's retail channel is analyzed in greater depth, as it is the channel that will be the focus of the study. The second subchapter (section 2.2) provides a demographic context in order to understand the typical Portuguese consumer and, therefore, JMD's target audience. The third subchapter (section 2.3), subdivided into three sections, aims to explain the company's supply chain, which is the focus of the study. In addition, the inbound, warehouse and outbound activities of the supply chain are described, as well as the challenges presented along the chain. Subsequently, based on knowledge of the company and its supply chain, the next subchapter (section 2.4) presents the problem to be studied throughout the work carried out. Finally, last subchapter (section 2.5) intents to present a conclusion throughout the case study analysis.

2.1 JMD

2.1.1 The company

JMD is the leading food distributor in Portugal with a history of more than 100 years, being created in 1921 as a family-owned business. Nowadays, JMD reports entirely to Movendo – Industries B.V. As a food distributor, JMD is responsible for the presence and distribution of several food and beverages brands in Portugal in the different retail shops and other channels. Thus, JMD is the connection point between the different brands and the markets, where they are going to be delivered. Over the years, JMD has been awarded in different categories, achieving important levels of performance, being some of them presented below:

- Responsible for over 55% of the total distribution in Portugal, being in the top 10 distributors sales

Source: D&B 2020

- Covers 10 food categories as a top 3 player

Source: Nielsen 2020

- Evaluated by several brands with Net Promoter Score 7,67

Source: JMD 2020 inquiries

Furthermore, it should be noted that in the last 8 years, JMD has outgrown the marketing, achieving 80 M€ of Net Sales.

JMD focuses his work on the partnerships built with the brands, aiming to deliver them knowledge to make them grow in the desired markets. To do this, the company offers expertise in different areas: Strategy & Consulting, Consumer & Customer Insight, Branding and Marketing Plan, Multichannel Reach and Execution Powerhouse. All the processes aim to be a collaborative one, giving power to the partnerships, while finding opportunities to maximize the growth of the brand and gaining market share, by covering the key channels. Regarding the values where this partnership is based, trust, agility, innovations, transparency, commitment, and collaborative are the ones that drive JMD's actions. Being divided in two groups (Business Discovery and Business Development), the focus is on both markets and brands' needs. The first one (Business Discovery) is responsible for studying the future and be aware of new trends, products, channels and opportunities. On the other side, the Business Development team is constituted by specialists focused on delivering results today, by knowing well the brand, market, as well as the executions and guidance.

From the supply side, JMD represents 37 food and beverages brands divided into 9 categories, building a diversified portfolio: cereals, coffee, tomato and dressings, snacks, indulgence, biscuits, dairy/desserts, drinks, and grocery others, as it is presented in the figure 1.

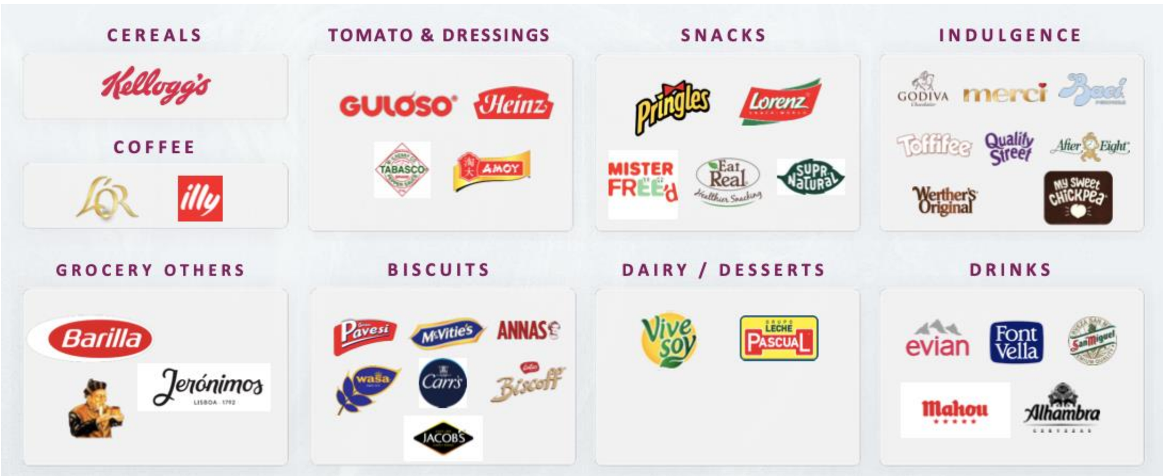


Figure 1 - JMD's food and beverage brands divided into categories

Furthermore, JMD has built a solid market coverage, being working with 6 different channels: Modern Retail, Wholesalers, Horeca, the also known as Out of Home (OoH), Independent stores, E-commerce and International. The modern retail channel is the largest one and the principal focus of the company, where the customers are daily met with their products; this channel is represented by the hypermarkets, supermarkets, discounters, and proximity stores in the Portuguese market. The wholesalers are a key channel in the Portuguese market, fulfilling the Food Service Industry and the proximity stores. Regarding the HORECA channel, JMD has a dedicate team working on this one, focused on leverage the brands and making them arrive to the customers in Gas Stations, Service Stations, Restaurants, Theme Parks and Airports, giving more margin that the modern retail. In the independent stores, the brands represented by JMD are category leaders in this channel, reaching thousands of consumers daily. JMD has been a pioneer company in the e-commerce channel aiming to answer to the strong and solid growth of the e-commerce over the last years in Portugal. In this channel, JMD is working with the main e-retailers and with the delivery platforms as Uber Eats, Glovo or Bolt. Finally, the international channel represents 5% of JMD's business, being represented in all the formal retail in Angola. Table 1 presents the net sales in 2022 per national channel.

Table 1 - Net sales in 2022 per national channel

Channel	Net Sales (in thousands of euros)	Percentages
Retail	67 987	76,23 %
Wholesalers	12 521	14,04 %
Islands	4 200	4,71 %
HORECA	4 421	4,96 %
Total	**89 182**	

Taking table 1, it is possible to affirm that the Retail Channel is the most representative, being responsible for around 76% of the net sales in 2022. For this reason, the current work will be focused on this channel. Later, the sales of this channel will be assessed for the development of the study. However, based on data provided by the company, it should be noted that companies as Kellogg's and Pringles are responsible for around 30% of all the net sales, followed by the companies part of the category "Tomato and Dressings".

Looking into JMD's strategy, it can be resumed into four points:

- Continue to invest in top retailers. It is important to continue to protect the relationship with certain clients, which have a considerable share market. In the retail channel these clients rely on Continente and Pingo Doce, that holds 55% of the market. However, sometimes these relationships are harder to manage, since these clients have a strong negotiation position.
- Over invest in proximity formats: These new formats have been gaining market share in the last years. At the same time, they have been revealing being more profitable, presenting a healthier growth.
- Increase footprint in discounters and specialists: By discounters and specialists, the company is referring retail supermarkets as Lidl or Aldi, presenting a different strategy from the biggest clients.
- Gain traction in OoH: This channel is composed by some pillars as organized restaurant, centralized hotels, capillary distributors, vending machines, petrol stations, service areas and theme parks. Among these places, the most sold products vary. For example, Evian water is one of the most sold products in service areas and the Pringles chips in theme parks.

2.1.2 Internal structure

JMD is essentially divided into 5 departments: Information and Technology (IT), Finance, Sales, Marketing (Brand Partnership) and Human Resources. The Sales and Marketing teams were the ones more involved in the development of this work, providing information and data. The sales team is divided into the 4 different channels (retail, wholesalers, OoH, and international), also including the trade marketing team (responsible for the execution of store audits and sales management at the point of sales), the customer care team, and also one person responsible for the logistics.

Furthermore, the marketing team is the responsible for the connection between the company and the brands. This connection is established through the definition of brand implementations, structuring a plan and defining the KPI's, which is done in conjunction with sales. At the same time, this team is responsible for engaging, receiving and retaining happy brands.

There is also a supply team, composed by 1 manager, 4 supply planners and 1 master data, who is responsible for the supply planning and master data, meaning:

- Stock management and purchase planning
- Creation and maintenance of master data (SAP), which involves some complexity

This team's work is, therefore, focused on ensuring stock availability at the right time for sale, communicating purchasing forecast to brands, ensuring timely disposal of stock, optimizing the time of the products in the warehouse, and guaranteeing the quality of internal JMD information, through the master data. At the same time, there is an articulation with the marketing team through the negotiation with the brands and the insertion of new products, and with the sales team through the clients forecast.

2.1.3 Retail Channel

As it was presented previously, JMD operates in different channels, being responsible for the representation of its brand partners in different stores. However, the core of its business is in the retail channel, representing around 65% of its operations. The retail channel includes all the supermarkets and hypermarkets, as well as convenience stores. Within the retail channel, 56% of JMD's operations are related with supermarkets and around 22% with hypermarkets. Figure 2 presents the distribution of the main clients in the retail channel in terms of market share in 2022 *(Kantar by ECO, 2023).*

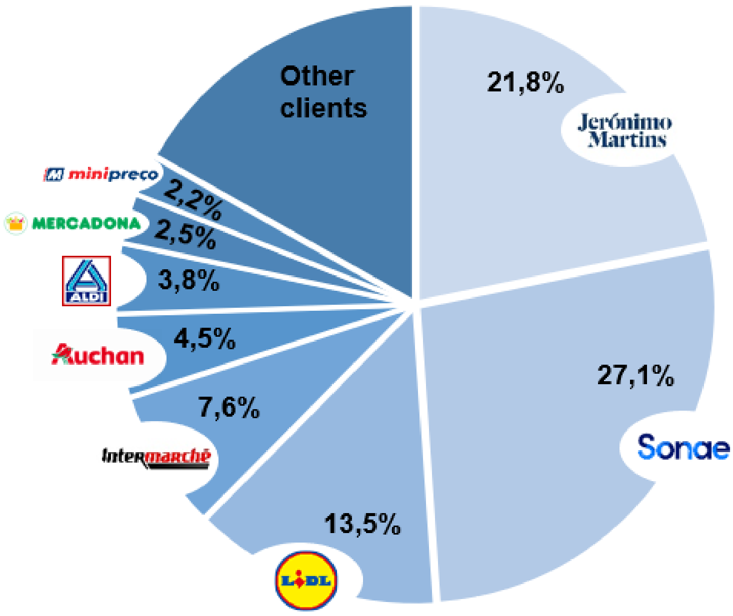


Figure 2 - Distribution of the retail sector in terms of market share in 2022

To continue to be the leader in the distribution channel in Portugal, JMD must be able to understand the fluctuations in the market, as well as to be sensitive to possible changes and to adapt themselves quickly. Some important notes about expected changes in the market were discussed with the company and presented below:

1) An important aspect to note is that the emergence of Mercadona in the Portuguese market can provoke some changes in the behavior of the other clients and in the overall market. It is expected that Mercadona will gain market share, taking it out from the players with lower shares (Minipreço, Aldi, Auchan, and Intermarché). Jerónimo Martins and Sonae have a high bargaining power, being able to establish requirements and, therefore, making them more demanding customers. However, it is also expected that their negotiating power starts to decrease over the years with these changes in the market.

2) It is also possible to observe that it has been existing a migration of the customer to the supermarket, instead of the hypermarkets. This impacts JMD, since the supermarkets choose only the brand leader in each category, due to space restrictions. Thus, JMD's strategy should be linked with having brand leaders in its portfolio, enabling the company to have presence in the supermarkets, and to be where the customers are and, therefore, where the sales are.

The modern retail channel presents some challenges, one of them is dealing with the expiry date. In this channel, it is considered that the products have only $\frac{2}{3}$ of the real validity, since they can not be sold to the clients after that date has expired. When the product reaches the limit validity, making it impossible to sell it in the modern retail, JMD sells it to the wholesalers, where the restrictions are not so strict or give it to “Banco Alimentar”, a Portuguese association who works against food waste and hunger.

2.2 Demographic Contextualization and Consumer Profile

JMD operates essentially in Portugal, which corresponds to 95% of its operations. The other 5% are related to the international channel, which is the only opportunistic channel aiming to increase sales volume. For this reason, it is necessary to study and analyze the context where Portugal is inserted on. By understanding the market contextualization in Portugal, as well as the Portuguese living conditions, since it will influence the average purchasing power, JMD is able to adapt and taking the most advantage of its operations.

There are two main factors that influence the purchasing power and Portuguese behavior in the retail shops: the inflation rate and the unemployment rate. The first one is directly related with the average purchasing power, when the inflation rate increases, the average purchasing power decreases, because with the same amount of money, people can buy less products. The second one also influences the purchasing power, due to people who are unemployed usually have a lower purchasing power than the employed ones, considering the active population. However, it is important to take into account that this rate is not always representative of the society, as it only considers the active population, taking out of the equation retired persons, who have an interesting consumption profile.

In Portugal, there is a big density of people in the middle age (between 40 and 70 years old). The way the population is distributed has a big influence on the consumer market. People of different ages look for different products and have different behaviors, which is reflected in their purchases of food consumer goods. Figure 3 presents the distribution of the population in Portugal according to their age and gender *(Population Pyramids of the World from 1950 to 2100, 2022).*

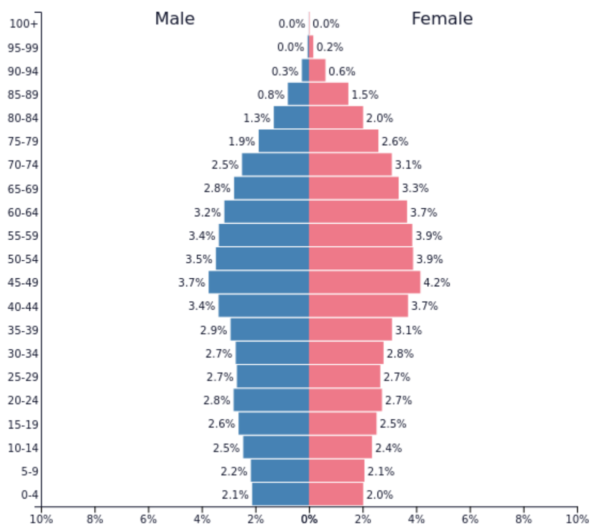


Figure 3 - Distribution of Portugal's population according to age and gender

In figure 3, the graph's shape indicates that there is a greater number of middle-aged people. This implies that there is a greater percentage of retired people, than active ones, tending to emphasize this difference over the years, since the birth rate is not keeping pace with the ageing population. This population distribution is crucial for JMD to understand the strategy they need to follow for each brand. For example, younger people look more for snacks and cereals. Nevertheless, there is a greater percentage of people in middle age going to the supermarkets than young ones. Therefore, the products in the supermarkets should also be targeting this age group in order to increase the sales. Furthermore, the number of foreign people is increasing, being most of them of a young age. This has a direct impact in some different channels:

- The restaurants' revenues increase
- The consumption in proximity stores (convenience stores) increase, explained by the fact that these people don't have car to go to bigger stores, as they usually live away from the city center
- The online sales, such as Glovo, UberEats, etc., increase. For example, for JMD the most sold product in the online channel is the water's bottle of Evian, explained by the fact that French people don't have access to Evian water in the proximity stores and, therefore, they buy it online. Thus, with the increased number of proximity stores, it is expected that online sales also increase, since this kind of stores have too many limitations to be able to sell certain brands that customers look for, making them buying it online.

When analyzing the Portugal contextualization, it should also be considered the overall scenario of wages and purchasing power. Portugal has one of the lowest average salaries in Europe, emphasizing the contrast with nearby countries such as Spain, France and Italy *(Average Annual Salaries in Europe 2019, n.d.).*

This economic frame situation makes Portugal a country addicted to special offers. According to some data given by JMD, 47% of the products bought in Portugal are in sales, comparing to a percentage of 17% in Spain. However, it is expected that the trend will be to normalize the prices at the lowest value possible. Furthermore, it is important to consider the fact that 64% of the consumers see the products for the first time in the supermarket. Therefore, JMD has an important role in putting its products with high visibility in the supermarket, having in mind that around 60% of the consumers that go to the supermarkets are more than 50 years old.

2.3 JMD Supply Chain

JMD has a linear supply chain, which is presented in figure 4, divided into three main areas: Inbound Operations, Warehouse Operations and Outbound Operations. Between these operations there are different entities involved in the process and different relationships to be managed.

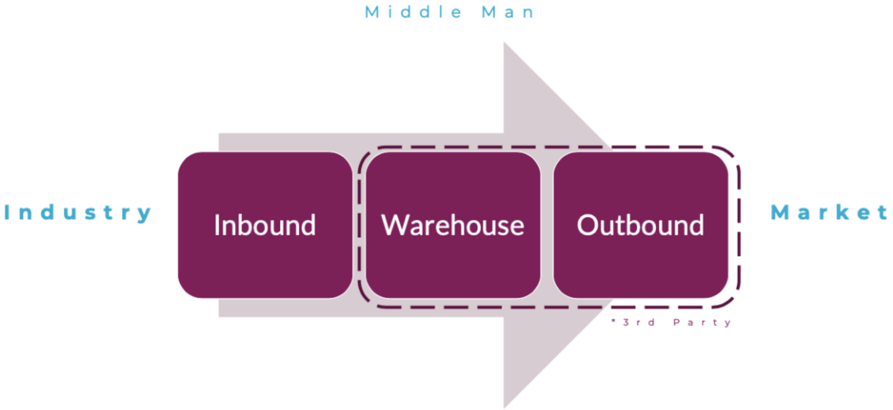


Figure 4 - JMD's supply chain representation

The different brands produce their products in their own facilities and deliver them in the warehouse, which is responsible to receive, store and distribute the products to the different clients. In the warehouse and outbound operations, JMD works with 3PL (third-party logistics), being Luís Simões responsible for all the operations in these two phases, which include the activities of receive, store and distribute the products. Luis Simões' warehouse is located in Azambuja, in the center of Portugal, from where all the products are then delivered to the different clients in Portugal.

In order to monitor the service among the supply chain, ensuring the customers' desires are met and protecting the relationships, JMD measures three different service levels: *complete, on time and in full*. The service level *complete* is related with what JMD invoices comparing to the number of orders received. Benchmarking the industry, an optimal value would be around 95%. However, JMD presents its service level at 86,6% and has been trying to improve it, by starting to understand where the root cause of this value is. The service level *on time* concerns what the brands, as suppliers, deliver to the warehouse. Lastly, the service level *in full* measures what Luis Simões delivers comparing to what was invoiced.

2.3.1 Inbound

The brands that JMD represents are the ones responsible for this part of the process. These brands produce their products in their own facilities and deliver them in Luis Simões' warehouse, where the inbound operations finish.

JMD works with around 37 brands, being some of them clustered in only one brand, since there are some big companies that own different brands. In this work, these companies are considered only has one brand, because the flow within these brands, that are part of the same company, is the same. These companies are JDE, that includes Illy and L'Or, both coffee brands; Pladis Biscuits, owning brands as McVities, Carr's and Jacob's, all biscuits brands; Lotus Bakeries, including Lotus and Annas biscuits; Storck, that owns Merci, Toffifee and Werther's, all known chocolate brands; Mahou – SM, a beer company, also has Cervezas Alhambra and San Miguel; Nestlé also holds brands as After Eight and Quality Street. After this clustering, the final list of brands is presented in table 2.

Table 2 - List of brands with partnership with JMD

Brands		
Baci	Heinz	Mister Free'd
Barilla	JDE	Nestlé
Calidad Pascual	Jerónimos	Pladis Biscuits
Eat Real	Kellogg's	Pringles
Evian	Kerrygold	Storck
Exportação	Lorenz	Tabasco
Font Vella	Lotus Bakeries	True Gum
Gran Pavesi	Mahou – SM	Turci
Guloso	Mandarin	Wasa

In the scope of this work, the term supplier refers to the brand's factory. In other words, some brands have more than one production site and, therefore more than one supplier. These exceptions apply to Nestlé, Pladis Biscuits, Guloso, Kellogg's and Pringles, with two suppliers, and Jerónimos, with four suppliers. The locations of the different suppliers will be analyzed forward in the Data Collection and Treatment chapter. These suppliers are responsible to produce and store the different Stock-Keeping Units (SKUs) until receiving a shipment order.

Concerning the inbound process itself, JMD develops a rolling forecast every three months. This forecast considers the expected demand for the period forward and takes into account possible special offers, the rotation of the products, the seasonality, and other important aspects that could influence the clients' will to buy the product. The supply team of JMD, previously presented, analyzes the sales forecast and by incorporating the brand's restrictions, obtains the purchasing forecast, which is communicated to the different brands. This communication allows the suppliers to be able to predict and prepare the orders according to expected demand.

The products are then transported to Luis Simões' warehouse, through the incoterm DDP (Delivered Duty Paid), meaning that the seller (supplier) is assuming all the risks and responsibilities over the transport until the place defined by JMD. Each supplier is then responsible to prepare the truck with its own products and to send them to the warehouse.

2.3.2 Warehouse and Outbound

As it was mentioned, in the second and third stage of the process, JMD works with a third-party logistics, Luis Simões, acting as a logistic operator. Through its warehouse, Luis Simões is therefore responsible for receiving, storing and distributing the products, managing the stock and the order flows.

This process in the warehouse follows some steps. The products arrive to the warehouse, in the trucks that are the suppliers' responsibility. After being carried out, the warehouse receives the goods and prepare them to be stored in the determined location. At the same time, Luis Simões will manage the stock inside the warehouse, knowing the number of products that comes in and out every day and, therefore, the number of products in inventory. When some client demands for a certain product, an order is launched and Luis Simões receives it and starts to initiate the process to prepare that product to arrive to the client. This process starts with the picking, where it is indicated to the operator the specific product in the pallet that should be taken out. The warehouse follows a FIFO rule ("First In, First Out"), meaning that the products that arrive first, should be the first ones to leave the warehouse to the markets. In the specific case of JMD, this should be taken seriously, since there are expiry dates that must be respected, otherwise, if the products stay more days in the warehouse than what was supposed to, could be enough to stop it being sold in the modern retail channel. In this line of thought, more than following a FIFO rule, Luis Simões looks for following a FEFO one ("First Expire, First Out). Following the FEFO rule, Luis Simões has a challenge in incorporating the returns in the flow. Since the products are sensitive to the validity, when there is a return in the process, it is important to put it quickly again into the flow to be shipped as soon as possible, in the cases that there is not any problem that obligates to return it or give it away. After being picked in the warehouse, the product is shipped in Luis Simões' trucks until its destination. These trucks are organized according to the necessary routes for each day and not always their maximum capacity is being used. The organization of the trucks and routes is responsibility of Luis Simões, meaning that they could optimize it in the best possible way for them. For example, sometimes Luis Simões decides to ship products between warehouses to put the product close to its final destination, sending products from the warehouse in Azambuja to Porto, that are later shipped to the client in the North of Portugal.

Regarding the demand management, Luis Simões supports its decisions on the forecast developed by JMD for the different SKUs and the different clients. Thus, it will be prepared for the orders it will receive and to be able to answer it. However, to cope with possible fluctuations in the demand that were not expected, Luis Simões has a safety stock for each SKU. This safety stock enables Luis Simões to have some flexibility, not depending only on the suppliers and to respond quickly to the demand requests. For the calculation of this value, the different lead times of each supplier are considered, since it is expected that for products with suppliers in different locations, not to have the same flexibility to respond to the demand. For example, it will not take the same time for a supplier in Spain to deliver products in the warehouse as for a supplier in Poland.

2.3.3 Challenges

JMD has challenges to face, even more being part of a very dynamic market. Some of the challenges presented by the company will be discussed further.

Firstly, one of the biggest challenges for JMD is the stock management and to ensure the timely disposal of stock. Besides the storage being responsibility of Luis Simões, JMD is still responsible to plan the supply of the different products. Here, it is important to consider that, as it has been mentioned previously, the products can quickly become obsolete, due to the validity requirements. Nowadays, these obsolete products represent around 0,21% of JMD's net sales, being a significant number, since it is lost money. Thus, it is necessary to balance between the reaction time of the suppliers and the validity of the products, meaning to find a balance between the lowest number of coverage possible and the necessary stock to achieve the sales objectives. Furthermore, this activity becomes more complex when considering seasonality, which obligates to ensure the stock to cope with the peaks, and the promotional activities, having to manage the different suppliers' lead times with the promotion timings.

Regarding the information management within the company, JMD looks for to use it to improve its service level. In this line of though, JMD should have a detailed knowledge of partners' production processes, which contributes also to the supply planning and the stock management. At the same time, it is important to improve IT processes to facilitate operations and to ensure necessary information and on time, based on the master data.

Furthermore, one of the challenges faced by JMD is the complexity of the set of products represented by the company, meaning that it represents many different brands and not all of them are available in all the clients, in other words, each client has its own set of products. This complexity increases the company's difficulties to forecast the demand and planning the supply, as well as to follow the market dynamism.

JMD has also been working on developing a more accurate forecast, since the current one has an accuracy of 68%. However, there are some challenges in this activity related with the fact that the demand in the modern retail stores deals with a lot of fluctuations. It is possible to forecast based on a standard behavior of the consumer, considering possible seasonality, but it can quickly change according to unexpected events.

JMD is therefore dedicated to making its operation as efficient as possible, seeking to respond to customer demand and needs quickly, while keeping costs as low as possible. In addition, given the importance of the partnerships established by the company, JMD strives to be close to its partners, both brands and end customers. For these reasons, it is very important to study and optimize its supply chain by relocating entities to keep costs down.

2.4 Problem Definition

In the course of this work, the problem will be approached in a strategic level, meaning that the aim is to determine the **configuration of the network**, regarding its entities' locations and possible flows, instead of study operational issues. The main goal would be that the optimized proposed solution supports JMD in dealing with the challenges previously presented, through the minimization of costs and making a more resilient supply chain.

The current scenario includes all the different suppliers presented in the "Inbound" section, the warehouse in Azambuja and the markets, that will be assessed as the different districts of Portugal. The scope of this study will be related with changing the warehouse location or adding new ones to the network. The company wants to understand if there is a way to configure its network and positioning its warehouses that could optimize its service, meaning lowering the costs, increasing its service level, and incorporating sustainability. Different options for the warehouse could be considered and, therefore, some selection criteria that are presented later in this work will be considered for new possible warehouse's locations, in discussion with the company.

2.5 Chapter Conclusion

In this chapter the JMD company, a food distributor in Portugal, is presented, highlighting aspects regarding its operations and supply chain. JMD is a renowned food distributor with over 100 years of history, being the connection point between numerous food and beverage brands and the Portuguese market. In this line of thought, JMD has an established partnership with 37 food and beverage brands, being part of nine different categories: cereals, coffee, tomato and dressings, snacks, indulgence, biscuits, dairy/desserts, drinks, and grocery others. The presence of JMD in the markets its divided into six channels: Modern Retail, Wholesalers, Horeca, Independent stores, E-commerce and International. Furthermore, the internal structure of the company is elucidated, consisting of five major departments: Information Technology (IT), Finance, Sales, Marketing (Brand Partnership), and Human Resources. The Sales and Marketing teams were highlighted as relevant to the research. A deeper dive is made into the retail channel, since it is the core of JMD's business and where this study is focused, representing around 65% of its operations. The different clients that are part of this channel are presented in terms of market shares and it is discussed how new emerging circumstances can impact JMD operations. Since JMD's activity is centralized in Portugal, a demographic context of Portugal is emphasized, as well as its influence on consumer behavior. Some important factors that characterize the consumer profile are explored, such as the inflation rate, unemployment rate and age distribution, in order to draw conclusions regarding the consumer preferences and purchasing power.

Then, a detailed examination of JMD's supply chain is provided, focusing on inbound, warehouse and outbound operations. In the inbound operations, the different suppliers existing are presented. Regarding the warehouse and outbound operations, it should be noted that JMD collaborates with third-party logistics, Luis Simões. The focus of the work developed is the designing and planning of the presented supply chain network.

The challenges faced by JMD consist of stock management, disposal of obsolete products, information management, the complexity of product diversity, and the need for more accurate demand forecasting. Some of these challenges are not going to be addressed in the scope of this work, as they consist of tactical and operation activities, instead of strategical ones.

This chapter concludes with the problem definition, which revolves around optimizing JMD's supply chain network configuration. The company wants to explore the possibility of changing warehouse locations or adding new ones to improve service levels, reduce costs and incorporate sustainability. In this line of thought, research on the important concepts related with design and planning a supply chain network, as well as existing optimization model tools, will be addressed in the next chapter.

Chapter 3 – Literature Review

Considering the problem defined in the previous chapter, as well as the challenges face by the company, the present chapter intends to perform a literature review of the most relevant topics for the work.

This chapter is divided into five sections. The first two sections (section 3.1 and section 3.2) describe the concepts of Supply Chain and Supply Chain Management, considering their evolution over time. The following subchapter (section 3.3) highlights the concern for incorporating sustainability into supply chain management, characterizing the Triple Bottom Line approach and the importance of reverse logistics. Then, section 3.4 describes the main ideas to consider when planning and designing a supply chain, as well as its challenges. The next subchapter (section 3.5) corresponds to research on the optimization models developed and having been applied to supply chain network design problems. Finally, section 3.5 aims to conclude the topics approached amongst the literature review and to stablish a connection with JMD case study.

3.1 Supply Chain

Over the years, the definition of supply chain (SC) has changed, becoming defined as a more complex system. At a starting point, a supply chain was defined as the network of facilities and activities that performs distinct functions from product development to distribution of these products to the customers and after-market support (Mabert & Venkataramanan, 1998; Papageorgiou, 2009). Although there are not as many definitions to SC as there are Supply Chain Management (SCM), some of the concepts related with SCM that are going to be mentioned afterwards, already include a certain definition of SC, since both concepts are interrelated.

A supply chain is not a simple network, but a complex one that aims to cooperate to improve the flows of material and information within the different participants, from the suppliers to the customers. Being a network, although the different participants can perform complementary activities or compete for the same one, the different partners should cooperate, forming a unique entity with a unique strategy, with fairly shared benefits and losses (Govil, M., & Proth, J. M., 2002). Thus, the different entities collaborate to obtain, deliver, and recover a product or a set of it (Calleja et al., 2018).

In a supply chain there are two different flows that move in opposite directions: the flow of materials and the flow of information. While the flow of materials moves downstream, the flow of information moves upstream. The flow of materials begins in the suppliers and ends in the customers, whereas the flow of information has its starting in the customers with their demand and requirements and flows upstream to the retailers, manufacturing companies, logistics and suppliers. The information in a supply chain should flow smoothly, ensuring that all participants have access to enough information at the same time (Govil, M., & Proth, J. M., 2002).

Nowadays, a stronger weight has been put in the customer satisfaction when talking about supply chains. A supply chain is defined as a combination of processes, including all possible network entities, whose goal is to fulfil customers' requests. As a final goal, the different processes cared by a supply chain are oriented to meet the customer satisfaction at a minimum cost (Barbosa-Póvoa et al., 2018). Aiming to satisfy the customer as a central objective, there are some performance goals that a supply chain looks for to accomplish. These performance goals will be overseen in the "Supply Chain Management" section.

Supply chains have been appearing with an extreme importance since they are responsible for the delivering of goods in the right location with the right quantity at the right time.

3.2 Supply Chain Management

As mentioned above, there are several definitions of SCM and until now there is not any decision globally accepted. The concept SCM has appeared in the literature for the first time in 1982 (Barbosa-Póvoa et al., 2018) and is being studied and developed since then. The supply chain management has continued to change to fit the need of the growing global supply chain, and its definition continues to be improved over the years. The Council of Supply Chain Management Professionals (CSCMP, 2018)defines supply chain management as following:

> *"Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies."*

Many studies have been developed to compare the different proposed definitions for SCM and to gather all the concepts to build a more consensus definition among the community, such as Stock & Boyer, (2009) or LeMay et al., (2017). According to (Stock & Boyer, 2009)most of the definitions proposed agree that SCM includes coordination and integration, cooperation among chain members and the movement to the final customer. However, there is still a confusion between Logistics Management and Supply Chain Management. The CSCMP defines Logistics Management as:

> *"Part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements."*

In the study made by Stock & Boyer, the authors have divided SCM in three major themes: Activities, Benefits and Constituents/Components; and six sub-themes. As part of the activities there are the flows of materials, services, finances and information and the network of internal and external relationships. The benefits consist in efficiency and value creation, and customer satisfaction.

Over the years, different approaches have been given to the SCM concept, including a marketing one, with the view to build more sustainable customer relationships and considering the impact on organization effectiveness (Stock & Boyer, 2009). The final definition relies on:

> *"The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, finances and information from the original producer to final customer with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction"*

More recently, this concept has been developed in the sense of defining it as a design and coordination between multiple entities being part of a network. This network is defined as "through which organizations and individuals get, use, deliver, and dispose of material goods; acquire and distribute services; and make their offerings available to markets, customers, and clients" by LeMay et al., (2017), also it concerns the people, materials, information and financial flows between entities and operations (Calleja et al., 2018).

It is also important to consider the underlying objectives when managing a supply chain. The primary objective of SCM is to fulfil end customer requirements by providing appropriate products and services when they are needed, at a competitive cost. To achieve this, five different operations performance objectives can be taken into account: quality, speed, dependability, flexibility, and cost. Regarding quality, one important aspect to have in mind is the fact that the quality of a final product or service depends on the quality of every operation that is part of the supply chain. The speed measures how fast can customers be served, and the time taken for goods and services to move through the supply chains, spending little time in inventory, ensuring that the fast movement is not achieved through resourcing or over-stocking. This leads to a reducing of overall costs, due to the reduction in working capital and inventory costs. Thus, it is important to balance the speed as responsiveness to customers' demand and as fast throughput. Dependability is often measured as 'on time, in full' deliveries, being a more desirable aim than speed, since it reduces uncertainty within the supply chain. Flexibility stands for the supply chain's ability to adapt to changes and disruptions, either in customer demand or in the supply capabilities of operations. Lastly, the cost contemplates all the costs incurred within each operation to transform its inputs into outputs and the additional costs that arise from each operation in the chain doing business with another (transaction costs). Nowadays, it is often considered a sixth objective related with sustainability, due to the increased concern in society regarding this topic (Slack, N, Brandon-Jones, A, Johnston, R & Betts, 2012).

When considering the design, planning and management of a supply chain, there are many decisions to be analyzed. Depending on the time span considered, the decisions are divided into three main levels: strategic, tactical, and operational. The strategical level deals with long term decisions, usually considering a time horizon of 3 to 10 years (Mota et al., 2018), such as the network design, including the number, location, and capacity of the different entities. The tactical level considers decisions in a time horizon of 1 to 12 months (Mota et al., 2018) and includes the resource planning, inventory policies definition, transportation strategies and material flows. Lastly, the operational level defines the day-to-day operations and decisions dealing with the scheduling, routing, truck loading and human resources allocation (Barbosa-Póvoa, 2014a).

3.3 Sustainable Supply Chain

As the society pressure for a wealth environment is increasing, the companies started to be concerned about their sustainability. Nowadays, a company's image is associated with the collaboration between all participants of the supply chain, moving toward to build a more sustainable activity. Thus, when designing and planning a supply chain, the societal and environmental concerns should be incorporated (Barbosa-Póvoa et al., 2018) (da Silva et al., 2020). Furthermore, the companies now see sustainability not as a constraint that they must meet, but as a business opportunity that enables the company to seek for a position in the market, and continuing to be competitive (Mota et al., 2018).

In 1987, the World Commission on Environment and Development defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Applying this concept to the supply chains and considering the three pillars of sustainability (economic, social and environmental), sustainable supply chains (SSC) are complex network systems consisted by "entities that manage the products form the suppliers to the customers and their associated returns, account for social, environmental and economic impacts" (Barbosa-Póvoa et al., 2018). In the same line of thought, sustainable supply chain management was defined (Koberg & Longoni, 2019) as:

> *"The management of material, information and capital flows as well as cooperation among companies in the supply chain while taking goals from all three dimensions of sustainable development (environmental, social and economic) into account which are derived from customer and stakeholder requirements."*

Considering the definition presented above, a sustainable supply chain management implies the same activities as the supply chain management, but now accounts for the three pillars of sustainability: environmental, social and economic. The challenge presented nowadays stands for the interconnection between these three pillars, to be simultaneously the three main objectives of the firm. In order to deal with this link between the three pillars, a new concept has emerged: the triple bottom line.

3.3.1 Triple Bottom Line

The Triple Bottom Line (TBL) concept stands for the alignment between the three pillars related with sustainability, already mentioned above: economic, social, and environmental. With the focus in these three objectives, the company should look for the balance between them in order to build a sustainable supply chain. Usually, these three pillars are known as the 3 P's: Profit (economic), People (social) and Planet (environmental) (Rajasekaran, 2013).

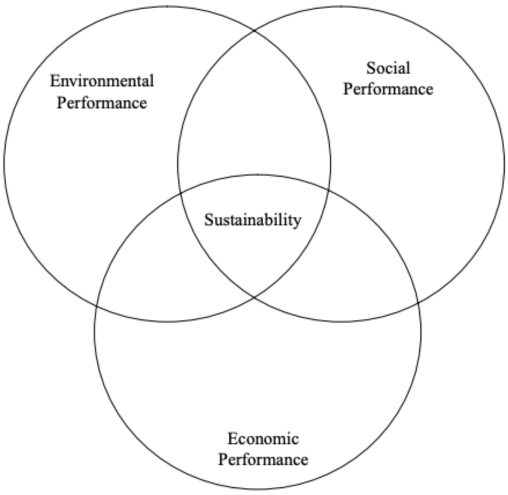


Figure 5 - Triple Bottom Line representation

Figure 5 is a visual representation of the TBL, where the three different dimensions are represented, with the sustainability being in the overlapping of them. By finding the intersection between these three pillars, companies can engage in activities that will have a positive impact in social and environmental dimensions, but also in the long-term economic benefits, as well as competitive for the firm (Carter & Rogers, 2008).

The supply chains are already complex systems, even more when considering the globalization occurring in the past years. By incorporating sustainability into these complex systems, this problem is further increased (Mota et al., 2018). The path has been built to incorporate the three different dimensions when designing, planning, and managing a supply chain. According to Koberg & Longoni, (2019), to achieve sustainable outcomes it is necessary to adopt environmental and social practices and to achieve environmental, social, and economic performance. When considering the network design problems, the sustainability level is larger since it deals with investments and decisions that will compromise later the tactical and operational ones (Mota et al., 2018). To design and planning a sustainable supply chain, it is important to consider the three pillars and to understand what is behind each one of them.

Firstly, the most understandable one is the economic dimension, since it is the objective that companies are created to work for. Before the other dimensions have been incorporated in the design of supply chains, they were planned to achieve the best economic situation possible, to maximize the profit and/or to minimize the cost. Thus, this dimension is the one the firms are familiarized with and that the decision makers within the company are able to deal and understand. Nowadays, this dimension is usually incorporated along with others, leading to multi-objective functions. Different authors have approached the economic pillar in diverse ways, doing differently both in considering it in the models developed and in the evaluation of its performance. According to Koberg & Longoni, (2019), the "economic performance can be operationalized in terms of market, operational or accounting based metrics." In terms of models, the economic pillar has been incorporated by the authors through the minimization of costs or maximization of profit (Barbosa-Póvoa et al., 2018). Although few authors have considered risk analysis, in the last years the risk evaluation has been increasing in the literature. Mota et al., (2018), has developed a model where the economic dimension was considered through the Net Present Value.

Regarding the environmental dimension, there are some environmental practices that can be adopted to achieve greater environmental performances and build a path towards sustainability, such as investments in pollution control and prevention, environmental health systems and compliance with certification. Considering the performance, the efficiency in resources utilization, the recycling and reduction of pollution, the waste and emissions are evaluated (Koberg & Longoni, 2019). In the developed models, the environmental dimension is usually treated as global warming or O2 based emission (Barbosa-Póvoa et al., 2018), usually assessed by the Life Cycle Assessment (LCA) method.

Lastly, the social dimension is the least approached one in the models, due to its difficult to quantify and measure. However, some social responsibility practices can be adopted in the design and planning of the supply chain, such as the compliance with local labor laws and adoption of social standards. The performance of this dimensions takes into account the human rights, labor practices and impact on local communities (Koberg & Longoni, 2019). Being not so often incorporated in the modelling, the social dimension is usually addressed as job creation or safety aspects (Barbosa-Póvoa et al., 2018).

A considerable number of studies have been developed, but most of them do not consider the three pillars simultaneously, but only two of them. According to Bals & Tate, (2018), it is rare for the three dimensions to be represented. Before the incorporation of the sustainability into the management of supply chains, the focus was on the economic dimension to only later include the environmental and social perspectives (Bals & Tate, 2018).

In the review developed by Eskandarpour et al., (2015), the author reaffirms that in most literature the objective stands for the economic dimensions, and the other ones are not addressed so often. Quantifying, within the 81 papers reviewed, 74 included the environmental and economic issues, while only 10 incorporated the three dimensions.

In the last years, the sustainability issues have been addressed in the literature by many different ways. Thus, design and planning of closed-loop supply chains have been considered and environmental issues have been added, leading to the concept of green supply chains. Afterwards, the contribution of social aspects has been incorporated in the design of supply chains (Barbosa-Póvoa, 2014b). Some studies quantified the environmental impact of the supply chain (Duque et al., 2010), other have utilized the LCA methods into the supply chains (Matos & Hall, 2007), others have incorporated the environmental impacts and regulations into the design and planning of supply chains (Bojarski et al., 2009), others have considered the trade-off between profit and environmental impacts (Pinto-Varela et al., 2011) and some have addressed closed loops supply chains. There were also some studies that are considered a little further, such as da Silva et al., (2020) that incorporated economic and environmental decisions under risk assessment and Mota et al., (2018) who developed a decision support tool considering the triple bottom line.

3.3.2 Reverse Logistics

Reverse logistics, as well as the other existing flows in the supply chain, are important aspects to consider regarding the sustainability, as it is going to be mentioned further. They are an opportunity for growth in terms of turning the supply chain greener and more sustainable.

The strategic design supply chain network can be modelled in one of these three ways: forward flow, reverse flow, and closed-loop supply chains. The forward flow model represents the traditional supply chain that terminates at the end consumers, while the reverse flow model begins at the consumers and finishes at the factory/recovery plants. Lastly, the closed-loop supply chain model takes into account both forward and reverse flows simultaneously (Salema et al., 2010a). The reverse flow consists in the series of steps necessary to retrieve a used product from customers with the intention of reusing, repairing, remanufacturing, recycling, or disposing of it (Agrawal et al., 2015). Many authors have been defining reverse logistics in different ways. Roger and Tibben-Lembke,1999, proposed a definition of reverse logistics commonly accepted:

> *"The process of planning, implementing and controlling the efficient, cost-effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal."*

Over the years, the incorporation of reverse logistics in the design and operation of a supply chain has become a challenge. Deepen the knowledge in this area and consider it in the design and planning of the supply chain enables the firm to lower its costs, while improving coordination and customer service (Salema et al., 2010a). At the same time, the increased concern regarding environmental issues, legislation, corporate social responsibility, and sustainable competitiveness, has given more importance to reverse logistics, being now seen as a business opportunity and a competitive advantage. A better understanding of the reverse flow can lead to a minimization of environmental impacts, through the waste prevention, material recycling, energy recovery and disposal option, making the reverse logistics a necessity for sustainable competitiveness (Agrawal et al., 2015; Salema et al., 2010a). The reverse logistics activities are now being incorporated within the existing network, through the collection and treatment of end-of-life products, having simultaneously the forward and reverse logistics and creating a closed-loop supply system (da Silva et al., 2020). Closed-loop supply chains are logistics systems that aim to maximize the value created throughout a product's entire life cycle by pursuing a dynamic recovery of the product's value from various types and quantities of returns through their design, planning, and operation (Barbosa-Póvoa et al., 2018).

3.4 Supply Chain Network Design

Supply chain design is a dynamic concept, defined as “identifying the desired strategic outcomes for the firm and developing, implementing, and managing over time the resources, processes, and relationships that seek to make the attainment of such desired outcomes inevitable over time” (Melnyk et al., 2014). Nowadays, it is vital to have an optimal supply chain design to succeed in the market. An optimal supply chain design should reflect the best possible configuration and operation of all the elements that are part of the supply chain, such as suppliers, manufacturers, and distributors (Garcia & You, 2015).

The process of designing a supply chain must compromise all the decisions that are necessary to define its configuration, including the objectives, the criteria to assess its performance and the elements that are part of the SC, as well as their relationships (Calleja et al., 2018). These decisions include the number, location, and capacity of production facilities (manufacturing sites, warehouses, and distribution centers), the allocation of each market region to one or more locations and the supplier selection (Barbosa-Póvoa, 2014a) (Meixell & Gargeya, 2005). The supply chain design should not only include the network project itself but should consider simultaneously the planning, enabling to structure how the entities and flows are going to be managed over time, aligning it with the firm’s supply chain strategy. According to Barbosa-Póvoa, (2014a), the main goal is to meet the right balance between sourcing, production, inventory, and transportation costs, guarantying a service level that leads to a maximum profit.

The network design problem involves a large amount of data related with the customers, facilities and supplies. The mathematical models presented in the literature are being developed in the sense of deal simultaneously with the design and planning of the supply chain, combining the strategic design with the tactical planning, enabling to cover supply, production, storage, and distribution. They integrate multiple levels in decisions such as capacity constraints, tactical decisions, and product flows (Eskandarpour et al., 2015). The goal is to design a supply chain, while optimizing the associated aggregate planning of purchases, production, storage, and distribution (Salema et al., 2010b).

3.5 Optimization models

As described in the previous section, the network design problem is a complex one to consider, since it involves many decisions at different levels. Thus, the complexity increases when sustainability is incorporated and this decision should also not only the financial concerns, but also the environmental ones. For this reason, it is necessary to develop tools to support decisions regarding the design of a network, such as the models solving it through optimization, contributing to the development of the approach being made to this problem.

The models developed in the literature regarding the design and planning of an optimal supply chain take into consideration the concerns previous exposed. In this sense, the authors have been working in innovative models, incorporating new technologies and new methods. The focus of these models stands for the issues presented that are gaining importance in todays' society, such as sustainability (triple bottom line). At the same time, models considering the reverse flows have been study. Furthermore, the risk and uncertainty have been incorporated in the models, in order to design more resilient supply chains able to respond quickly to a disruption. Nowadays, building a resilient supply chain is a real competitive advantage, due to the increase uncertainties (Bottani et al., 2019). According to Christopher & Peck, (2004), resilience of a supply chain is defined as:

> *"The ability of a supply chain to both respond quickly to disruption and unforeseen events and to recover operational capability after disruptions occur."*

Mota et al., (2018), proposed a decision support tool for the design and planning of closed loop supply chains. The focus of this model is the strategic-tactical problem incorporating data regarding the supply chain design, production/remanufacturing planning, inventory planning, supply planning, inventory planning, transportation network planning and product recovery planning. Despite the focus being in a more broaden level, the tactical-operational decision can then be considered through vehicle routing or scheduling problems. The three pillars of sustainability are incorporated as objective functions. Summing up, given a possible structure for the location of the supply chain entities, as well as information regarding each entity; the possible production and remanufacturing technologies and information of each technology; the possible transportation modes between each pair of supply entities and information for each mode of transportation; the products within the supply chain and information for each product, it is possible to design and planning the supply chain, by maximizing the profit, minimizing the environmental impact and maximizing the social benefit.

da Silva et al., (2020), followed the same path and developed a new model with different objective functions. Instead of considering the three dimensions of the sustainability, only two of them were incorporated (economical and environmental), by maximizing the profit and minimizing the environmental impacts. However, this model considers the risk assessment through the calculation of the conditional value-at-risk (CVaR) measure, which is added to the objective function as a minimizing function. A few differences can be noticed in the way each of the objectives is quantified.

Bottani et al., (2019), developed a bi-objective mixed-integer programming formulation aiming to maximize the total profit over a one-year time span and minimizing the total lead time of the product along the supply chain. The model employed in this study is appropriate for developing a multi-product food supply chain that is resilient and capable of handling unforeseen market demand fluctuations and disruptions in the supply of raw materials by utilizing multiple sourcing policies, with the assistance of an Ant Colony Optimization (ACO) algorithm. The focus of this model is on the resilience of the supply chain, since the globalization of the supply chains is increasing its exposure to uncertainties, risks, and disruptions. This model is applied to the food supply chain, where the disruption problems are usually related with the sourcing of critical materials or with quality problems. In this paper, the aim is to devise an efficient and effective design for a food supply chain that is both resilient enough to ensure continuous operations during significant supply disruptions and capable of handling demand variability. Suppliers are then categorized between critical (high quality or low quality) or non-critical suppliers, and the date required for the model is related with the food products type and characteristics, the number and type of players and their criticality, the supply-demand relationships between the activities and the number of options available to perform each activity. The activities are divided into three phases: food supply, food processing and food distribution, and the objective is to select the supply, processing, and delivery options, while considering the trade-off between risks and supply chain performance.

Regarding the reverse flow, Salema et al., (2010b) proposed a multi-period and multi-product network for the design and planning of supply chains with reverse lows. In this model, the strategic design is dealt simultaneously with the tactical decisions, such as supply, production, storage, and distribution. In this model, the supply chain considered should incorporate both the forward and reverse flow, consisting in three integrated processes: Production and Inventory, Logistics and Distribution, and Reprocessing. The objective is to determine the network structure, the production and storage levels, the flows amount and the non-satisfied demand and return volumes, while minimizing the global supply chain cost.

3.6 Chapter conclusion

The literature review of this work aims to understand some concepts related to the development of this study, based on the literature existing, and to research how the current works are approaching the supply chain network design problem.

Firstly, the concept of supply chain and supply chain management are studied, as well as the objectives behind this activity management (quality, speed, dependability, flexibility, and costs). The three decision levels when managing a supply chain are presented (strategical, tactical, and operational), highlighting the differences between them. Applying these concepts to JMD case study, described in chapter 2, the problem in study will be approached in a strategical level, as explained previously, meeting some of the objectives of the supply chain management, by lowering the costs and building a more resilient supply chain.

Then, the sustainable supply chain concept is introduced as an emerging key concept in supply chain management, being based in three pillars (TBL): economic, social and environmental. These three dimensions should be considered when designing and planning a supply chain. In the development of this work applied to JMD case study, although the social dimension is not going to be considered, the other two pillars will be addressed, which is already a step towards the incorporation of sustainability in the supply chain management. The reverse logistics is also assessed in this chapter, describing its concept and its importance towards moving into a sustainable supply chain. At the same time, in JMD case study, the reverse flow is a concern to be considered since it constitutes a challenge in the supply chain, although the scope of this work only includes the forward flow.

Finally, the process of designing and planning a supply chain is described, naming the different decisions to consider, such as the number and location of the entities, that will also be the focus of the work developed. This study aims to design and plan JMD's supply chain, finding the right balance between the sourcing, production, inventory and transporting costs, being beneficial for the company in terms of costs and environmental. In this line of thought, it is researched how the scientific community has been approaching the strategic level of structuring and planning of a supply chain in terms of optimization models. Thus, different optimization models that incorporate more than one dimension of the TBL are presented, to being used as models for the development of the current study.

Taking into consideration the problem to be studied described in Chapter 2, an optimization model, based on (da Silva et al., 2020), will be developed to address the design and planning of a supply chain, considering the economic and environmental dimensions of TBL.

Chapter 4 – Model Formulation

This chapter is divided into two different sections. The first one (section 4.1) presents the main characteristics of the distribution chain of the case study (JMD) considered for developing the model. In the second section (section 4.2), the model developed will be described mathematically.

4.1 Model characterization

In the problem in study three different sets of entities are considered: suppliers, warehouses, and markets. The suppliers' set correspond to the different brands (e.g., represented by JMD in the Portuguese market), who are responsible to produce their products and then distribute and transport them until the warehouse. The warehouse, working as a 3PL system, receives, stores and distribute the pallets received. The products leave the warehouse, as soon as it receives an order with that indication, and the 3PL is responsible to deliver it in the client. The final set of entities is the markets, meaning the ones that demand the product and where the order has to arrive complete and on time. The mode of transport used between the suppliers and warehouses, and between the warehouses and markets is the truck, besides being trucks with different capacities. A different scenario is also considered, including the flow between warehouses, also made by truck. Figure 6 presents the generic distribution chain considered in the model: entities, products, and transportation modes. It should be noted that the model only contemplates the forward distribution flow, and not the reverse one, and that flows out of this scope are not going to be considered.

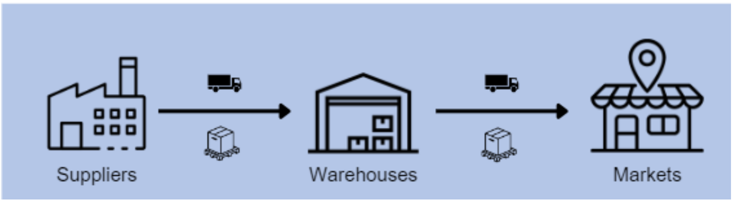


Figure 6 - JMD's distribution chain

By studying this distribution channel, the main goal is to strategically optimize the chain, with the possibility of making some changes in the warehouse stage of the process. The optimization of the model will be considered according to a decision based on cost efficiency, combined with environmental concerns.

The problem statement is summarized below.

Given:

- Structure of potential or existing entities in the supply chain

- Location of each entity
- Number of warehouses to be opened
- Maximum and minimum stock in the warehouse and flow capacities
- Stock in the first period of time in the warehouse
- Costs associated with the use of the warehouse (receiving cost, storage cost and picking cost)
- Set of products
- Relationship between products and entities
- Relationship between products and transports
- Allowed transports in each flow
- Transports capacities
- Distance between facilities (suppliers and warehouses, warehouses and markets)
- Transport costs
- Time horizon in study
- Product demand by market in each period of time

Determine:

- Network structure (number and location of warehouses)
- Flow of products between suppliers, warehouses and markets
- Transports used
- Inventory in warehouses

So as to:

- Minimize network's costs
- Minimize network's environmental impact

4.2 Model Mathematical Formulation

The model developed was based on the one developed by da Silva et al., (2020), which has two objective functions regarding the environmental and the economic dimension. However, the risk assessment will not be applied in this study and the economic dimension is going to be incorporated as a minimization of the costs, instead of maximization of the profit. Firstly, the sets will be presented, followed by the parameters related to entities, transports and demand. Then, all the variables needed in the model (continuous, integers, binaries and auxiliar) will be defined. Finally, the constraints, that allow the implementation of the model as close to the reality as possible with limited resources, will be explained, as well as the final objective function.

4.2.1 Indices

n, o, d	Supply chain entities
v	Transportation modes
t	Time
p	Products

4.2.2 Sets

A Set of all entities

$A = \cup_{i \in I} \ N_i, I = \{s, w, m\}$

N_s	Suppliers
N_w	Warehouses
N_m	Markets

B Set of transportation modes

$B = \cup_{i \in I} \ V_i, I = \{a, b, c, d\}$

V_a	Truck a
V_b	Truck b
V_c	Truck c
V_d	Truck d

C Set of products

$C = \{1, \dots, NP\}$

D Set of product-entity relations

$D = \{(p, n): p \in C \land n \in N\}$

E Set of connection between entities

$D = \{(n, o): n \in N \land o \in O\}$

F	Set of product flows between entities
	$F = \{(p, n, o) : (p, n) \in D \wedge (n, o) \in E\}$
	F_{inw} — Input flow to warehouse
	F_{outw} — Output flow from warehouse
	F_{betw} — Flow between warehouses
G	Set of transportation modes between entities
	$G = \{(v, n, o) : v \in V \wedge (n, o) \in N\}$
H	Set of all network characteristics
	$H = \{(v, p, n, o) : (v, n, o) \in G \wedge (p, n, o) \in F\}$
T	Time period set
	$T = \{1, \dots, NT\}$

4.2.3 Parameters

Entities

$stockmin_{p,n}$	Minimum product stock p in entity n
$warehousecap_n$	Maximum capacity available at the warehouse
$stock1_{p,n}$	Stock of product p in entity n in the first period of time
$distance1_{n,o}$	Distance between the suppliers n and the warehouse o (km)
$distance2_{n,o}$	Distance between the warehouse n and the markets o (km)
$distance3_{n,o}$	Distance between the warehouse n and the warehouse o (km)
$receivingcost$	Receiving cost in euros per month per SKU
$storagecost$	Storage cost in euros per month per SKU
$pickingcost$	Picking cost in euros per month per SKU

$fpallets$	Number of SKUs per pallet
$SupProd_{n,p}$	Relationship between the supplier n and the product p

Transports

$captransp_v$	Maximum capacity of the mode of transport v
$mincaptransp_v$	Minimum load to transport by mode of transport v
$transpcost$	Transportation cost in euros per km per pallet
$transpcostwar$	Transportation cost between warehouses in euros per km per pallet
$EnvImp$	Environmental impact of transports in $pallets.km$
$SupTrans_{n,v}$	Relationship between the supplier n and the mode of transport v
$WarTrans_{n,v}$	Relationship between the warehouse n and the mode of transport v

Demand

$demand_{p,n,t}$	Demand of product p by market n in time period t

4.2.4 Variables

Continuous variables

$z1$	Objective function
$z2$	Objective function
$X_{p,v,n,o,t}$	Quantity of product p moved with the mode of transport v between entities n and o in the time period t
$Stock_{p,n,t}$	Quantity of product p that is in stock at entity n in time period t
$UCap_{n,t}$	Utilized capacity in entity n in time period t
$UCap1_{n,t}$	Utilized capacity in entity n in the first period of time
$TransCost$	Total transportation cost

$EnvT$	Total environmental impact of transports
$TotalCost$	Total cost

Integer variables

$ntrips_{n,o,v,t}$	Number of trips between entities n and o with transportation mode v in time period t

Binary variables

y_n	$y = 1$, if the warehouse n is opened; $y = 0$, if not

Auxiliar variables

$InWar_{p,n,t}$	Flow of product p entering the warehouse n in the time period t
$OutWar_{p,n,t}$	Flow of product p leaving the warehouse n in the time period t
$UCap\_ex_{p,n,t}$	Capacity being utilized by product p in warehouse n in time period t in SKUs
$UCap\_ex1_{p,n,t}$	Capacity being utilized by product p in warehouse n in the first period of time in SKUs
$TCost\_sup_v$	Transportation cost per transportation mode v between suppliers and warehouses
$TCost\_war_v$	Transportation cost per transportation mode v between warehouses and markets
$Env1_v$	Environmental impact of transports per transportation mode v between suppliers and warehouses
$Env2_v$	Environmental impact of transports per transportation mode v between warehouses and markets
$Env3_v$	Environmental impact of transports per transportation mode v between warehouses
RC	Receiving cost

SC	Storage cost
PC	Picking cost

4.2.5 Constraints

Demand constraint: The demand constraint (1) presented below ensures that for each product in each period of time the flow that goes to the final markets corresponds to the demand of that market for that product in that period of time.

$$\sum_{\substack{n:(p,n,o)\in F_{outw} \\ v:(v,p,n,o)\in H}} X_{p,v,n,o,t} = demand_{p,o,t}\,, \qquad \forall p \in P, o \in N_m, t \in T \tag{1}$$

Mass balance constraint: The first two restrictions ((2) and (3)) define the flow of each product entering and leaving the warehouse in each period of time. The second part of the sum is only added to the equation for the scenario where the flows between warehouses are considered. The equations (4) and (5) guarantees the mass balance in the warehouse in each period of time, ensuring that what enters and leaves the warehouse is also aligned with the stock in each period of time.

$$InWar_{p,o,t} = \sum_{\substack{n:(p,n,o)\in F_{inw} \\ v:(v,p,n,o)\in H}} X_{p,v,n,o,t} + \sum_{\substack{d:(p,d,o)\in F_{betw} \\ v:(v,p,d,o)\in H}} X_{p,v,d,o,t}\,, \qquad \forall p \in P, o \in N_W, t \in T \tag{2}$$

$$OutWar_{p,o,t} = \sum_{\substack{n:(p,n,o)\in F_{outw} \\ v:(v,p,n,o)\in H}} X_{p,v,n,o,t} + \sum_{\substack{d:(p,o,d)\in F_{betw} \\ v:(v,p,o,d)\in H}} X_{p,v,o,d,t}\,, \qquad \forall p \in P, o \in N_w, t \in T \tag{3}$$

$$InWar_{p,o,t} + stock1_{p,o} * Y_o = OutWar_{p,o,t} + stock_{p,o,t}, \qquad \forall p \in P, o \in N_w, t = 1 \tag{4}$$

$$InWar_{p,o,t} + stock_{p,o,t-1} = OutWar_{p,o,t} + stock_{p,o,t}, \qquad \forall p \in P, o \in N_w, t > 1 \tag{5}$$

Capacity constraints: These restrictions are related with the capacity of the warehouse. The first equation (6) ensures that the stock in the warehouse is greater than the minimum stock stablished per product in each period of time. The equations (7) and (8) define the number of SKUs per product in the warehouse in each period of time, differentiating between the first period of time and the other ones. The following ones ((9) and (10)) determine the capacity being utilized in each period of time in the warehouse in pallets, one for the first period of time and one for the others. The final one (11) guarantees that the capacity being utilized in the warehouse in each period of time doesn't exceed the maximum capacity available.

$$Stock_{p,n,t} \geq stockmin_{p,n} \times Y_n, \qquad \forall p \in P, n \in N_w, t \in T \tag{6}$$

$$UCap\_ex1_{p,n,t} = InWar_{p,n,t} + \ stock1_{p,n} * Y_n, \qquad \forall p \in P, n \in N_w, t = 1 \tag{7}$$

$$UCap\_ex_{p,n,t} = InWar_{p,n,t} + \ stock_{p,n,t-1}, \qquad \forall p \in P, n \in N_w, t > 1 \tag{8}$$

$$UCap1_{n,t} = \sum_p \frac{UCap\_ex1_{p,n,t}}{fpallets}, \qquad \forall n \in N_w, t = 1 \tag{9}$$

$$UCap_{n,t} = \sum_p \frac{UCap\_ex_{p,n,t}}{fpallets}, \qquad \forall n \in N_w, t > 1 \tag{10}$$

$$UCap_{n,t} \leq warehousecap_n * Y_n, \qquad \forall n \in N_w, t \in T \tag{11}$$

<u>Transportation constraints:</u> These transport restrictions are related with the capacity of the trucks, ensuring that in each period of time, the quantity of SKUs transported doesn't exceed the total capacity of the number of trucks in service (12), as well as respects the minimum capacity to load in the total number of trucks (13).

$$\sum_{p:(v,p,n,o)\in H} \frac{X_{p,v,n,o,t}}{fpallets} \leq captransp_v \times ntrips_{n,o,v,t}, \qquad \forall (v,n,o) \in G \tag{12}$$

$$\sum_{p:(v,p,n,o)\in H} \frac{X_{p,v,n,o,t}}{fpallets} \geq mincaptransp_v \times ntrips_{n,o,v,t}, \qquad \forall (v,n,o) \in G \tag{13}$$

<u>Warehouse's constraints:</u> The following equation (14) defines the number of warehouses to be opened. By changing the right-hand side of the equation, it is possible to determine to study different options: have only one warehouse working or multiple ones (two or three).

$$\sum_{n \in N_w} Y_n = 1 \tag{14}$$

4.2.6 Objective functions

The problem in study is a muti-objective one, presenting more than one objective function: the environmental impact related functions and the cost functions. The objective of this study is to minimize both the environmental impact of the transports and the overall costs in the supply chain.

Environmental functions: The following equations define the environmental impact of transportation in the distribution chain. The equation (15) is related with the environmental impact in the transports between the suppliers and the warehouse, while the equation (16) refers to the transport between the warehouse and the markets. The equation (17) corresponds to the transport between warehouses, used only in the scenario where this kind of flow is considered. Finally, the equation (18) sums the environmental impact in all routes, aiming to minimize it.

$$Env1_v = \sum_{\substack{t \in T \\ (p,n,o) \in F_{inw}}} distance1_{n,o} * \frac{x_{p,v,n,o,t}}{fpallets} * EnvImp, \quad \forall v \in V \tag{15}$$

$$Env2_v = \sum_{\substack{t \in T \\ (p,n,o) \in F_{inw}}} distance2_{n,o} * \frac{x_{p,v,n,o,t}}{fpallets} * EnvImp, \quad \forall v \in V \tag{16}$$

$$Env3_v = \sum_{\substack{t \in T \\ (p,n,o) \in F_{inw}}} distance3_{n,o} * \frac{x_{p,v,n,o,t}}{fpallets} * EnvImp, \quad \forall v \in V \tag{17}$$

$$z1 = \min EnvT = \sum_{v} Env1_v + Env2_v + Env3_v \tag{18}$$

Cost functions: The cost function includes the total cost of transportation and also the variable costs related with the warehouse. The equations (19), (20), and (21) define the transportation costs: the first one (19) is related with the transports between the suppliers and the warehouse, then between the warehouse and the markets (20), and finally between warehouses (21) for the scenario where these flows are considered. The sum of all transportation costs is represented in equation (22). The equations (23), (24) and (25) aims to calculate the receiving cost, storage cost and picking cost in the warehouse, respectively. It should be noted that the second part of the sum in equation (23) and (25) should only be added when the flows between warehouses are considered. The final equation (26) sums all the costs.

$$TCost\_sup_v = \sum_{\substack{t \in T \\ (p,n,o) \in F_{inw}}} distance1_{n,o} \times transpcost \times \frac{X_{p,v,n,o,t}}{fpallets}, \quad \forall v \in V \tag{19}$$

$$TCost\_war_v = \sum_{\substack{t \in T \\ (p,o,n) \in F_{outw}}} distance2_{n,o} \times transpcost \times \frac{X_{p,v,o,n,t}}{fpallets}, \quad \forall v \in V \tag{20}$$

$$TCost\_betwar_v = \sum_{\substack{t \in T \\ (p,n,o) \in F_{betw}}} distance3_{n,o} \times transpcostwar \times \frac{X_{p,v,n,o,t}}{fpallets}, \quad \forall v \in V \tag{21}$$

$$TransCost = \sum_{v} TCost\_sup_v + TCost\_war_v + TCost\_betwar_v \tag{22}$$

$$RC = \sum_{\substack{t \in T \\ (p,n,o) \in F_{inw} \\ v:(v,p,n,o) \in H}} receivingcost * X_{p,v,n,o,t} + \sum_{\substack{t \in T \\ (p,d,o) \in F_{betw} \\ v:(v,p,d,o) \in H}} receivingcost * X_{p,v,d,o,t}\,, \quad p \in P, o \in N_W, t \in T \tag{23}$$

$$SC = \sum_{\substack{t \in T \\ (p,o) \in D}} storagecost * Stock_{p,o,t}\,, \quad p \in P, o \in N_W, t \in T \tag{24}$$

$$PC = \sum_{\substack{t \in T \\ (p,n,o) \in F_{outw} \\ v:(v,p,n,o) \in H}} pickingcost * X_{p,v,n,o,t} + \sum_{\substack{t \in T \\ (p,o,d) \in F_{betw} \\ v:(v,p,o,d) \in H}} pickingcost * X_{p,v,o,d,t}\,, \quad p \in P, o \in N_W, t \in T \tag{25}$$

$$z2 = \min TotalCost = TansCost + RC + SC + PC \tag{26}$$

4.3 Chapter Conclusion

A generic model for supply chain design and planning has been described in this chapter, in which only the forward flow is included. This model includes three different sets of entities: suppliers, warehouse and markets, and uses trucks as transportation mode.

The mathematical formulation of the problem in study is then presented, considering the sets, parameters, variables, and constraints to implement. Finally, both objective functions (minimizing the costs and minimizing the environmental impact) are formulated, consisting of two of the dimensions of sustainability. The resulted model is a Mixed Integer Linear Programming (MILP) model.

Subsequently the developed model will be applied to the case study described in Chapter 2. In this sense, the data relating to the JMD case study must be processed. In the next chapter, the data required to implement the model is collected and then treated in order to reduce the complexity of the problem.

Chapter 5 – Case Study: Data Collection and Treatment

In this chapter, the data describing the case study in analysis is presented. Also, the strategies developed, and assumptions made to enable the handling of the complexity of the data are discussed.

5.1 Assumptions and Simplifications

In order to solve the problem in hand, it is necessary to process data from the case study, which was provided by the company. However, the complexity of this data was beyond the scope of this work and, therefore, some assumptions and strategies of simplification are developed to decrease the extent of the data. Furthermore, when designing and planning a supply chain network, as the present study, the data should be processed to assess the problem without a level of complexity and detail that makes the problem infeasible.

The following section presents the strategies adopted for handling the data in the different phases of the distribution chain, as well as for the objective functions to explore, having in mind that the goal is to be as closer to the reality as possible.

This database provided by the company includes information regarding the transportation costs and warehouse operation costs; the sales; the warehouse, in terms of capacity; the brands, appointing their active SKUS, their lead time, the mode of transportation used, their location and some brand's transportation costs. Furthermore, it was given information related with the SKU's flow quantities between different entities (suppliers to warehouses and warehouses to markets).

Regarding the time dimension, the problem will be analyzed for a time horizon of 2,5 years. The data given considers the beginning of 2021 (January 2021) until May 2023. This time horizon is justified by two reasons. Firstly, since the world was living the Covid pandemic, the year of 2020 is not a feasible year to base strategic decisions and demands forecast, besides being important to increase the resilience in the supply chain. Secondly, JMD implemented a change in the software they work with and where all the forecasts and SKU's data base are inserted in, moving to an SAP's system. For this reason, the data before this implementation is organized in a different way compared to after it, so it would not be feasible to work with both datasets, with the time and resources constraints.

5.2 Data Collection and Treatment

The following sections describe how the data was processed and the assumptions or simplifications made in each topic.

5.2.1 Suppliers

It's important to start by pointing out that there is a difference between suppliers and brands, which is taken into account several times throughout the work. Different suppliers can be responsible for products of the same brand. In other words, JMD works with 27 brands with active SKUs: Baci, Barilla, Calidad Pascual, Eat Real, Evian, Exportação, Font Vella, Gran Pavesi, Guloso, Heinz, JDE, Jerónimos, Kellogg’s, Kerrygold, Lorenz, Lotus Bakeries, Mahou – SM, Mandarin, Mister Free’d, Nestlé, Pladis Biscuits, Pringles, Storck, Tabasco, True Gum, Turci, Wasa.

However, within each brand, certain products may come from different suppliers (with different locations and supplying different types of products). Thus, there are brands whose products are split between more than one supplier, giving a total of 35 suppliers. These suppliers are the ones responsible to supply the products from their factories to JMD’s warehouses. In the data treatment is not considered suppliers that had not presented any sales in the past months or the ones which their SKUs are no longer active in JMD’s database. At the same time, an ABC analysis is performed to each one of the major clients (referred in the following section), enabling to understand the most important SKUs, as well as their suppliers, for each client. An important aspect to take out from this is that there are 4 of these 35 suppliers that are not going to be considered, since the analysis only considers the 20% of SKUs that are responsible for 80% of the sales in each client. Thus, these suppliers didn’t have any SKU with significant sales in the clients analyzed and, therefore, their weight in the sales was not outstanding to be studied in the problem. These four suppliers are: Kerrygold, Turci, True Gum and the one designated as “Exportação”, leading to a total of 31 suppliers considered in the analysis. The location considered for each supplier corresponds with the exact location of the factory, in the cases that was possible to have access to that information. In the other cases, in order to simplify the process, it was considered the capital of the country or the city with more industrial impact. Table 3 shows the different suppliers, as well as their locations (due to JMD’s compliance policies regarding data confidentiality, only the countries are presented) and the type of products commercialized in the ones where the brands are divided in more than one supplier.

Table 3 - List of suppliers with respective locations and type of product

Suppliers	Locations	Type of product
Baci	Italy	
Barilla	Italy	
Calidad Pascual	Spain	
Eat real	United Kingdom	
Evian	France	

Table 3 - List of suppliers with respective locations and type of product (continuation)

Font Vella	Spain	
Gran Pavesi	Italy	
Guloso PT	Portugal	All products except sauces
Guloso IT	Italy	Sauces
Heinz	Spain	
JDE	France	
Jerónimos TH	Thailand	Coconut milk
Jerónimos NT	Netherlands	Mayonnaise
Jerónimos ES	Spain	Cocoa and chocolate powder
Jerónimos PT	Portugal	Gelatine, oat flakes, sweet corn, chili, grated coconut
Kellogg's ES	Spain	All other products
Kellogg's UK	United Kingdom	Crunchy nut, Rice Krispies and Special K bars
Lorenz	Germany	
Lotus Bakeries	Belgium	
Mahou – SM	Spain	
Mandarin	Portugal	
Mister Free'd	Spain	
Nestlé GE	Germany	Total After Eight + Quality Street Can
Nestlé CZ	Czech Republic	
Pladis Biscuits UK	United Kingdom	All products except "Thins"

Table 3 - List of suppliers with respective locations and type of product (continuation)

Pladis Biscuits RO	Romania	“Thins” biscuits
Pringles BE	Belgium	All products with 165g or 175g
Pringles PO	Poland	All products with 40g or 70g
Storck	Germany	
Tabasco	USA	
WASA	Italy	

5.2.2 Product’s aggregation per supplier

JMD has 644 different SKUs active from the 35 different suppliers. In order to approach the case study, the different products are aggregated according to their suppliers, as to decrease the complexity and the extent of the data. Thus, SKUs’ clusters are formed depending on its supplier, and to each cluster a location is designated, as presented in the previous table.

This simplification was made after analyzing the different products coming for the same supplier. Comparing the products commercialized by each brand, it is possible to conclude that within the same brand, in most of the cases, the products are all part of the same products’ category. Some existing exceptions are also made up for by splitting the brand between several suppliers, separating the products from different categories. This justifies the aggregation of SKUs by supplier.

JMD divides their partner brands into main categories as: Cereals & Bars, Coffee, Tomato & Dressings, Pasta, Snacks, Confectionary, Biscuits, Dairy, Drinks and Home Fragrances. A note to take is that the last category (home fragrances) includes candles, and it has been a commitment for the company this year, since they are trying to penetrate this new market of the non-food related items, working with a team full dedicated on that. For this reason, there are not enough data related with these products, thus this it will not be included in the analysis developed.

Table 4 presents the different categories and the brands allocated to each one, excluding the ones referred in the previous section (Kerrygold, Turci, True Gum and Exportação).

Table 4 - List of brands divided into categories

Cereals & Bars	Coffee	Tomato & Dressings	Pasta	Snacks
Jerónimos Kellogg's	JDE	Barilla Guloso Heinz Tabasco	Barilla	Eat Real Lorenz Mister Free'd Pringles

Confectionary	Biscuits	Dairy	Drinks
Baci Mandarin Jerónimos Storck Nestlé	Pladis Biscuits Gran Pavesi Lotus Bakeries WASA	Calidad Pascual	Evian Font Vella Mahou - SM

5.2.3 Warehouses

As it has been described previously, JMD has only one warehouse in its distribution channel, which is managed by Luís Simões (LS), in a 3PL system. This warehouse is part of a LS' operation center, covering the south centrality, from Azambuja. In this stage of the process, the products (aggregated by brands in the model) need to be received, stored, picked and then distributed to the different markets. For this process, Luís Simões provides two warehouses of the ten available in the operation center. One of the warehouses contemplates almost all the JMD's products, and the other one, a more recent one (automatic warehouse) stores less JMD's products, since the focus is on the non-food related items. At the current scenario, LS has an available total capacity for JMD's products of 31 858 pallets, with possibility of increasing. Considering that the total capacity of the operation center in Azambuja is of 145 000 m^2, or that it can store 180 000 pallets, JMD's capacity represents between 20% and 30% of the total warehouse capacity.

Regarding the inventory in the warehouses, the study conducted considers the existence of a minimum stock and stock in the first period of time. Due to lack of information provided by the company in this area and understanding the importance of having a safety stock in a warehouse, which must meet the clients' demand while dealing with different lead times in delivery orders, some assumptions were considered. In terms of the stock in the first period of time, it is considered that the stock in the warehouse in this period is enough to cope with the demand in that period. In respect of the minimum stock, the different lead times for the suppliers were considered, and a different number of quantities for each product, corresponding to each supplier, was designated. Thus, it is assumed that if the supplier's lead time is equal or greater than 15 days, the minimum stock corresponds to 60% of the average sales among the years studied. Otherwise, the minimum stock corresponds to 30% of the average sales.

As the main goal of this work is to study the location of the warehouse, in order to suggest possible new locations that enable the company to reduce the costs and the environmental impact. Thus, it is also necessary consider new warehouses in the study, to understand which ones will optimize the distribution chain studied. For this decision, in discussion with the managing director of the company, the following criteria was established: start by studying the options where the partnership between JMD and LS will remain, meaning to analyze the scenarios where the other warehouses working were also from LS. As in the current scenario JMD's products correspond to around 25% of the total area available in Azambuja, for the sake of simplification of the study, the same percentage is considered for the other scenarios. In terms of stock in the first period of time and minimum stock, the same values as for the Azambuja's warehouse were considered, when the warehouse is operating.

Table 5 presents the two warehouses' options from the LS' portfolio to be considered for future scenarios.

Table 5 - Characteristics of the warehouses in Gaia and Madrid

	Operation center - North of Portugal	**Operation center - Madrid**
Location	Vila Nova de Gaia – Leixões	Guadalajara – Cabanillas
Total capacity	50 000 m^2	156 000 m^2
Space available	60 000 pallets	274 00 pallets
Space for JMD	15 000 pallets	68 500 pallets

Having in mind the importance for JMD of stablishing strong partnerships (with suppliers and clients) and considering these two warehouses and the one already being used, multiple scenarios and combinations will be tested to analyze which one could optimize JMD's results.

5.2.5 Markets

JMD is responsible for the presence of its brands in many different clients. Thus, its distribution channel includes 307 clients, that launch orders of the different SKUs. In order to build a less complex problem and enabling its analysis with the existing resources, an ABC analysis to the clients was conducted. This analysis was implemented to the quantities ordered, invoiced quantities and sales. By dividing the clients into three classes (A, B and C), it was possible to obtain the clients responsible for 80% of the quantities ordered, invoiced quantities and sales (class A). The three lists obtained were compared, forming a final list of 17 clients. Discussing the results with the company, there were two more clients referred by JMD as relevant ones to be considered: Lidl and Aldi, that were then added to the list of clients, obtaining a final one with 19 clients. This simplification enables a deeper analysis considering the most impactful clients in the company’s results. Due to JMD’s compliance policies regarding data confidentiality, the name of the clients can not be shown and, therefore, the clients are identified from client A to client R.

5.2.6 Demand

To deal with the demand, it was considered the data related with the sales, instead of the order quantities. In this way, it will not be considered the expected quantities that should arrive to the warehouse and that should go to the markets, but the effective quantities that arrived at the final destination: the clients – markets. When dealing with the sales’ data, there were some suppliers presented that were not considered, supported by the fact that some of these suppliers don’t present any sales during the time considered, others sold some products in the first years analyzed and then stopped to sell. Thus, the sale’s suppliers accounted in this study are the ones with significant sales in the present year, meaning that the partnership between JMD and each supplier still exists.

As explained above, the study is developed based on an aggregation of the SKUs per supplier, meaning that the demand data is going to be also presented per supplier, instead of per SKU. In consequence, the possible fluctuations and different behaviors in demand for different products within the same supplier are not being considered.

Looking inside the sales of the 19 clients previously presented, there are several SKUs from different suppliers to be considered. Thus, once again, to decrease the complexity of the problem in study and respective model, there were only considered the most relevant SKUs in the sales of each client, the ones belonging to class A, that were then aggregated by supplier.

These 19 clients have retail stores spread all over the country, making it impossible to establish just one location for each client. To deal with this barrier, it was developed an analysis of the different delivery locations of each client, that were then aggregated by district. By having the exact number of sales of each supplier by district and client, it was then possible to put together all the sales per supplier in the same district, independently of its final client. At the same time, the time dimension is taken into account by considering the sales per month among the 2,5 years being analyzed. For this reason, the markets considered are the different districts where sales existed.

5.2.7 Market’s locations

As explained in the section above, the markets considered were clustered by district. Thus, the markets contemplated in this study correspond to the ones where the most significant clients sold the most impactful brand products, obtaining a final list in Continental Portugal: Aveiro, Braga, Bragança, Castelo

Branco, Coimbra, Évora, Faro, Leiria, Lisboa, Porto, Santarém, Setúbal, Viana do Castelo, Vila Real and Viseu. And then adding the two Portugal's island, Açores and Madeira. The following table presents the quantities sold in the 2,5 years in percentage per district.

Table 6 comes with a geographic representation of the districts in figure 7, where it is possible to visually understand the difference between the most significant districts in terms of sales in percentage (Lisboa and Porto) and the ones that follow them (Santarém and Setúbal).

Table 6 - Distribution of the quantities sold per district (in percentage)

District	Quantities sold in %
Aveiro	0,65 %
Braga	1,19 %
Bragança	0,10 %
Castelo Branco	0,14 %
Coimbra	0,20 %
Évora	0,12 %
Faro	3,26 %
Leiria	0,34 %
Lisboa	53,48 %
Porto	28,56 %
Santarém	4,43 %
Setúbal	3,30 %
Viana do Castelo	0,05 %
Vila Real	0,07 %
Viseu	0,23 %
Açores	2,39 %
Madeira	1,50 %

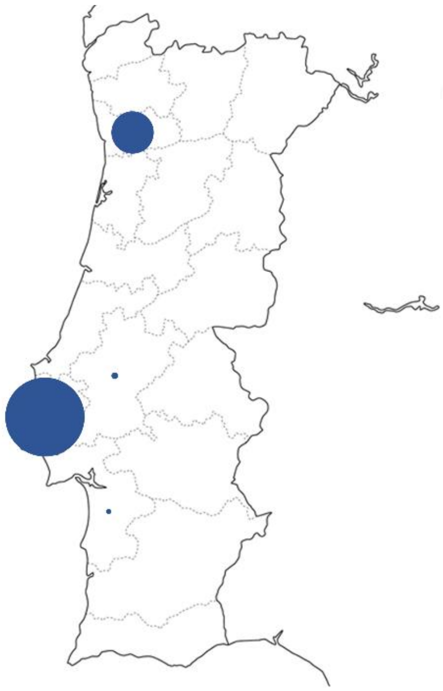


Figure 7 - Geographical representation of the quantities sold (in percentage) in the top-four districts

Due to time and resources limitation, a deep analysis into all the districts was not conducted to decide in which specific location should the market be allocated. Thus, in most of the cases, is considered the center of the district. However, the exception stands for the two districts with more impact in the market's context (Lisboa and Porto). Giving the different regions within the district, where the orders must be delivered, it is possible to conclude in which region in Lisboa and Porto, there is more affluence of routes and deliveries. Since Lisboa and Porto are the metropolitan cities in Portugal, with most impact on the national economy, being cities with considerable size with many living contrasts between them, it has been decided to understand better where the market should be specifically located on both districts. Taking the Lisboa case, it should be noted that around 42% of the SKUs delivered in Lisbon are delivered in Azambuja and around 20% in Vila Nova da Rainha (the region next to Azambuja). For this reason, it makes sense to establish the Lisboa's market in Azambuja. Regarding Porto, around 40% of the SKUs are delivered in Maia and around 27% in Alfena, distancing only 11 km between one and another. Thus, in order to decrease the complexity of the decision, the Porto's market is considered in Maia, where most of the orders are delivered.

5.2.8 Transports

In terms of transports, in terms of simplification, it is considered the same kind of transportation mode between suppliers & warehouses and warehouses & markets. Besides being the responsibility of different roles in the distribution chain, since the first ones are hold by the suppliers (brands) and the other one as part of the logistic operated by Luis Simões, both of them use trucks to transport their products. There are three different brands (Jerónimos, Pringles and Tabasco) that use also maritime transport. Since this mode of transport is not significant among all the products transported by road, it was considered that the transportation is only made by road, taking into account the different capacities of the trucks used by the suppliers.

Four different kinds of trucks are considered, one of them with a maximum capacity of 24 pallets, used by Tabasco, other with 17 pallets, operated by Mandarin, and the other two with capacities of 33 pallets and 66 pallets. Regarding the trucks used in the flow going out of the warehouse, it was assumed trucks with a maximum capacity of 33 pallets, as well as for the scenario where flows between warehouses are considered. Furthermore, no restrictions on the number of trucks used are considered, meaning that if the flow quantities increase, it will be possible to allocate more trucks to the transportation service. In terms of minimum capacity, it is assumed that there is obligation to deliver all the necessary orders and, therefore, a value of zero is designated.

5.2.9 Economic Data

As it was described in the model formulation, one of the objective functions to study is cost-related. The costs considered for the economic data are the ones related with the use of the warehouses (receiving costs, storage costs and picking costs) and the ones involving products' transportation.

In respect of the costs related with the use of the warehouse, it is only considered variable costs, depending on the number of pallets handled in the warehouse.

Thus, three different costs were assumed related with the warehouse: receiving costs, storage costs and picking costs.

The receiving costs are the costs involved in processing inventory that comes into the warehouse, through the shipments. The storage costs include all the costs related with storing the inventory. Lastly, the picking costs involve the costs related with the process of taking a product out of the storage to be shipped, after an order.

In order to calculate these costs, the number of SKUs invoiced per year was considered, as shown in table 7, as well as the total costs of receiving (table 8), storage (table 9) and picking (table 10) per year, presented above. Due to JMD's compliance policies regarding data confidentiality, the annual costs can not be presented.

Table 7 - Number of SKUs invoiced per year

Year	**Number of SKUs invoiced**
2021	5 076 557
2022	5 331 519
2023	1 872 177

Table 8 - Receiving costs per year (in euros)

Year	**Receiving costs (in €)**
2021	-
2022	-
2023	-

Table 9 - Storage costs per year (in euros)

Year	**Storage costs (in €)**
2021	-
2022	-
2023	-

Table 10 - Picking costs per year (in euros)

Year	**Picking costs (in €)**
2021	-
2022	-
2023	-

By dividing the total cost per year over the number of SKUs invoiced in the corresponding year, it is possible to obtain an approximate value of each cost per SKU. Then, an average was made with the three years' data, obtaining one final value for each cost per SKU.

In order to establish the connection between the capacities of the warehouse and transports, it is necessary to convert the number of SKUs in number of pallets. For this conversion, due to missing information and time restrictions, a value of 50 SKUs/pallet is assumed (Coimbra et al., 2011).

In addition, it should be noted that the variable costs (receiving, storage and picking) were considered the same in both warehouses, since they are all operated by LS.

Regarding the costs of transportations, accounted for the objective function beyond the costs related to the use of the warehouse, there were some assumptions and simplifications made. Giving the data provided and considering the load carried out in August 2023, table 11 presents the cost of transporting one pallet from some suppliers, as well as the distances travelled between those suppliers and the warehouse.

Table 11 - Transportation cost of one pallet per supplier and corresponding distance

Suppliers	Cost of transportation of one pallet (€/pallet)	Distance (km)
Lotus Bakeries	75	2153
Jerónimos	200	2305
Jerónimos	84	7408
Lorenz	100	2348
Tabasco	111	10575

By dividing the cost of transportation of one pallet by the distance travelled, it is possible to obtain an average value of the cost per pallet in euros in each route. For the problem, it is considered an average between the five different values, ending up with a final one of 0,03 €/pallet/km. Although this value is calculated based on the transport from the suppliers to the warehouse, it is assumed the same value for the transport between the warehouse and the markets.

The total costs of each transport service also depend on the distance travelled by the truck. Although these distances implemented in the model do not have a high accuracy, the problem is being approached at a strategic level and, therefore, a deeper level of precision is not required.

5.2.10 Environmental Data

In terms of the environmental data, the study will only consider the impact of the products' transportation. Other components of the distribution chain, such as the environmental impact of using warehouse, will not be assessed in this environmental study. As this analysis is being made in a strategic point of view and the warehouses are already part of the distribution chain or are already being used for LS, their environmental impact will not be added to the society and, therefore, will not be accounted for the study.

To assess the environmental impact of the transports, the article "Sustainable supply chains: An integrated modeling approach under uncertainty" was considered (Mota et al., 2018). In this paper, an LCA was developed through the methodology ReCiPe, obtaining different values for the environmental impact of the different stages of the supply chain in many categories. In terms of simplification, the value used for the environmental impact in this study was the total value of all the midpoints categories considered for the transportation with truck 1, having a final value of $1{,}05 \times 10^{-5}$ per $kg.km$.

5.3 Chapter Conclusions

This chapter intends to assess the data treatment process, as well as to delineate the simplification and assumptions made to address the complexity of the problem. The dataset provided by the company includes information on costs, sales, warehouse capacity, and brand details. The analysis covered a 2,5-year period from January 2021 to May 2023, justified by the impact of the Covid-19 pandemic and changes in data organization after the implementation of a new software system.

Regarding the data treatment, different topics are addressed, presenting the relevant information to consider in the model implementation. The main insights are presented below:

- JMD works with 27 active brands, and some brands have multiple suppliers with different locations, totaling 35 suppliers to be implemented in the model. Four suppliers with insignificant sales to major clients were excluded. Some simplifications were made regarding the locations defined for each supplier.
- JMD manages 644 active SKUs from 35 suppliers, considering only the food related products. To simplify the analysis, SKUs are grouped by supplier, based on the observation that products within the same brand are usually from the same category.
- JMD operates though a single warehouse managed by Luis Simões, in Azambuja, with a capacity of 31 858 pallets, corresponding to around 25% of the total operation center's capacity. The study includes minimum stock and initial stock assumptions, considering the demand for the product and the corresponding supplier's lead time. New warehouse's locations are considered, involving continued partnership with LS, in Gaia and Madrid.
- To simplify the analysis of JMD's extensive client base, an ABC analysis on the clients is conducted, revealing the top-performing clients responsible for 80% of orders, invoiced quantities and sales. The final list considered has 19 key clients, allowing a more in-depth analysis of the clients with the most significant impact on the company's results.
- The analysis of demand focused on sales data, aggregating it per supplier and, therefore, possible demand fluctuations within the same suppliers are not considered. An important aspect is that suppliers with no significant sales in 2023 are not included. The clients' delivery locations were grouped by district, consolidating the sales per supplier within the same district. The final data is presented on a monthly basis.
- The study focused on markets clustered by districts in Portugal, considering the districts where the most significant clients sold impactful brand products. The analysis showed that Lisboa and Porto stood out as the most significant in terms of percentage sold in each district. Therefore, a more detailed analysis of the regions within the district was conducted in Lisboa and Porto, leading to set the Lisboa's market location in Azambuja and Porto's one in Maia.
- The study simplifies the transportation mode by considering only road transport (trucks) between suppliers, the warehouses, and the markets. Four types of trucks are considered, with maximum capacities of 17, 24, 33, and 66 pallets, and no restrictions on the number of trucks

are assumed. There is no minimum capacity requirement for delivery, meaning all orders must be fulfilled.

- The model focuses on two main cost categories: warehouse-related costs and transportation costs. Warehouse costs include receiving costs, storage costs, and picking costs, which are calculated based on the annual costs over the number of SKUs invoiced per year. These costs are assumed to be the same for all warehouses due to the common operator (LS). Transportation costs are calculated according to the transportation cost and distances of five different suppliers, obtaining a value per pallet and kilometer, and assuming then the same value for the transportation cost from the warehouse to the markets.
- The environmental study in this analysis focuses solely on the impact of product transportation, not considering the environmental impact of using the warehouse. Based on an LCA methodology study, a value for the environmental impact for truck transportation (per kilogram and kilometer) is obtained.

Considering all the aspects mentioned above, the model developed for the JMD case study is implemented in the GAMS software, with the aim of optimizing the distribution chain. In the next chapter, the results obtained will be presented, comparing the different scenarios. The discussion of the results is going to be conducted, as well as a sensibility analysis to defined parameters, finalizing with a recommendation for the company.

Chapter 6 – Results and Discussion

In this chapter the results obtained when applying the developed model to the case study will be presented, as well as analyzed and discussed. The chapter is divided into four sections. The first one (section 6.1) aims to describe the approach to the solution for obtaining the results. The following one (section 6.2) presents the results for different scenarios, analyzing and comparing it. In section 6.3, a sensibility analysis is conducted to different costs' parameters, as well as to demand values. The chapter ends with a conclusion regarding the results presented, in section 6.4.

6.1 Solution approach implementation

To solve the problem presented in chapter 2, the mathematical model formulation presented in chapter 4 was implemented in the GAMS software, considering the data process mentioned in chapter 5. To perform all the simulations, it was used GAMS version 44.1.1, with CPLEX 22.1.1.0 on a computer with processor Intel® Core™ i5-10310U CPU @ 1.70 GHz. The computational results presented further were obtained through simulations performed in GAMS.

Four different scenarios were considered, and for each scenario the model was run. The first scenario (scenario 1 - "As Is") corresponds to the current network. The next two scenarios consider the existence of 3 warehouses, the one existent and two new locations. On one hand, scenario 2 restricts the operation to only one warehouse and on the other hand scenario 3 runs the operations on a maximum of two warehouses. The last scenario (scenario 4) considers the flow between warehouses at a lower cost. For the first three scenarios, two objective functions were considered: minimizing the costs and minimizing the environmental impact. For the last scenario, only the cost-optimized solution is studied, since the incorporation of flows between warehouses will increase the distances traveled and, therefore, the scenario that focuses on the environmental impact will not show better performance.

6.2 Single objective optimization

In this section, each objective function will be studied individually. For each scenario within the first three, the model will be optimized twice: one with the objective of minimizing the costs and other aiming to minimize the environmental impact. Both results will be presented in each scenario and some conclusions will be drawn comparing both optimizations. In the fourth scenario only the optimization object of minimizing the costs is considered.

6.2.1 Scenario “As Is” – current network

Firstly, the problem was solved using the current network configuration presented in chapter 4.1 and applying the data described in chapter 5. This configuration includes the suppliers, the warehouse in Azambuja and the markets, the different districts in Portugal. The model was run twice, one with the aim of minimizing the costs and the other one minimizing the environmental impact studied. Table 12 presents the results obtained in both optimizations.

Table 12 - Scenario 1 results (cost and environmental impact) in both optimizations

Optimization objective	Costs	Environmental impact
Costs minimization	9 769 295,57	46 154 860
Environmental impact minimization	10 791 000	46 154 860

As it can be seen from table 12, the value for the environmental impact remains the same in both optimizations, being equal to 46 154 860, this number does not have units. However, the costs are lower when the objective function aims to minimize them. These results were presented to the company and approved.

Analyzing the costs in both situations, in the first one, where the costs are minimized, a value of 9 769 295,57 € is obtained. However, when the concern is not focused in minimizing the costs, this value increases for 10 791 000 €. These two different situations can be compared, by analyzing the costs distribution in each one of them, as shown in figure 8.

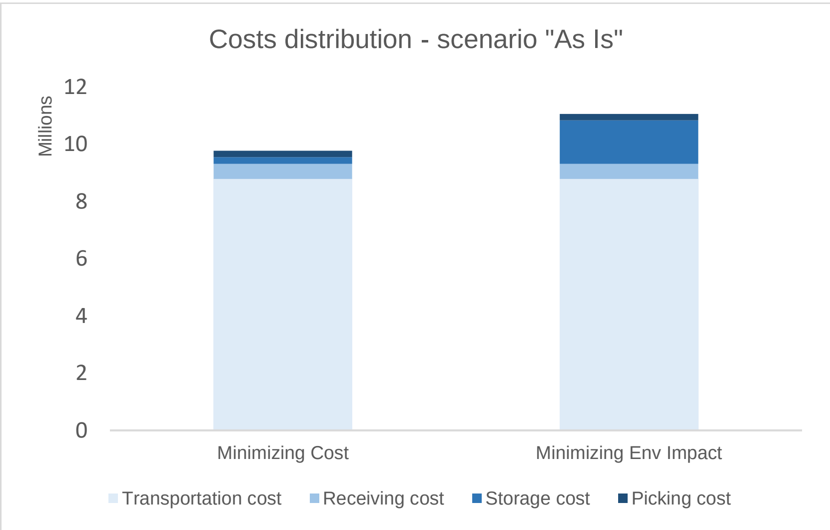


Figure 8 - Costs distribution in scenario 1 for both optimization objectives

Comparing the costs of transportation, receiving, storage and picking, it is possible to conclude that the values remain almost the same in absolute terms in both optimizations, excepting for one, the storage costs. In the situation where the optimization is not focused in minimizing the costs, the storage costs increase significantly, explaining the increase in the overall costs from one situation to the other. This result is explained by the fact that without the concern of minimizing the costs, the products will be in the warehouse, as stock, for a longer period. Besides the total flows being the same, which explains the same value for the environmental impact, the flow quantities changes over time, enabling the existence of higher inventory in the warehouse. With this solution, the company incurs in higher costs, but could take the possibility of creating resilience in the supply chain by not relying in the direct supply from the brands and dealing better with brand's lead times. Therefore, this scenario could possibly support the company in react faster to unexpected situations or fluctuations in the demand that were not forecasted.

Regarding the environmental impact, the results are the same on both optimizations, either the goal is to minimize the costs or the environmental impact, achieving a value of 46 154 860. This outcome was expected, since it was presumed that the flows will remain the same between the suppliers and the warehouse and between the warehouse and the markets. With only one warehouse in the current scenario and a defined demand per product to be met, the flows entering and leaving the warehouse over time are the same. Thus, the configuration of the networks, as well as the total flows will not change among the different optimizations, changing only the flow quantity in each period of time. This justifies the fact that the value for the environmental impact remains the same in both optimizations, since the routes travelled by the transports are the same.

Taking into consideration the network configuration, figures 9 and 10 present the flow configuration, as well as the entities' locations considered for the current scenario. This scenario aims to present JMD's current supply chain and, therefore, warehouse's location is not being chosen. In figure 9 it is possible to observe the flows from the suppliers, represented in red, to the current Luis Simões' warehouse in Azambuja, in color blue. There are two suppliers that are out of this representation due to their long distance from the warehouse, being them the supplier of Tabasco, located in Avery Islands, United States of America and the supplier of Jerónimos in Thailand, with an assumed location in Bangkok. Figure 10 presents the flows from the warehouse to the markets, represented in green. Açores and Madeira, both islands of Portugal are also not shown in the figure. This network configuration remains the same independently of the optimization objective (minimize the costs or minimize the environmental impact).

Figure 9 - Network configuration: flows between suppliers (red pins) and warehouse in Azambuja (blue pin) for scenario 1

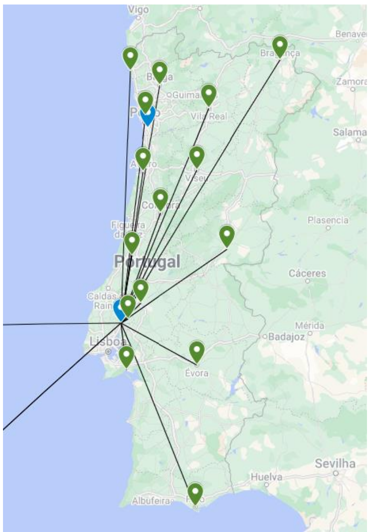


Figure 10 - Network configuration: flows between warehouse in Azambuja (blue pin) and markets (green pins) for scenario 1

6.2.2 Scenario 2 – with one warehouse open

When considering the possibility of adding two warehouses (one warehouse in the North of Portugal and one warehouse in Madrid) to the network configuration, the first scenario here studied is the one where only one of the three existing warehouses is open. The model was solved in order to, again, minimize the costs and then minimize the environmental impact. In both optimizations, the solution presented considers the opening of the warehouse in the North of Portugal. Thus, in a configuration where the company decides to be working with only one warehouse, the best option is to work with Luis Simões' warehouse in Gaia, Portugal, according to the study being developed and not with the warehouse in Azambuja. Table 13 presents the results obtained in both optimizations.

Table 13 - Scenario 2 results (cost and environmental impact) in both optimizations

Optimization objective	Costs	Environmental impact
Costs minimization	9 752 498,73	46 066 680
Environmental impact minimization	10 320 820	46 066 680

Once again, it is possible to verify that comparing the cost minimization with the environmental impact minimization, the value for the environmental impact remains the same, meaning that the routes' configuration for both solutions is similar. However, the costs increase from one to another. This increase, as in the scenario of the current configuration, is justified by the increase in the storage cost, as it can be seen in figure 11, where the cost distribution in both optimizations.

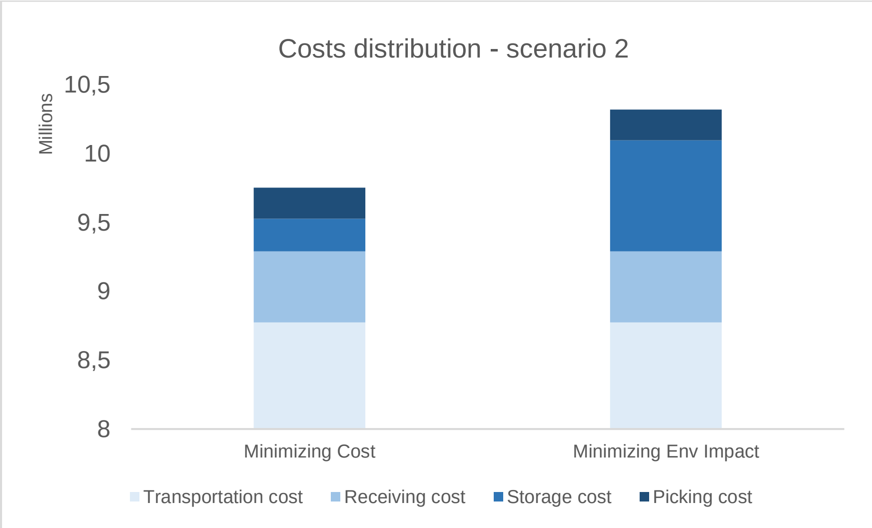


Figure 11 - Cost distribution in scenario 2 for both optimization objectives

Regarding the network configuration, the following pictures show the flows between the suppliers and the warehouse (in the North of Portugal) and between the warehouse and the markets. The three warehouses are represented in blue (Azambuja, Gaia and Madrid), but only the one in Gaia (North of Portugal) has flows entering and leaving. As in the previous scenario, the suppliers of Tabasco and Jerónimos Thailand are not represented in figure 12 nor are islands markets, Açores and Madeira, in figure 13. The following network configuration remains the same in both optimizations, being the difference only in the quantity flow transported at each period of time.

Figure 12 - Network configuration: flows between suppliers (red pins) and warehouses (blue pins) for scenario 2

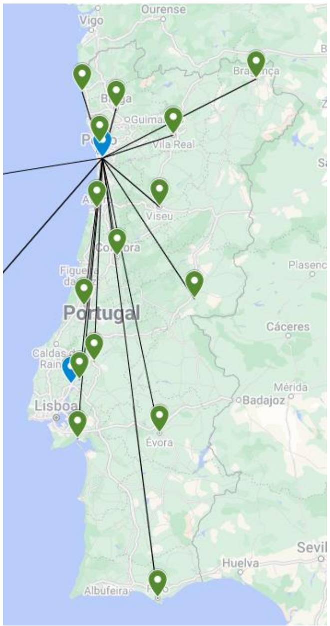


Figure 13 - Network configuration: flows between warehouses (blue pins) and markets (green pins) for scenario 2

6.2.3 Scenario 3 – restrict to a maximum of two warehouses operating

In the third scenario presented, the three warehouses are again incorporated in the model, but without the restriction of having only one warehouse open. The model was solved considering the restriction of having a maximum of two warehouses working simultaneously.

As in the previous scenarios, the model was solved firstly with the objective of minimizing the costs and then with the objective of minimizing the environmental impact. In both optimizations, the configuration proposed is the incorporation of the warehouses in Azambuja and in Gaia in the network. Table 14 presents the results obtained for the cost and environmental impact for the configuration with two warehouses (Azambuja and Gaia) in both optimizations.

Table 14 - Scenario 3 results (cost and environmental impact) in both optimizations

Optimization objective	Costs	Environmental impact
Costs minimization	9 435 774,25	43 174 500
Environmental impact minimization	11 995 000	43 171 302,78

The results show that for the optimization objective of minimizing the costs, the cost of the proposed network is 9 435 774, 25 €. However, when the optimization objective changes from minimizing the costs to minimizing the environmental impact, the result obtained for the cost increases around 3 million euros, to 11 995 000 €. As in the previous scenarios, this increase is related to the presence of more products in inventory and, therefore, to the increase in storage costs, although there is a slight decrease in transportation costs.

In terms of environmental impact, the results show a slight decrease of this value when the optimization objective is to minimize the environmental impact instead of minimizing the costs. After analyzing the results, it is possible to verify that there is a slight increase in the environmental impact of the transport between the suppliers and the warehouse, but then there is a greater decrease in the environmental impact of the transport between the warehouse and the markets. This decrease is justified by the decrease in the distances travelled in these flows, also lowering the costs of transportation. Without the concern of the costs related to the warehouse, as the storage cost, the stock can be hold in the warehouse to respond to the demand, especially for cases where the flows between the warehouses and the markets were minimum, increasing the independency of the warehouse. Thus, there is more flexibility for the flows to be allocated to routes with lower distances, decreasing the environmental impact.

Considering the network, both optimizations present very similar configurations. All the suppliers have flows to both warehouse (in Azambuja and Gaia), meaning that the suppliers distribute their products between the two warehouses, according to the demand needs in the markets nearby the warehouse. In the solution presented, some flows between the suppliers and warehouses are not visible, since that in the time period considered, these warehouses use the stock existing from the first period of time to meet the demand. However, it was verified that even if there wasn't any stock in the warehouse, the flow between these suppliers and warehouse would exist anyway. In the same way, considering the flows between the warehouses and the markets, it is possible to verify that both warehouses present flows to all the markets with the cost minimization objective. However, there are some exceptions when the optimization objective changes to the minimization of the environmental impact. These exceptions stand for the flows between the warehouse in Gaia and the markets Évora, Faro and Santarém. In these cases, since the flow quantities in the cost minimization optimization objective were minimum, the existence of higher stock in the warehouse enables to meet the demand with the flow of only warehouse. Figures 14 and 15 present the flows between suppliers and warehouses and between warehouses and markets, respectively, for the optimization objective of minimizing costs.

Figure 14 - Network configuration: flows between suppliers (red pins) and warehouses (blue pins) for scenario 3

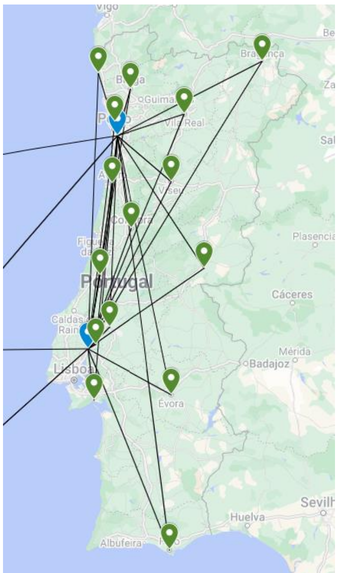


Figure 15 - Network configuration: flows between warehouses (blue pins) and markets (green pins) for scenario 3

Taking the cost minimization solution and considering the flows between the different entities, it is possible to understand the pattern between the usage of one warehouse or another. As it was previously mentioned in the Data Collection and Treatment chapter, the Lisboa and Porto markets have the highest demand, with a significant difference from the other markets considered. In this way, the solution presented show that, in general, Azambuja warehouse is used to meet the demand in Lisboa and Gaia's to respond to Porto's demand, having some exceptions due to space constraints in the warehouse. Thus, the suppliers distribute the products between the warehouses according to their final destination:

in general terms, if the demand for that brand is higher in the North of Portugal, then a big percentage of products will go to Gaia's warehouse; if the demand is higher in the Center or South of Portugal, the majority of the products should go to Azambuja's warehouse, which has bigger capacity. Figure 16 presents the composition of the product distribution from each warehouse to each market, in percentage, verifying the conclusions presented.

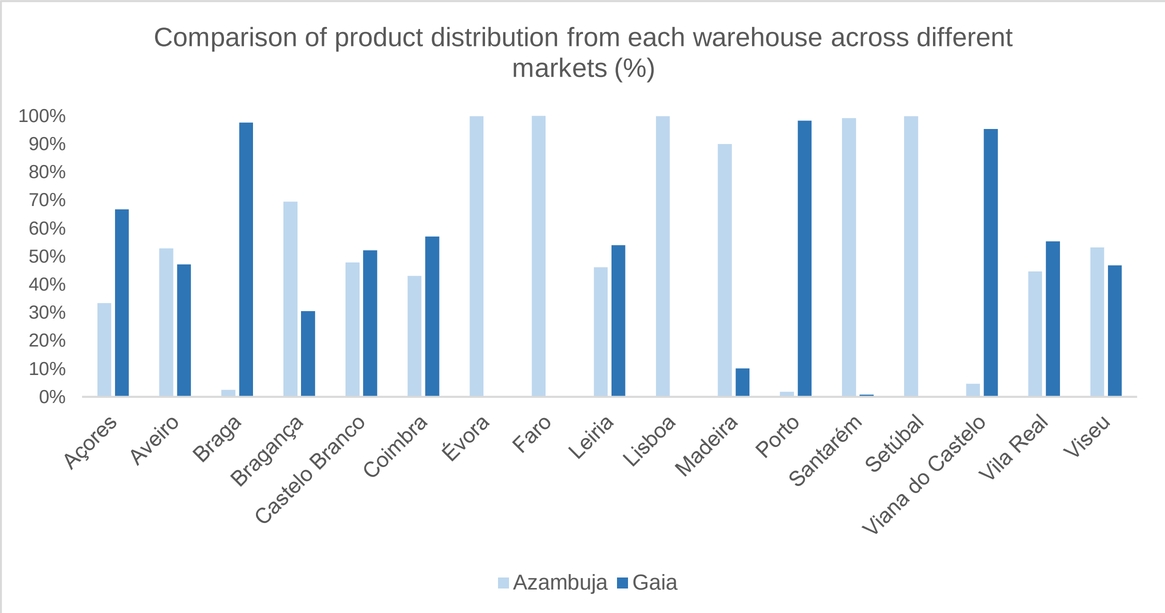


Figure 16 - Comparison of product distribution from each warehouse across different markets for scenario 3 cost-optimized (in percentage)

6.2.4 Comparison between the three scenarios

As it was possible to analyze by solving the problem with the two different optimization objectives, the value for the environmental impact remained the same in both optimizations in the first two scenarios. The exception stands for the third scenario, with two warehouses working, where the value for the environmental impact in the cost objective optimization is higher than in the environmental impact objective optimization, as discussed previously. For this reason, for the first two scenarios will only be considered the optimization which minimize the costs and for the final scenario both optimizations will be taken into account. Figure 17 presents a comparison of the total costs between these scenarios, and figure 18 a comparison of the environmental impact values.

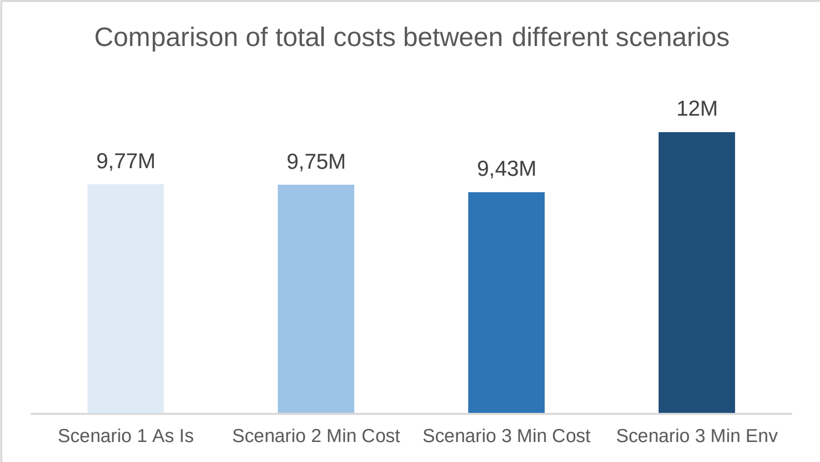


Figure 17 - Comparison of total costs between scenarios 1, 2 and 3 cost-optimized and 3 with environmental impact optimization

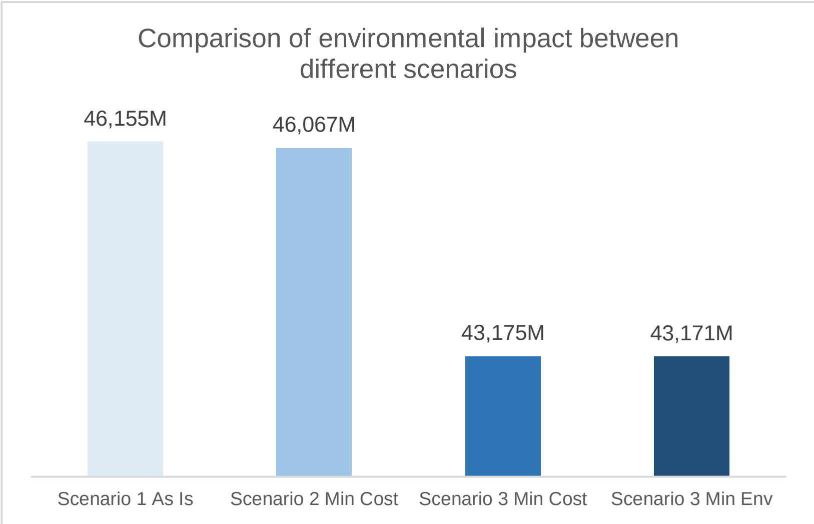


Figure 18 - Comparison of environmental impact between scenarios 1, 2 and 3 cost-optimized and 3 with environmental impact optimization

As can be seen in figure 17, the scenario presenting lowest costs is scenario 3 with the optimization objective of minimizing the costs. This scenario also has one of the lowest values for environmental impact, and the only scenario that performs better for this value is scenario 3 with the objective function of minimizing environmental impact ("Scenario 3 Min Env"). Figure 18 shows that there is a great benefit on going form scenario 1 "As Is" or scenario 2 to scenario 3, since the difference in the environmental impact is significant. When comparing the same value in both optimizations for scenario 3, the difference is not that significant contrasting with the first ones. Furthermore, contrasting the costs in these two scenarios, there is a significant difference, since the "Scenario 3 Min Env" presents costs considerably higher. Therefore, when weighting up the decrease in the environmental impact in the last scenario with the increase in the costs, it will not be beneficial for the company to incur in a cost of around 2,5 million, an increase of almost 30% comparing to "Scenario 3 Min Cost" to save in less than 0,01% regarding environmental impact.

In terms of warehouses' capacities, the different solutions presented deal with the usage of the warehouses in different ways. Recapping, the first scenario (scenario "As Is"), which is the current situation, considers only the usage of the warehouse in Azambuja. The second scenario, restricted to the use of one warehouse, has only the warehouse in Gaia (north of Portugal) working. Finally, the last scenario considers both warehouses of Azambuja and Gaia. Figure 19 shows the percentage of each warehouse being used in each scenario.

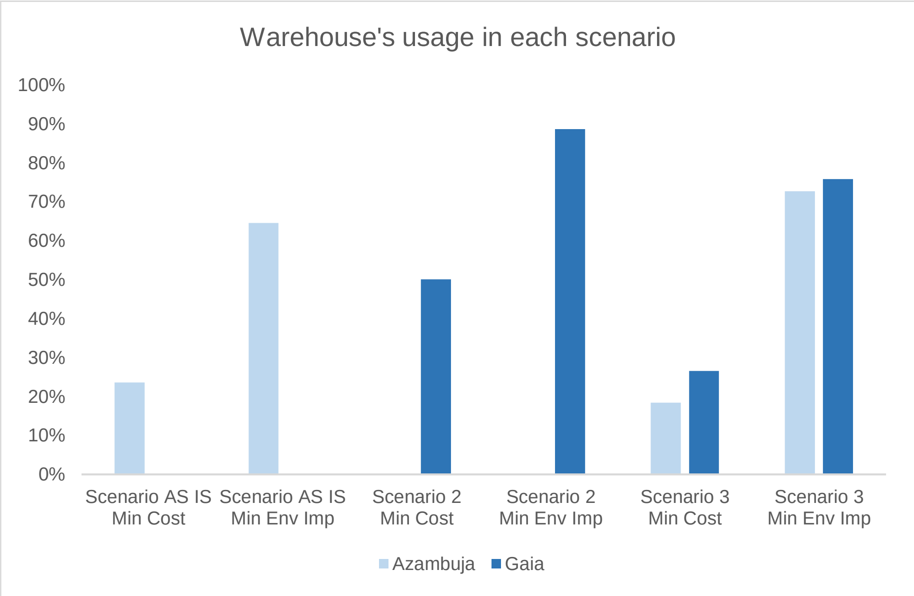


Figure 19 - Warehouse's usage for both optimizations in each scenario

Within each scenario, it is possible to verify that when changing from minimizing the cost to minimizing the environmental impact, the percentage of usage of the warehouse (in all scenarios) increases significantly. This happens since the storage costs are not a concern in the second optimization and, therefore, don't need to be lowered and the products remain in the warehouse, occupying more space available.

Furthermore, it should be noted that the warehouse in Gaia has around half of the capacity of the warehouse in Azambuja. The first one has capacity for 15 000 pallets and the one in Azambuja for 31 858 pallets. Thus, it is expected that, comparing the first scenario, where the Azambuja's warehouse is the only working, and the second scenario, where it is only considered the warehouse in Gaia, the percentage of usage of the Gaia's warehouse should be significantly larger than the percentage for the Azambuja's one, since the flow quantities remained the same in both warehouses.

Finally, the third scenario considers the balance between the use of the warehouse in Azambuja and Gaia, having lower percentages in each warehouse comparing to the scenarios where the warehouse is the only used. With the incorporation of one more warehouse in the network configuration, it is possible to build a more flexible and efficient distribution chain, since the products are now distributed between two warehouses, enabling its proximity with the final market. Furthermore, an important aspect to note is the fact that with two warehouses, the company doesn't rely in only warehouse. Thus, if an expected event occurs and harms one of the warehouses, there is one more to cope with the demand until the activity is reestablished, making the supply chain more resilient.

It was also implemented a warehouse in Madrid that was not chosen for the model for any scenario. As the problem was presented in these scenarios, it was expected for the solution to rely in the warehouses in Portugal, since they are the ones with more proximity with the final markets. Besides Madrid being closer to some suppliers, by balancing the distances that the company will be able to save with this warehouse, with the increase in the others for the final clients, was not beneficial for the company.

6.2.5 Scenario 4 – with flows between warehouses

Beyond to the scenarios considered before, one more hypothetical scenario was studied, where the same entities and modes of transport were considered, adding only the possibility of existing flows between warehouses. Since these flows are responsibility of Luís Simões, consisting only in an intern process, it was assumed that the costs of transportation would be lower than the considered for the rest of network transportations, establish a value of 30% of the one considered for the other costs of transportation. With this scenario, it is expected that JMD would take advantage of both the proximity of the warehouse in Madrid with the suppliers, and the proximity between the warehouses in Portugal and the markets. It should be noted that, nowadays, Luis Simões has already trucks with big capacities doing the transportation between the warehouse in Madrid and the warehouse in Lisbon. Therefore, with big capacities and being able to operate with the truck full, Luis Simões is able to perform this service at a lower price.

The solution provided includes the operation of the three warehouse simultaneously: the warehouse in Azambuja, the warehouse in Gaia and the warehouse in Madrid. Table 15 presents the results of the cost and environmental impact for this scenario regarding the cost minimization objective. It should be noted that it is not considered the optimization objective of minimizing the environmental impact, since the solution gotten for this optimization objective does not incorporate the flows between warehouses. These flows will increase the distance travelled and, therefore, will increase the environmental impact. Thus, solutions considering only the flows between suppliers and warehouses and between warehouses and markets, with one or two warehouses operating will have better performances in the environmental impact than a solution including flow between warehouses.

Table 15 - Scenario 4 results (cost and environmental impact) in cost optimization objective

Optimization objective	Costs	Environmental impact
Costs minimization	9 166 506,67	43 678 150

Regarding the costs and comparing this scenario with the one with overall better performance of the ones previously presented (scenario 3 with the optimization objective of minimizing the costs), there is a decrease of around 270 000 €, going from 9 435 774,25 € to 9 166 506,67 €. Figure 20 compares the different costs (transportation costs, receiving costs, storage costs and picking costs) between these two scenarios. As figure 20 shows, there is an increase in the receiving, storage and picking costs that is offset by the decrease in the transportation costs. Although the distance travelled increased, the transportation costs of the routes travelled between the warehouses is lower, enabling the company to take advantage of transport their products to Portugal at a lower cost.

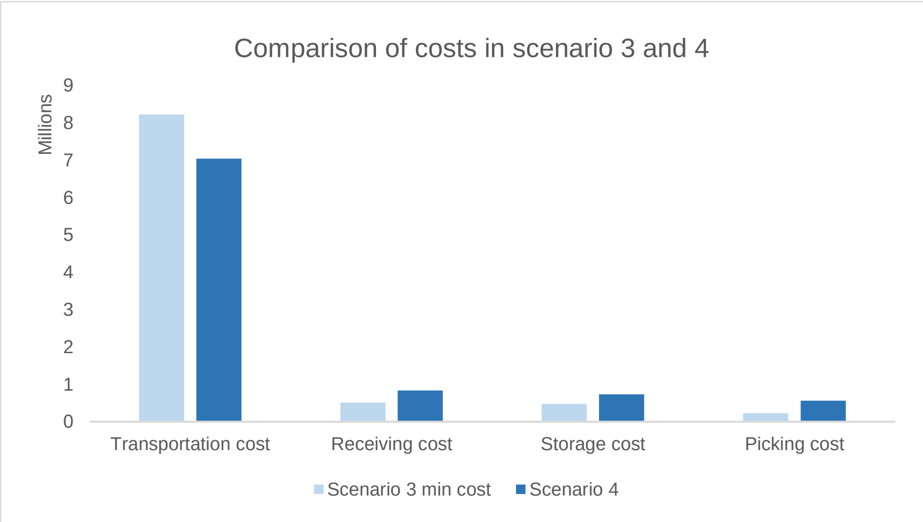


Figure 20 - Cost's comparison in scenario 3 and 4

Even though the company benefits with this scenario in terms of costs, the environmental impact does not have a better performance in this situation. This was expected for the reason presented above: the distances travelled increase, since the flows between warehouses are being incorporated, instead of directly sending the products to the final warehouse or market. Since the study considers only the environmental impact of transports, depending on the distance travelled and the flow quantity, this scenario does not present any benefit regarding the environmental impact.

Considering the network configuration, it is verified that almost all the suppliers send their products to the warehouse in Madrid, the exceptions stand for the suppliers located in Portugal that will send directly to one of the two warehouses in Portugal (Azambuja or Gaia) – Guloso PT, Jerónimos PT and Mandarin. Beyond these suppliers, the two suppliers more distant (Tabasco and Jerónimos TH) have different behaviors: Tabasco, located in the United States of America, send the products to Azambuja and Gaia, instead of Madrid and Jerónimos TH, in Thailand, send products to all warehouses. All the suppliers based in Spain and Italy ship their products to the warehouse in Madrid, except Calidad Pascual (located in Spain), that also sends to the warehouse in Gaia, since it is closer to Portugal. Finally, all the suppliers located in the other countries in Europe (France, Belgium, Netherlands, Germany, United Kingdom, Czech Republic, Poland and Romania) distribute their products between the warehouses in Gaia and Madrid. With this network, Madrid becomes the warehouse receiving more products, which is then going to export them and distribute them between Azambuja and Gaia warehouses in order to be shipped for the different markets where they are demanded. The distribution to the different markets in Portugal is essentially made by the warehouses in Portugal (Azambuja and Gaia). However, the warehouse in Madrid also sends products directly to the final market, this happening for Açores, Bragança, Castelo Branco, Évora, Vila Real and Viseu. It should be noted that the demand for these markets is only met with the complement of the products coming from at least one of the warehouses in Portugal. Figures 21 and 22 present the network configuration referred.

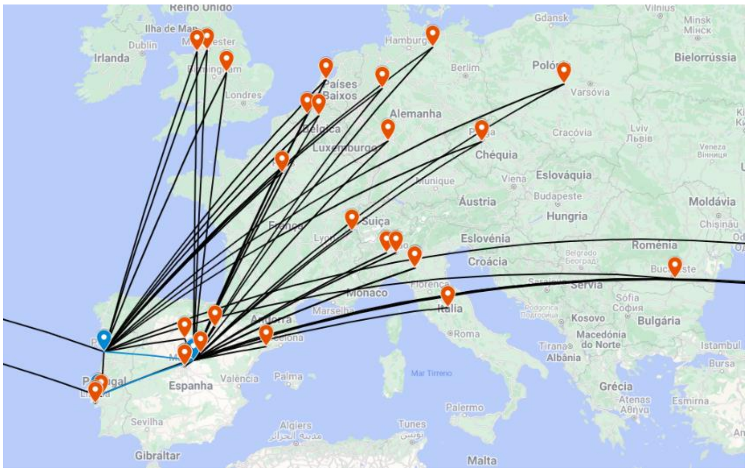


Figure 21 - Network configuration: flows from suppliers (red pins) to warehouses (blue pins) in black, and flows between warehouses in blue for scenario 4

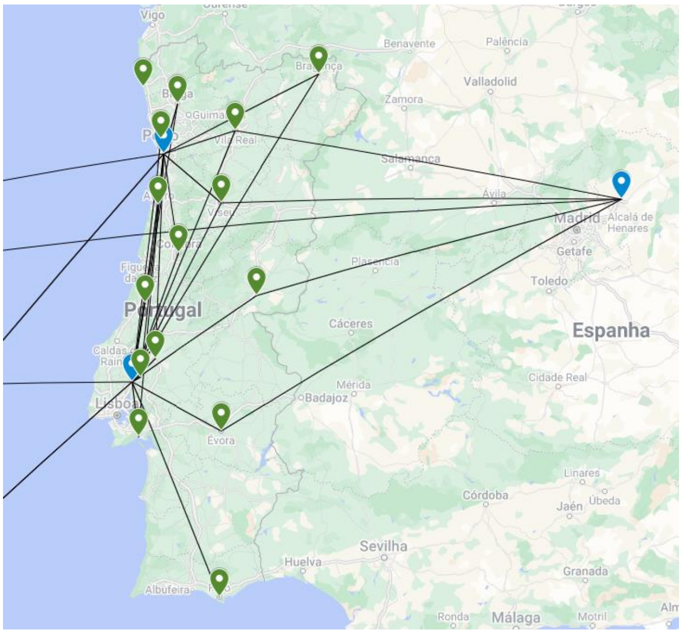


Figure 22 - Network configuration: flows from warehouses (blue pins) to markets (green pins) for scenario 4

Regarding the capacity utilization of the warehouses, since this scenario includes the operation of the three warehouses, the percentage of capacity being occupied in each warehouse is expected to be lower when compared to the scenarios where only one or two warehouses were working. Table 16 presents the average percentage of capacity used in each warehouse.

Table 16 - Capacity being utilized in each warehouse in scenario 4, in pallets and in percentage

Warehouses	Total capacity (in pallets)	% of capacity utilized
Azambuja	31 858	18,45
Gaia	15 000	26,11
Madrid	68 500	8,49

This scenario proposes a solution where the company can take advantage of the use of the three warehouses from Luis Simões, decreasing the overall costs of the network and gaining flexibility. However, this solution does not present favorable results, comparing to the other scenarios, for the environmental impact. It should be also noted that this solution would imply the establishment of a new agreement between JMD and Luis Simões, where the costs proposed for the flows between the warehouses could differ from the present ones.

6.3 Sensibility analysis

A sensibility analysis is conducted to study the robustness of the scenarios presented, when facing changes in some parameters.

For this analysis, the scenarios considered were the ones which the optimization objective is minimizing the costs. This decision is supported by the fact that, as it was seen in the previous section, there are not significant variations in the environmental impact when changing the optimization objective and, therefore, the solutions that minimize the costs constitute a better option for the company. Furthermore, despite the effort and interest in minimizing environmental impacts, the company's main focus is on reducing its costs (in addition to improving customer relations).

The fact that various assumptions and simplifications were made throughout the data processing, so that it was possible to develop the model with the existing resources, adds a level of uncertainty to the parameters. The time horizon considered, about 2,5 years, is not a major element of uncertainty. In addition, it is also important to understand that some parameters, regardless of their associated uncertainty, carry a great weight in the results, meaning that changing them will have a major impact on the overall scenario.

In this sense, the parameters considered in this analysis are related to costs, since they will have a direct impact on the total cost of the network, which is sought to be reduced. A sensitivity analysis was carried out on transportation costs, warehouse operating costs and transportation costs between warehouses. The aim is to understand the impact of changing these parameters on the total cost and in the network configuration. Furthermore, it is also taken into account the potential growth of the company, considering an increase in the demand and its impact in the network configuration.

6.3.1 Transportation costs

As it was verified in the scenarios results, when the costs distributions were presented, the transportation costs have a high weight in the total cost of the network. For this reason, it could be interesting to analyze how the variation of these costs will impact the overall cost of the network. Furthermore, it should be noted that some simplifications and assumptions were made to calculate the cost of transportation per pallet and km and, therefore, there is uncertainty allocated to this value. It should also be noted that the transportation costs include the fuel costs and, therefore, it will also depend on the fluctuations of the fuel price, making this value less accurate for a long period of time. For the development of this sensibility analysis, scenario 3 (two warehouses operating) with the optimization objective of minimizing the costs was used as an optimal scenario. Table 17 presents the results for the sensibility analysis of this parameter. Due to JMD’s compliance policies regarding data confidentiality, the cost values can not be presented in the table.

Table 17 - Sensibility analysis' results for transportation costs

Variation	-100%	-50%	Optimal scenario	+ 50%	+ 100%
Used Value	-	-	-	-	-
Warehouses operating	Azambuja	Azambuja	Azambuja	Azambuja	Azambuja
	Madrid	Gaia	Gaia	Gaia	Gaia
Total Cost	1 211 172,65	5 323 713,87	9 435 774,25	13 547 574,43	17 659 292,50
Total Cost variation	-87,15%	-43,58%	0%	+43,58%	-87,15%

The results show that the variation in the transportation costs have a strong impact in the total cost variation. A variation of 50% in the transportation costs means a change of around 44% in the total cost of the network and a variation of 100% will impact around 87% in the overall value of the costs. At the same time, it is verified that the increase in the transportation costs (until 0,06 €/pallet/km) will not modify the network configuration, remaining the two warehouses (Azambuja and Gaia). However, in the hypothetical situation, where the transportation cost is zero, meaning that this cost is not responsibility of JMD, the new proposed network configuration includes the warehouse in Madrid and the warehouse in Azambuja.

6.3.2 Warehouses costs

Regarding the operation costs of the warehouses (Azambuja, Gaia and Madrid), since they are all operated by Luis Simões, it was assumed the same costs for receiving, storing and picking products in the different warehouses. However, there is some uncertainty associated with this parameter, since Luis Simões can charge different prices for the same operation in Portugal or in Spain, or even within Portugal. For this analysis, as the previous one, it was used scenario 3 (with the optimization objective of minimizing the costs) as an optimal scenario.

Table 18 presents the results for the sensibility analysis when varying the costs of operation of the warehouse in Madrid, assuming that the other warehouses remain with the same operation costs. It should be noted that the values presented are in €/SKU and that it was considered the same variation for each one of the costs (receiving, storage and picking). Due to JMD's compliance policies regarding data confidentiality, the cost values can not be presented in the table.

Table 18 - Sensibility analysis' results for Madrid's operational costs

Variation	-40%	-20%	Optimal scenario	+20%	+40%
Used Value (receiving cost)	-	-	-	-	-
Used Value (storage cost)	-	-	-	-	-
Used Value (picking cost)	-	-	-	-	-
Warehouses operating	Azambuja	Azambuja	Azambuja	Azambuja	Azambuja
	Madrid	Gaia	Gaia	Gaia	Gaia
Total Cost	9 319 721,00	9 435 774,25	9 435 774,25	9 435 774,2	9 435 774,25
Total Cost variation	-1,23%	0%	0%	0%	0%

From table 18, it is possible to conclude that within the variations considered, the total costs will only change with a decrease of 40% of the operating costs in the warehouse in Madrid. Looking into the warehouses operating for each scenario, the negative variation of 40% is the only one where the Gaia warehouse is replaced for the one in Madrid. The other scenarios do not incorporate the warehouse in Madrid in their configuration and, therefore, varying the operation costs of this warehouse will not have any impact in the overall network costs. In this line of thought, it could be interesting to understand how much the operation costs in Madrid would have to decrease in order to be more beneficial for the company to include it in the network configuration, instead of one of the warehouses in Portugal. Figure 23 presents the total costs over the negative variation in the operation costs in Madrid's warehouse.

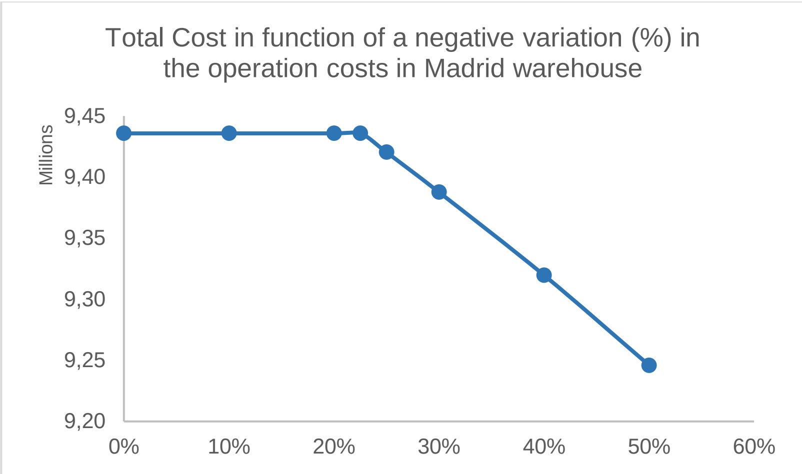


Figure 23 - Variation of total costs in function of the decrease in Madrid's operational costs

As figure 23 shows, when the operation costs of Madrid's warehouse decrease more than 22,5%, the total costs start to decrease. Until that point, the warehouse in Madrid is not being included in the network configuration, since the solution with the Azambuja and Gaia's warehouses is less costly for the company. However, if the operation costs of Madrid's warehouse are more than 22,5% lower than the value considered in the optimal scenario, this warehouse would be incorporated in the network, as the costs would lower. Concluding, with a decrease greater than 22,5% in the value of the costs in Madrid, it will always be financially beneficial to the company to use the warehouse in Madrid.

Then, a sensibility analysis was conducted to the operation costs in Gaia, understanding also how the total costs changes with the variation of this parameter, using again, as an optimal scenario, scenario 3 with the optimization objective of minimizing the costs. Table 19 presents the results for this analysis. It should be noted that lower percentages of variation were considered for this analysis, since it is expected that the differences in the operation costs between Gaia's warehouse and Azambuja's warehouse would not be as sharp as the possible difference between Madrid's warehouse and Azambuja's one, due to their location in different countries. Due to JMD's compliance policies regarding data confidentiality, the cost values can not be presented in the table.

Table 19 - Sensibility analysis' results for Gaia's operational costs

Variation	-20%	-10%	Optimal scenario	+10%	+20%
Used Value (receiving cost)	-	-	-	-	-
Used Value (storage cost)	-	-	-	-	-
Used Value (picking cost)	-	-	-	-	-
Warehouses operating	Azambuja	Azambuja	Azambuja	Azambuja	Azambuja
	Gaia	Gaia	Gaia	Gaia	Gaia
Total Cost	9 339 447,50	9 388 170,19	9 435 774,25	9 482 571,39	9 525 980,11
Total Cost variation	-1,02%	-0,51%	0%	+0,50%	+0.96%

Table 19 shows that the variation in the operation costs in the Gaia's warehouse does not cause a great impact in total costs. Thus, a variation between 0 and 20% in the operation costs in this warehouse will imply a variation between 0 and around 1% in the total costs. For the values of variation studied, the network configuration remains the same with both warehouses in Portugal (Azambuja and Gaia). Figure 24 presented below presents the variation of the total costs over the positive variation in the operation costs of the warehouse in Gaia. If the value of the operation costs in Gaia increases 32,5%, the best possible solution is to replace the Gaia's warehouse for the one in Madrid, lowering the overall costs.

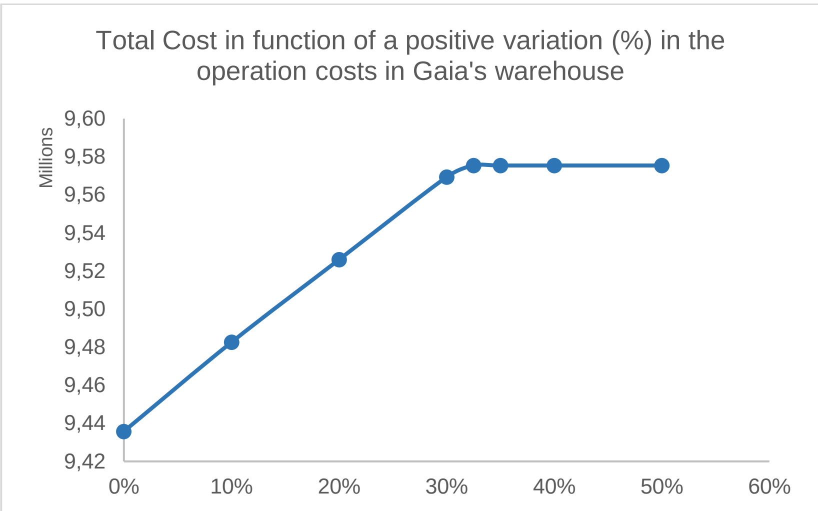


Figure 24 - Variation of total costs in function of the increase in Gaia's operational costs

6.3.3 Transportation costs between warehouses

The last parameter studied in the sensibility analysis is the cost of transportation allocated to the flows between the warehouses (scenario 4). As it was mentioned in the results of the scenario 4, this scenario-considers the flow between warehouses at lower costs of transportation. In this line of thought, table 20 shows how the total costs vary over the variations in the transportation costs between warehouses. The lowest variation considered (the value decreases 100%) is the scenario where this flow between the warehouses is the responsibility of Luis Simões and no additional costs are charged to JMD. Due to JMD's compliance policies regarding data confidentiality, the cost values can not be presented in the table.

Table 20 - Sensibility analysis' results for inter-warehouse transportation costs

Variation	**-100%**	**-50%**	**Optimal scenario**	**+ 50%**	**+ 100%**
Used Value	-	-	-	-	-
Warehouses operating	Azambuja	Azambuja	Azambuja	Azambuja	Azambuja
	Gaia	Gaia	Gaia	Gaia	Gaia
	Madrid	Madrid	Madrid		
Total Cost	8 418 556,74	8 810 849,45	9 166 506,67	9 435 774,24	9 435 774,24
Total Cost variation	-8,16%	-3,88%	0%	2,94%	2,94%

Taking the results from table 20, it is possible to conclude that a decrease in the transportation costs between warehouses will have a considerable impact in the total cost variation and the solution of having the three warehouses operating continues to be the best one. However, the same does not happen when the transportation costs suffer an increase. The table shows that with an increase of 50% in the transportation costs between warehouses, this scenario (having three warehouses operating and flow between them) is no longer the best option to the company. For an increase in this transportation costs greater than 50%, the scenario 3 should be adopted (both warehouses in Portugal operating and without flows between them). Different scenarios for an increase lower than 50% in the transportation were tested, and the conclusion states that the increase of 50% as the break-even point, where, starting from that point, scenario 3 should be adopted, instead the one considering the flow between warehouses.

6.3.4 Demand's increase consideration

Finally, a scenario was considered in which demand for each product in each market increases by 1% every year compared to the same period in the previous year, thus increasing JMD's sales. This scenario aims to take into account the company's potential growth over the next 5 years. To develop this scenario, warehouse operation was restricted to a maximum of two warehouses operating simultaneously, considering only the cost optimization scenario.

In this sense, the results show that the distribution network which includes Azambuja and Gaia warehouses continues to be the optimum solution for an increase in demand of 1% per year over the next 5 years. Furthermore, as it was seen in cost optimization scenario 3, all suppliers have flows to both warehouses and the two warehouses are responsible for distributing the products to all markets.

As for the capacities used for each warehouse, these remain similar to those presented in scenario 3, which aims to minimize costs. Thus, there is an increase of around 0.2% in the average monthly use of each warehouse over the 5 years. The warehouse in Azambuja, which in scenario 3 had a used capacity of 18.42%, now has an average monthly usage of 18.54% of its total capacity. At the same time, the warehouse in Gaia went from being used by 26.6% to 26.86%. As it can be noticed, the change in the percentage utilization of the warehouses is quite small.

6.3.4 Sensibility analysis conclusion

In conclusion, throughout this analysis the objective of minimizing the costs has been taken as the focus, evaluating how the different parameters will impact in the overall costs of the network, using scenario 3. In this line of thought, this sensibility analysis reveals that the transportation costs have a significant impact in the problem studied, meaning that a slight variation in these values can cause notable changes in the overall costs. This impact is visible in the first sensibility analysis conducted to the transportation costs, where a variation of 50% of the transportation costs led to a variation of around 44% in the total costs.

Furthermore, in contrast, it is seen that the operation costs of the warehouses do not have such a significant impact in the total costs. However, at the same time, there is a considerable uncertainty associated with these costs, due to the simplifications and assumptions made throughout the study. For this reason, it is also important to understand how the total costs depend on the warehouse's operation costs, as well as the network configuration itself. Following this and remembering that the configuration proposed in scenario 3 includes the operation of Azambuja and Gaia warehouses, it is verified that a decrease of, at least, 22,5% in the operation costs of Madrid's warehouse, will change the proposed network, replacing Gaia warehouse with the one in Madrid. At the same time, if the operation costs in Gaia increase, at least, 50%, it would be more beneficial for the company to replace it for the warehouse in Madrid.

It was also developed an analysis to scenario 4 considering the transportation costs between the warehouses. The most relevant aspect to take into account is the fact that an increase of 50% in the transportation cost between warehouses will impact the network configuration. Thus, with this increase, this scenario has a worse performance in the overall costs and the solution proposed changes for the one presented in scenario 3, considering only two warehouse and no flow existence between warehouses.

The final consideration regarding the increase in the demand in the following 5 years aims to study the impact of the potential company’s growth in the network configuration. By increasing the demand for each product in each market in 1% per year and restricting the operation to a maximum of two warehouses, the optimal network configuration obtained was the same, as well as the flows between entities. This analysis reinforces the resilience of the proposed network configuration.

6.4 Chapter Conclusion

This study addressed the problem discussed in Chapter 2 by implementing the mathematical model presented in Chapter 4, with the considerations developed in Chapter 5, in GAMS software. Four different scenarios were analyzed, each corresponding to a specific constraint in the network configuration.

- Scenario 1 (As Is) represented the current network.
- Scenario 2 introduced two additional warehouses while restricting operation to one warehouse.
- Scenario 3 allowed the operation of two warehouses.
- Scenario 4 considered flows between warehouses

Each objective function is studied separately for each scenario, optimizing the model twice: once to minimize the costs and once to minimize the environmental impact.

Starting with scenario 1 “As Is”, in both optimizations, the environmental impact remains the same, since the network configuration and total flows do not change. When focusing on cost minimization, the total costs amount is 9 769 295,57 €. Between both optimizations, there is a trade-off between increasing the costs and raising the storage in the warehouse, which allows for a faster response to unexpected demand fluctuations or unforeseen situations. In this scenario, the flows go from each supplier to the warehouse in Azambuja, and from the warehouse to all the Portuguese clients.

After adding two warehouses to the network configuration, scenario 2 with only one warehouse open was considered. The model was optimized to minimize costs and to minimize the environmental impact. In both optimizations, the solution suggests that the warehouse in the North of Portugal (Gaia) should be operational. As in the previous scenario, the environmental impact value remains the same in both optimizations, and the total cost increases while shifting from cost minimization to environmental impact optimization, due to the higher storage costs. However, for the cost minimization objective optimization, the values for the total cost (9 752 498,73 €) and for the environmental impact (46 066 680) are lower than in scenario 1, where the Azambuja's warehouse is used. The network configuration remains consistent across both optimization objective, differing only in flow quantities transported over time, presenting the flows between suppliers and the warehouse in Gaia, and between the warehouse and the markets.

In the third scenario, all three warehouses are incorporated into the model, with the restriction of having a maximum of two of them operating. The model was optimized with both costs and environmental impact objectives, and the configuration included Azambuja and Gaia warehouses. When the objective is to minimize the costs, the cost of the proposed network is 9 435 774,25 €, whereas with the objective of minimizing environmental impact, the cost increases by around 2,5 million €, explained again by the increasing in the storage costs. As for environmental impact, there is a slight decrease when the objective shifts to minimizing this factor, due to decreased transportation distances, supported by the increasing of inventory in the warehouse and the flexibility in route allocation. Despite the decrease in the transportation costs, this solution, where the environmental impact is lower, implies an increase in the inventory in the warehouse. The reduction in the environmental impact is minimum (0,01%) compared to the increase in the costs (30%). Furthermore, it is not suitable for the company to rely on inventory since it will increase the probabilities of handling with obsolete products. In terms of network configuration, both optimizations present very similar configurations, as, in general, suppliers have flows to both warehouses (Azambuja and Gaia), and both warehouses supply all the markets. The analysis of flows between entities reveals a pattern in warehouse usage based on demand. Generally, Azambuja warehouse is used to meet demand in Lisboa, while Gaia warehouse serves Porto. This is due to the higher demand in Lisboa and Porto compared to other markets. Space constraints in the warehouses may lead to exceptions.

A hypothetical scenario was studied where flows between warehouses were considered with lower transportation costs. This scenario aimed to leverage the Madrid warehouse's proximity to suppliers and the Portuguese warehouses' proximity to markets. In this scenario, where only the cost minimization objective was considered, all three warehouses are operational: Azambuja, Gaia, and Madrid. Comparing this scenario to the best-performing previous one, it reduced costs by around 270 000 €, due to a decrease in transportation costs. Despite the increased distances, that increase the environmental impact value, the transportation costs for routes between warehouses are lower, enabling the company to transport its products to Portugal at a reduced cost. In terms of network configuration, most suppliers sent products to Madrid warehouse. Therefore, Madrid receives more products, which are then, in general, exported and distributed between Azambuja and Gaia for shipment to various markets in Portugal. This scenario proposes a solution where the company uses all three warehouses from Luís Simões, reducing overall network costs and gaining flexibility. However, it does not yield significant environmental benefits. It's also important to note that implementing this solution would require establishing a new agreement between JMD and Luís Simões, potentially resulting in different costs for flows between warehouses.

In conclusion, throughout this analysis the objective of minimizing the costs has been taken as the focus, evaluating how the different parameters will impact in the overall costs of the network, using the scenario 3 presented. In this line of thought, it is possible to conclude that transportation costs significantly affect total costs and, therefore, its fluctuations should be monitored. At the same time, uncertainty associated with these costs should be considered when planning the supply chain in order to decrease the impact in the supply chain, making it more resilient. On the other side, warehouse operation costs have less impact in total costs, but some variations will lead to changes in the configuration proposed. However, it has shown that a reduction of 22,5% in Madrid's operation costs may replace Gaia's choice, and a 50% increase in Gaia's costs may favor Madrid's use. Other relevant note to take is the fact that if the transportation costs between warehouses increase 50%, that will lead to a less cost-effective configuration compared to the one where flows between warehouses are excluded. Finally, the analysis to an increase in the demand of 1% per year in the next 5 years, contributing to the company growth, reveals that the network configuration and flows between entities remain the same. Therefore, the results show that the network configuration with two warehouses operating is the optimal solution, even taking into account an increase in the intensity of the activities performed.

6.4.1 Recommendations

After an extensive analysis of different scenarios studied and compared with company's current scenario and aligned with JMD objective of decreasing the supply chain costs, it is concluded that the company should adopt the scenario 3 that is focused on cost minimization. This scenario, which includes 2 warehouses, one in Azambuja and other in Gaia, has proven to be the most financially advantageous among the studies performed revealing the lowest costs when facing the cost optimization for a reduction of 3,41%, around 333K€. At the same time, the adoption of scenario 3 with the cost optimization will decrease the environmental impact of the supply chain, in terms of transports, in 6,45%. Therefore, this scenario reveals to be a good compromise for the company in lowering its supply chain's costs and environmental impact.

It is crucial to better evaluate and monitor the transportation costs since they have a weight of 87% of the total expenses in this scenario, and a slightly variation can lead to a considerable impact on the cost, becoming a much higher or lower total cost for this scenario. The addition of the second warehouse in this scenario provides JMD with a more flexible and efficient supply chain since the products are distributed across the supply chain and closer to the end user. Also, it increases the coverage area of the distribution network, as well as making the chain more resilient, since it doesn't depend solely on one warehouse and therefore has greater capacity to deal with unexpected or unforeseeable events.

However, if flows between warehouses are a viable option for JMD supply chain, then the scenario 4 becomes the most reliable one, revealing a decrease of 6,17% of the total costs, around 602K€. This scenario is financially beneficial for the company as long as there is a maximum of 50% increase in transportation costs between warehouses compared to the value considered in the study, explained by a reduction in transportation costs. Nevertheless, it is important to note that this scenario does not show any improvement in environmental terms, as the distances traveled increase. Although the model only considers the environmental impact of transportation, this scenario has not only a greater use of transportation, but also of warehouses, so its environmental impact will also be greater. The biggest advantage of this scenario is that it takes advantage of the proximity of the Madrid warehouse to suppliers in the rest of Europe and the proximity of the Portuguese warehouses to the end markets in Portugal. This scenario thus increases the flexibility of the network, as well as its response capacity, achieved through greater geographical distribution of products. Lastly, it is important to note that this scenario implies a new agreement with Luís Simões to take responsibility for transportation between warehouses.

In conclusion, while scenario 3 is recommended for its cost-effective nature, as well as its environmental impact performance, scenario 4 is more financially beneficial when considering inter-warehouse flows. The company should weight these scenarios, considering both financial and environmental impact, to determine the most aligned with its strategic goals and operational efficiency. Regular monitoring and evaluation of transportation costs and their influence on the network will be essential for ongoing optimization.

Chapter 7 – Conclusions and Future Work

The aim of this work is to provide JMD with insights into how it can structure its supply chain in a sustainable way. To this end, a strategic model was developed, obtaining results with the support of the GAMS software. This model seeks to determine an optimized configuration of the distribution network, through the relocation of warehouses. The aim is to provide the company with recommendations regarding its network, based on two of the three dimensions of sustainability, part of the TBL: economic and environmental.

Through the literature review, it was possible to define the main concepts of the supply chain and its management, as well as to analyze the process of designing and planning the configuration of the supply chain network. Thus, it can be concluded that the problem will be approached from a strategic point of view and, although there may be some overlap with tactical decisions, it will not include the operational level. At the same time, the importance of incorporating sustainability into supply chain management is reinforced, through its three dimensions (financial, environmental and social), constituting an opportunity for growth and business for the company.

Following the insights drawn from the literature review, a mathematical model was developed with a view to applying it to the problem under study. To develop this model, da Silva et al., (2020), model served as a basis, considering the financial and environmental dimensions as functions. This model also incorporates a risk assessment, which was not incorporated in the case under study. The mathematical formulation developed is generic and can therefore be applied to any supply chain with similar characteristics to the one studied: three sets of entities - suppliers, warehouses and markets - product flows between the entities which are transported by truck and a demand to be met. Furthermore, this model only incorporates the direct flow of products on a monthly basis. The aim of the model is to make strategic decisions about the number and location of warehouses. Although the focus of the work is at a strategic level, it is also possible to draw conclusions at a tactical level, such as product flow, storage and transportation.

The case study analysis proved to have a lot of complexity associated with it, which is why it was necessary to adopt strategies and simplifications in the data processing, trying to ensure that the impact of these simplifications was as minimal as possible on the results obtained. However, it was necessary to aggregate products by supplier, make assumptions about warehouses (capacity and inventory), simplify the customers analyzed and aggregate markets by district. In this sense, assumptions and simplifications were also made in terms of transportation, economic data and environmental data.

The use of the optimization model developed to address the case under study made it possible to analyze the structure of the distribution network configuration, arriving at an optimal solution, while at the same time making it possible to compare different scenarios in terms of cost, environmental impact, flows and storage. The main decision in designing and structuring the network configuration sought by the company concerned the number and location of warehouses. Therefore, it was possible to conclude that the optimum solution is one that incorporates the use of two warehouses (Azambuja and Gaia). By adopting this solution, JMD will have a lower cost associated with the configuration of the supply chain, as well as reducing the environmental impact of transportation along the chain. At the same time, the addition of a new warehouse to the network configuration makes the supply chain more resilient and flexible, increasing its response capacity. However, it is important to bear in mind that this scenario would involve re-establishing an agreement with Luís Simões (JMD's logistics operator) to distribute the products through the two warehouses in Portugal. In addition, this solution assumes that LS has space available in the Gaia warehouse to store products belonging to JMD. Another scenario also showed beneficial financial results for the company, although not for the environmental impact: the scenario that considers flows between warehouses. This solution has a lower total supply chain cost and takes advantage of the proximity of the Madrid warehouse to suppliers, as well as the proximity of warehouses in Portugal to end markets. This scenario has advantages when it comes to reducing costs and increasing JMD's response capacity, as well as potentially increasing its level of service. However, operating three warehouses simultaneously in the supply chain requires careful management of flows and storage.

The designated solutions were presented and recommended to the company. In this discussion, some aspects and potential improvements were addressed. Therefore, some limitations to be considered for future developments are indicated below, originating from the simplification strategies and assumptions considered.

7.1 Limitations and Future Work

The social dimension, one of the three pillars of sustainability, was not considered. The model used as a basis only considered two of the TBL dimensions (economic and environmental). However, in a future approach, it could be interesting to incorporate the missing dimension, both at an academic level and for the company, as it will thus be on the road to a sustainable supply chain.

Reverse logistics was not taken into account. Once again, the model used as a basis only considered the direct flow of products, and not reverse logistics. As mentioned in the literature review stage, reverse logistics has been gaining importance in supply chains, with the growth of sustainability concerns, and can be incorporated into supply chains in different ways. In addition, LS considered reverse logistics to be a very present challenge in JMD's distribution chain, since products have expiration dates and, therefore, it is necessary to quickly reintegrate products into the chain before they become obsolete. For these reasons, incorporating reverse logistics into the model would be an interesting study. In this study, JMD was not considered, as it would be important to look only at the direct flow as a first approach.

The aggregation of products by supplier does not allow the differentiation of products within the same supplier. This aggregation of products does not take into account possible differences that may exist between products, such as differences in demand. Different products, even if they come from the same supplier, have different demand curves, and some may even be seasonal. The need for this aggregation arose from the complexity associated with treating each product (SKU) individually. In this sense, in a future development, it would be interesting to consider the different products individually, so that the model could be more reliable.

Regarding transportation, certain assumptions were made. Thus, to calculate the cost of transport, an average value was assumed for the cost of transporting a pallet per kilometer. However, this average value was calculated on the basis of only 5 of the 35 suppliers, as this was the data available, and it was also assumed that Luís Simões charged the same price for the cost of transporting a pallet. In a future approach, it would be interesting to differentiate the cost for the two flows, to make the result more reliable. Furthermore, this cost of transporting a pallet was considered to be independent of the use of the truck. In other words, it was considered that transporting a pallet in an empty truck would be the same as transporting the same pallet in a full truck. However, in discussion with the company, it emerged that the scenario described does not correspond to reality, since the cost to the company is higher if the truck utilization rate is lower. At the same time, the partnership with Luís Simões allows the company to have the trucks managed by the logistics operator, so that products from different companies can be consolidated on the same truck. Therefore, in a future development, it would be important to consider this transportation cost as a variable depending on the truck utilization rate.

The model does not consider the different shelf lives of products. Being a food supply chain, the shelf life of products is something that must be taken into account, since the company has rules that it has to respect regarding the shelf life required for the product to be sold. Stock management is therefore very important, so that products don't remain in inventory for longer than expected. This work did not consider product expiry dates, due to the complexity inherent in this parameter, and because it is not a strategic issue. In addition, something that would also be interesting to consider in a future approach would be the relationship between the existence of two warehouses and the FEFO policy followed by the company. In other words, to ensure that, with two warehouses in operation, there is no generation of obsolete products due to the location of the products and that the policy continues to be followed.

The model studied makes various assumptions regarding inventory. Different assumptions were made regarding warehouse capacities, as well as initial inventory and minimum inventory for each time period. In this sense, in a future development, it would be interesting to present less uncertainty in these inventory values, since they have a direct impact on the total costs of the supply chain and the flows obtained. It was also assumed that each pallet has the same number of SKUs, which is an average value. The variation in this number has a major impact on the costs of the distribution chain, which is why, in a future development, it should be studied in greater depth.

Finally, the model only considers the environmental impact of transportation. However, throughout JMD's supply chain, there are various activities that have consequences for the environment, such as the operation of warehouses or the space occupied by different entities, or even production at suppliers. Therefore, in a future approach, the environmental impact should not be restricted to transport, since, as the results show, minimizing transport has the same tendency as minimizing costs. This addition will therefore bring considerable developments to the model.

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