

Viability Study on owning a warehouse in Iberia for a Glass production company

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Abstract

Supply chain management has undergone a significant transformation as a result of globalization, making it even more crucial for businesses to maintain their competitiveness in today's global market. Strategic warehouse placement is essential for supply chain management because it has a direct impact on customer satisfaction, operational effectiveness, and overall company performance.

In the packaging glass industry, continuous production throughout the lifespan of the furnace is crucial for maintaining the efficiency and performance of the company. Stopping a furnace has significantly negative impacts, affecting production capacity and generating losses. Therefore, it is natural that during periods of lower market demand, stock levels in the packaging glass industry reach much higher levels, necessitating the use of external warehouses.

This master's thesis explores the feasibility of establishing an own warehouse in the Iberian region for a glass production company and reduce the number of external warehouses. The research investigates various aspects of warehousing, including the current warehousing situation in BA Glass, historical trends of external stock in the Iberian market, a comparison between external stock and own stock per plant, analysis Iberia, and transportation considerations within BA Glass. It was utilized software tools such as Excel, Power BI, and Python in the analysis.

To assess the viability of owning a warehouse in the Iberian region, a mathematical model was developed using Python. The primary objective of the mathematical model developed in this study is to minimize transportation costs within the supply chain of the glass production company. Specifically, the focus is on minimizing the costs associated with transporting products from plants to warehouses and from warehouses to clients. The model incorporates calculations for route distance, transport costs, warehouses capacities, demands per region and capacity that each plant has to put product in the market. The transportation costs in this study were calculated using a price per kilometer. To determine distances, a Python distance calculator utilizing the Open Route Service API was developed.

Four scenarios were subsequently analyzed, and in three out of the four scenarios, the optimal location for the studied warehouse was determined to be in the PT26 region, primarily to support plant of Venda Nova. The final values for the four scenarios were found to be very similar to each other. Therefore, it will be up to the company to analyze any additional relevant constraints that they deem necessary for further decision-making.

Resumo

Estudo de viabilidade de possuir um armazém na Península Ibérica para uma empresa de produção de vidro

A gestão da cadeia de abastecimento passou por uma transformação significativa devido à globalização, tornando-se ainda mais importante para as empresas manterem a sua competitividade no mercado global atual. A localização estratégica de armazéns é essencial para a gestão da cadeia de abastecimento, já que tem um impacto direto na satisfação do cliente, na eficácia operacional e no desempenho geral da empresa.

Na indústria de embalagens de vidro, a produção contínua ao longo da vida útil do forno é crucial para manter a eficiência e o desempenho da empresa. Parar um forno tem impactos significativamente negativos, afetando a capacidade de produção e gerando perdas. Portanto, é natural que, durante os períodos de menor procura de mercado, os níveis de stock na indústria de embalagens de vidro atinjam níveis muito mais altos, tornando necessário o uso de armazéns externos.

Esta dissertação de mestrado explora a viabilidade de estabelecer um armazém próprio na região ibérica para uma empresa de produção de vidro e reduzir o número de armazéns externos. A pesquisa investiga vários aspetos do armazenamento, incluindo a situação atual dos armazéns na BA Glass, as tendências históricas de stock externo no mercado ibérico, uma comparação entre stock externo e stock próprio por fábrica, análise da Ibéria e considerações de transporte dentro da BA Glass. Foram utilizadas ferramentas de software como Excel, Power BI e Python na análise.

Para avaliar a viabilidade de possuir um armazém na região ibérica, foi desenvolvido um modelo matemático utilizando Python. O objetivo principal do modelo matemático desenvolvido neste estudo é minimizar os custos de transporte dentro da cadeia de abastecimento da empresa de produção de vidro. Especificamente, o foco está em minimizar os custos associados ao transporte de produtos das fábricas para os armazéns e dos armazéns para os clientes. O modelo incorpora cálculos de distância de rota, custos de transporte, capacidades de armazéns, procura por região e capacidade que cada fábrica tem de disponibilizar produtos no mercado. Os custos de transporte, neste estudo, foram calculados com base no preço por quilómetro. Para determinar as distâncias, foi desenvolvido um calculador de distância em Python, utilizando a API do Open Route Service.

Posteriormente, foram analisados quatro cenários, e em três deles, a localização ótima para o armazém estudado foi determinada como sendo na região PT26, principalmente para apoiar a fábrica de Venda Nova. Os valores finais para os quatro cenários foram encontrados, contudo são muito semelhantes entre si. Portanto, caberá à empresa analisar quaisquer restrições adicionais relevantes que considerem necessárias para tomadas de decisão futuras.

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Last but not least, I am immensely grateful to my family, particularly my parents, for their support and guidance throughout my life. They have been my pillars of strength, constantly encouraging me to chase my dreams and providing me with the tools and opportunities to succeed. Their unconditional love, sacrifices, and endless belief in my abilities have shaped me into the person I am today. They have instilled in me the values of hard work, perseverance, and resilience, teaching me that success comes through dedication and determination.

"Education is the most powerful weapon which you can use to change the world."

Nelson Mandela

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Acronyms and Symbols

3PL	Third Party Logistics
AI	Artificial Intelligence
AMR	Autonomous Mobile Robots
API	Application Programming Interface
AV	Avintes
BA	BA Glass, S.A.
BI	Business Intelligence
CIVE	Companhia Industrial Vidreira, SA
CSCMP	Council of Supply Chain Management Professionals
ERP	Enterprise Resource Planning
FLP	Facility Location Problem
FTL	Full Truck Load
IB	Iberia
IoT	Internet of Things
IT	Information Technology
LE	León
MG	Marinha Grande
MILP	Mixed Integer Linear Programming
ML	Machine Learning
RFID	Radio Frequency Identification
VF	Villafranca de Los Barros
VN	Venda Nova
SAP	Systems, Applications and Products

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Chapter 1

Introduction

The present dissertation was developed in a business environment with the aim of completing the Master's degree in Mechanical Engineering at the Faculty of Engineering of University of Porto.

This introductory chapter serves as a foundation for the entire thesis, providing a comprehensive overview of the project's motivations, objectives, and methodology. Additionally, it includes a presentation of BA Glass, the company in which the work was conducted, highlighting its significance in the context of the study.

Finally, this chapter concludes by outlining the dissertation's structure, providing a road map of the succeeding chapters' contents.

1.1 Motivation and Aim of the Project

In today's globalized business environment, efficient supply chain management is critical for businesses seeking to maintain a competitive advantage. As the demand for seamless distribution networks grows, strategic warehouse ownership becomes increasingly important. This chapter provides an overview of the research study, with a focus on the viability of owning a warehouse in Iberia.

The selection of an appropriate distribution strategy is critical for large-scale companies like BA Glass. As a major player in the industry, the company understands the importance of optimizing its distribution network to increase efficiency and lower costs. Currently, BA Glass manages its distribution operations in Iberia with the assistance of external warehouses. However, due to the growing scale of its operations and the complexities associated with relying on external dependencies, the company has initiated an investigation into the feasibility of owning a warehouse and reducing outsourcing.

BA Glass intends to gain insights into potential advantages, such as enhanced control over inventory management, improved customer service, and the potential for cost savings.

These insights will inform strategic decision-making and help the company determine the most effective approach to meet its logistical needs while maximizing operational efficiency.

This work was developed in the Iberian Distribution Department, which is responsible for all logistical matters related to warehouses, including stock and warehouse management, as well as the digitization of logistics operations.

1.2 BA Glass Presentation

BA Glass is a major producer of glass containers for the food and beverage industry, based in Portugal. The company has a long history, having been founded in 1912, and has since expanded its operations to seven different countries. On April 5th, 1912, Barbosa & Almeida, Lda was established with the primary objective of selling glass bottles. The company later began its manufacturing operations in Campanhã in 1930 and consequently renamed itself to "Fábrica de Vidros Barbosa e Almeida, Lda". In the late 1960s, the company relocated to Avintes (Vila Nova de Gaia), which led to significant growth and the company's rise to become the leading manufacturer of glass packaging in Portugal. Additionally, BA Glass acquired a new facility in Marinha Grande (CIVE - Companhia Industrial Vidreira, SA). Starting in 1998, the company continued to expand by acquiring additional factories across Europe, solidifying its success in the glass industry and producing more than 9 billion bottles and jars, per year. As shown in Figure 1.1, presently, BA Glass has a presence in seven countries, with a total of 12 manufacturing plants located in Portugal (Avintes, Marinha Grande, Venda Nova), Spain (León and Villafranca de Los Barros), Germany (Gardelegen), Poland (Jedlice and Sieraków), Romania (Bucharest), Bulgaria (Sofia and Plovdiv), and Greece (Athens).

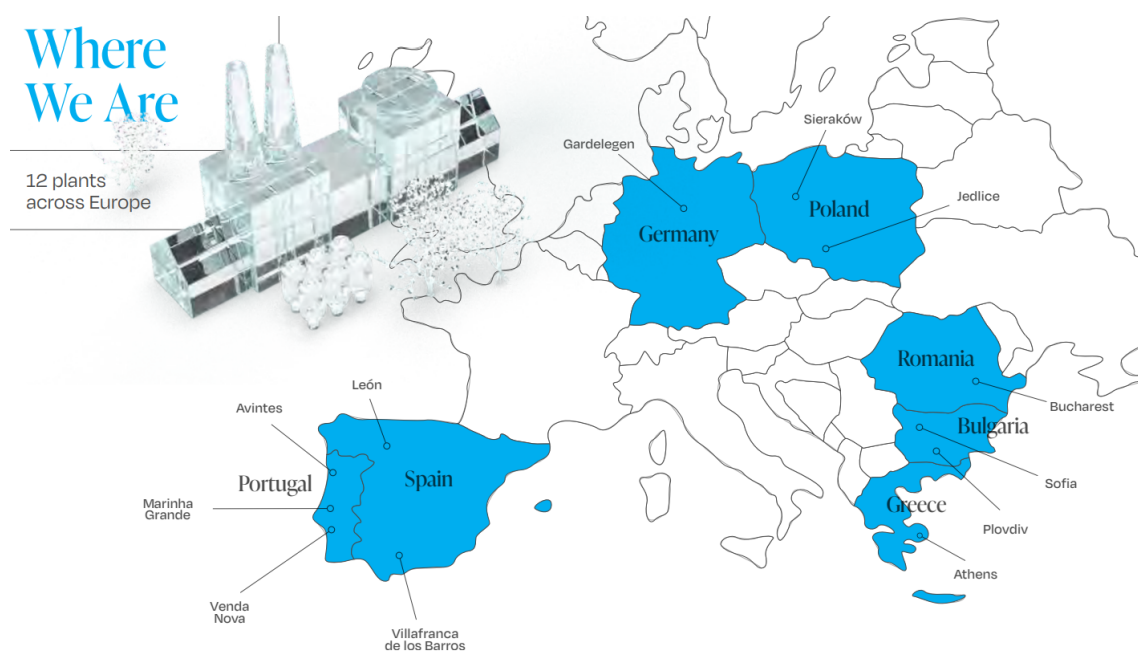


Figure 1.1: BA Glass Plants (Source: BA Glass, 2023)

The company is known for its commitment to quality, innovation, and sustainability. It offers a wide range of glass products, including bottles and jars for various applications, such as wine, beer, spirits, soft drinks, and food. BA Glass has also invested in state-of-the-art technology to enhance its manufacturing processes, reduce waste, and minimize its environmental impact. In addition to its production capabilities, BA Glass places great emphasis on customer service and satisfaction. The company works closely with its clients to understand their needs and provide customized solutions that meet their specific requirements.

1.3 Project Goals

This master's thesis has three specific objectives. The first objective is to provide a comprehensive overview of the main concepts of BA logistics. This includes an in-depth understanding of the different components of logistics, such as transportation, inventory management, warehousing, and distribution.

The second objective is to develop an economic study to the implementation of a warehouse. This study will analyze the costs and benefits of implementing a warehouse.

The third objective is to suggest solutions to decrease distribution costs.

1.4 Methodology

A Gantt chart is shown in Figure 1.2 outlining the major tasks carried out between February and June of 2023.

The emphasis during the first few weeks of the curricular internship was on integrating into the business. To become familiar with various departments and comprehend their importance, connections, and impact on the business' operations, a variety of training sessions were organized.

Later, a research phase was started to delve deeper into the issue at hand and find the most effective answers. An extensive amount of research was done to compile pertinent data, analyze the literature already in existence, and examine comparable case studies or methodologies applied in related fields.

The data processing phase was started as the research phase was wrapping up to handle the data required for problem-solving. During this stage, pertinent information was gathered from a variety of sources, including internal company databases.

Next, a Python-based mathematical model was created to aid in the decision-making process.

To conclude, the developed mathematical model was applied to different scenarios, and the obtained results were thoroughly analyzed.

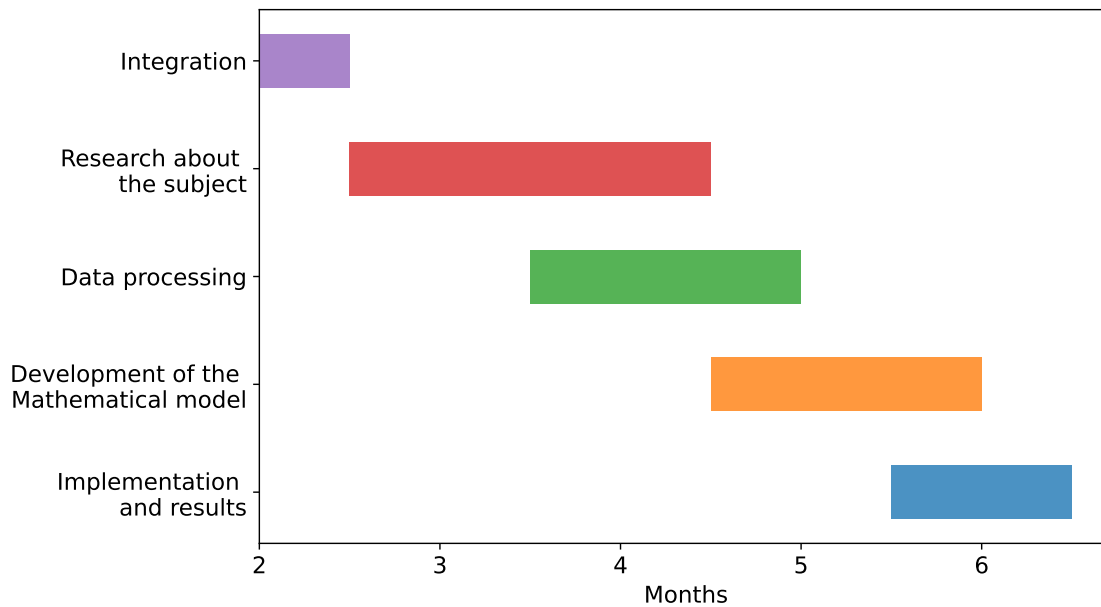


Figure 1.2: Evolution of the project

1.5 Dissertation Structure

The five chapters of this dissertation are intended to give a thorough analysis of the business, project, main objectives and the results.

In the first chapter, a comprehensive description of the company, the project, and the main goals was provided.

The literature review in Chapter 2 is the main topic, and it explores the project's theoretical setting. It provides a strong foundation for comprehending the fundamental ideas and trends in the sector by examining the state of the supply chain, transportation, and warehouses today and the challenges they face.

In Chapter 3, the dissertation provides an in-depth description of the problem, namely the current state of warehouses in the Iberian region. To gain a better understanding of the observed conditions, a meticulous data treatment was conducted, considering both direct and indirect factors that impact warehouse operations. This involved employing tools such as Excel, Python, and Power BI for comprehensive data analysis.

Chapter 4 provides a comprehensive overview of the methodology employed, as well as the results and decisions derived from the entire project. This chapter serves as a crucial component in understanding the approach taken and the outcomes achieved.

Chapter 5 serves as the final section of the dissertation, presenting the conclusions drawn from the project and outlining potential avenues for future work and research.

Chapter 2

Literature Review

The literature review chapter provides an overview of the current state of research in the field. It involves a thorough analysis of various studies, scientific articles, books, and other relevant sources to identify key concepts, theories, and gaps in the existing knowledge. By critically reviewing and synthesizing the available literature, this chapter establishes the theoretical and conceptual framework for the research, informs the research questions, and helps to justify the significance of the study. Additionally, it serves as a basis for identifying research methodologies and approaches that have been used in similar studies.

2.1 Supply Chain Management and Logistics

Council of Supply Chain Management Professionals defines "Supply Chain Management as the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. It also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. The goal of supply chain management is to create value for customers and stakeholders by achieving a sustainable competitive advantage through the efficient and effective management of resources, information, and relationships across the supply chain".¹

This refers to a comprehensive approach to managing logistics, manufacturing operations, and various business processes. It involves coordinating these activities with other key functions within the organization, such as marketing, sales, product design, finance, and IT. By doing so, the organization can achieve greater efficiency and effectiveness in its overall operations (Guedes, 2019).

According to Rushton et al. (2022), Supply Chain is divided in three parts, as show in Figure 2.1.

¹See <https://cscmp.org/>, accessed on 10/05/2023

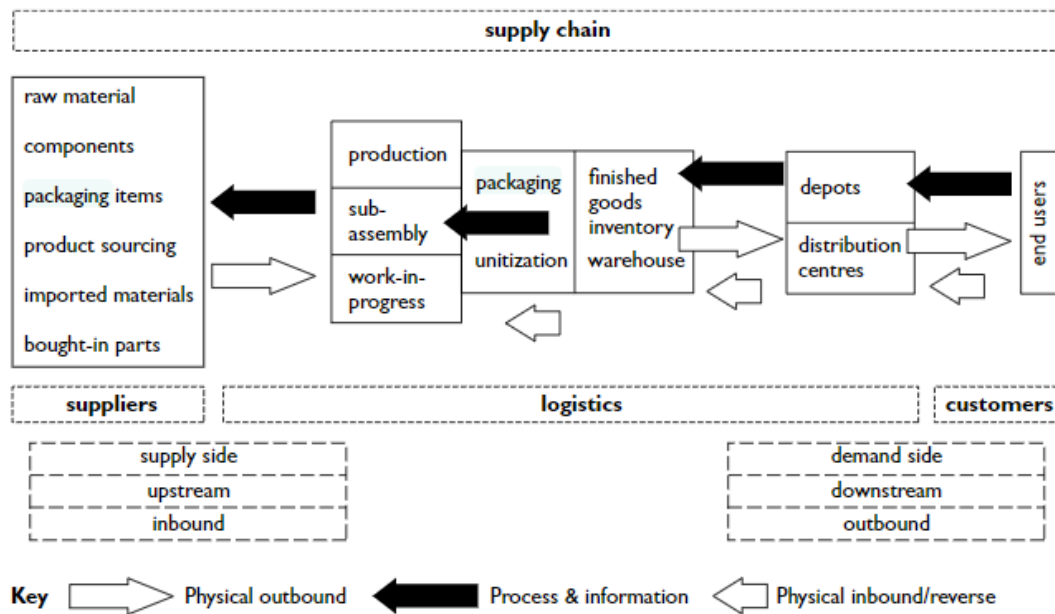


Figure 2.1: Supply Chain Diagram (Rushton et al., 2022)

- **Suppliers:** Suppliers are businesses or individuals who provide raw materials, components, or services to the manufacturer or producer. In a supply chain, suppliers are an important part of the process as they provide the materials or services necessary to produce the final product. Suppliers can be located anywhere in the world and can vary in size from small businesses to large multinational corporations. Suppliers play a critical role in the production and delivery of goods and services for businesses. They are responsible for providing the necessary raw materials, components, packaging items, and other necessary inputs to the production process (Chen and Zhao, 2012).
- **Logistics Management:** Logistics management is the process of planning, coordinating, and controlling the movement of goods and services from the point of origin to the point of consumption. It encompasses a wide range of activities, including production, packaging, warehousing, and distribution. The primary goal of logistics management is to ensure that the right product is delivered to the right place, at the right time, and in the right condition and cost-effective manner (Kain and Verma, 2018).
- **Customer:** Customers are a crucial part of the supply chain, as they are the end-users of the products or services produced by a company. Understanding customer needs and preferences is essential for businesses to create products that meet their expectations and ensure customer satisfaction (Martinelli and Tunisini, 2019).

As a result of the economic globalization and the establishment of a global market, the level of competition in all industries has intensified significantly (Liu and Wu, 2010).

The complexity of supply chain management has reached unprecedented levels in recent times, primarily due to the rapidly advancing phenomenon of globalization and the continuously changing dynamics of global markets (Tiwari et al., 2023).

The ultimate goal of Supply Chain Management is to achieve a seamless integration between supply and demand management, not only within a company but also across multiple companies. Therefore, it is crucial to establish efficient communication channels, streamlined processes, and a shared vision to enable successful supply chain operations (Wuni and Shen, 2023).

In the past few decades, the business landscape has undergone a significant shift due to globalization. The effective management of the supply chain is essential for businesses to succeed in today's global market. With the increased competition and changing customer demands, businesses must continuously improve their supply chain processes to remain competitive. One way to achieve this is by adopting new technologies that can streamline the various stages of the supply chain (Lee, 2002).

Industry 4.0 in Logistics

CSCMP refers that "Logistics management is the component 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 to meet the needs of customers".²

The fourth industrial revolution, known as Industry 4.0, ushers in a flood of innovative resources that will fundamentally alter business operations and supply chains. These new technologies and concepts will transform traditional practices and open up new avenues for efficiency, productivity, and competitiveness, being crucial to utilize technological tools such as (Ivankova et al., 2020):

- **Internet of Things:** The Internet of Things (IoT) is regarded as a critical component of the future Internet and is expected to include billions of intelligent communicating entities (Li et al., 2015). Sensors and RFID tags, for example, enable real-time monitoring and tracking of goods, assets, and vehicles across the supply chain (Chakrabarti et al., 2019).
- **Big Data Analytics:** Advanced analytics tools process massive amounts of data collected from a variety of sources, including IoT devices, ERP systems, and external data feeds. Logistics professionals can gain insights into demand patterns, optimize routes, predict maintenance needs, and make data-driven decisions to improve efficiency and reduce costs by analyzing this data (Wang et al., 2016).
- **Artificial Intelligence (AI) and Machine Learning (ML):** AI and machine learning technologies allow for automated decision-making and optimization in logistics operations. These technologies learn from data indefinitely, improving their accuracy and efficiency over time (Woschank et al., 2020).

²See <https://cscmp.org/>, accessed on 10/05/2023

- **Robotics and Automation:** Automation and robotics technologies such as autonomous mobile robots (AMRs), robotic arms, and automated sorting systems help to streamline warehousing, order picking, and material handling processes. They increase efficiency, decrease errors, and boost productivity by automating repetitive tasks and collaborating with human workers (Custodio and Machado, 2020).

These applications play a vital role in optimizing the logistics process and ensuring seamless operations.

2.2 Transports

Transportation is an essential component of logistics and supply chain management. It entails the transportation of goods from one location to another, whether by road, rail, air, sea, or a combination of these modes (Vida et al., 2023).

Transportation provides a company with the flexibility to optimize the placement of its resources and stock to strike the perfect harmony between effectiveness and agility. The selection of transportation mode, as shown in Figure 2.2, by a company can have a significant impact on the inventory management and facility placement within its supply chain (Chopra and Meindl, 2013).



Figure 2.2: Types of Transport

2.2.1 Modal Split of Freight Transport

Modal split refers to the distribution or allocation of freight transport volume among different transportation modes. Figure 2.3 represents the proportion of goods transported by each mode of transportation, such as road, rail, air, maritime, or inland waterways, as shown in Figure 2.3.³

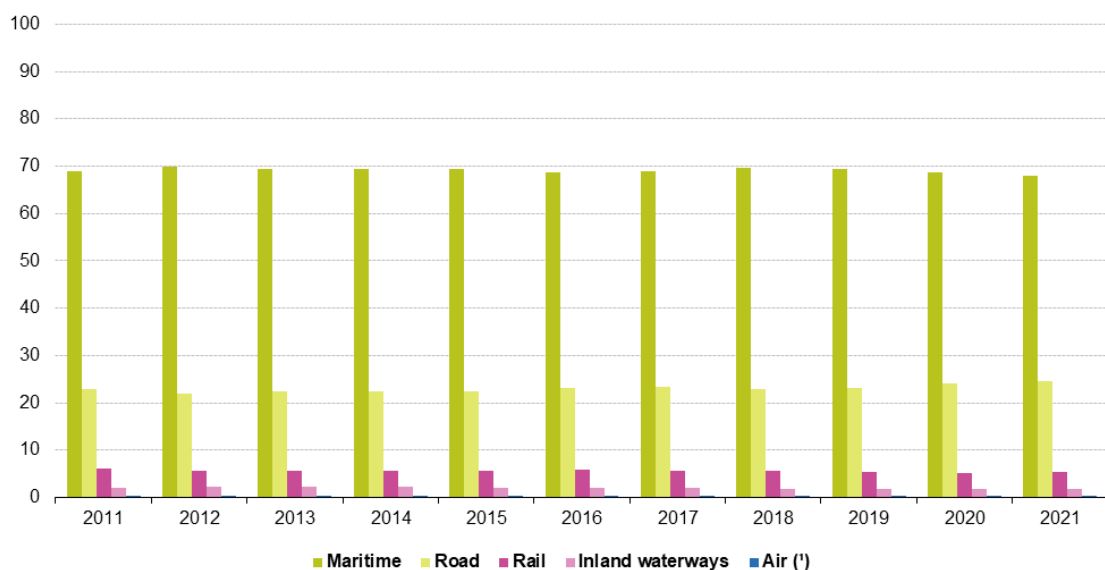
- **Road Transport:** Road transport by trucks is one of the most popular modes of freight transportation, particularly for short and medium distances (Dostál and Adamec, 2011). Due to its widespread availability and convenience, road transport tends to dominate the modal split in many regions (Delbart et al., 2021).
- **Rail Transport:** Railways have greater capacity than trucks and can be more cost-effective for transporting large volumes over long distances (Vida et al., 2023). Railroad companies strive to keep locomotives and crews busy (Chopra and Meindl, 2013).

³See https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Freight_transport_statistics_-_modal_split, accessed on 10/05/2023

- **Water Transport:** Water transport, including maritime shipping and inland waterways, is ideal for transporting large quantities of goods over long distances, particularly for international trade (Caris et al., 2014). Containers have transformed the shipping industry by allowing for the standardized, secure, and streamlined transportation of a wide range of products (Bu and Nachtmann, 2023).
- **Air Transport:** Air transport is the quickest mode of freight transportation and is typically used for time-sensitive or high-value goods traveling long distances or across international borders (He et al., 2022).

In international trade, water transport holds a prominent position as the primary mode for shipping a wide range of goods. Various products, such as automobiles, grains, apparel, and numerous other commodities, are transported via sea routes (Chopra and Meindl, 2013). It is easy to observe that immediately following maritime transport, road transport takes the lead.

Modal split of freight transport, EU, 2011-2021
(%, based on tonne-kilometres)



Note: Includes Eurostat estimates for rail transport for Belgium (2012-2021) and inland waterway transport for Finland (2017-2018), but does not include road transport for Malta, road international transport of Cyprus (negligible) and inland waterway transport for Sweden (2011-2015: negligible).
(*) 0.2 % for all years.

Source: Eurostat (online data code: tran_hv_ms_fmmod)

eurostat 

Figure 2.3: Modal Split of Freight Transport

2.2.2 Full Truck Load

Full Truck Load (FTL) refers to a mode of transportation in which a shipment takes up the entire capacity of a truck, typically a trailer or container, maximizing the load efficiency (Soares et al., 2019).

Here are some key points about full truck load:

- **Efficient Capacity Utilization:** FTL allows shippers to optimize truck capacity utilization by utilizing the entire space for their shipment. This reduces waste and ensures that the truck is fully loaded, resulting in cost savings and a lower carbon footprint (Ülkü, 2012).
- **Reduced Risk of Damage:** In FTL, the cargo is usually loaded and secured in such a way that the risk of damage during transit is minimized. Because the goods take up the entire truck, there is less risk of shifting or damage from mixing with other shipments. This is especially useful for fragile or sensitive items (Kotzab et al., 2015).

2.2.3 Road Freight Transport Costs

The expenses incurred in transporting goods via trucks or other road vehicles from one location to another are referred to as road freight transport costs. These costs can vary depending on a variety of factors such as distance, weight, fuel prices, vehicle type, route, and additional services (Dong et al., 2020). The cost of freight transportation has emerged as one of the most important economic indicators of supply chain efficiency (Izadi et al., 2020).

According to Rushton et al. (2022), resources can be categorized:

- **Manpower:** In order to accurately calculate the cost of a transport operation, the wages and other costs associated with the drivers must be taken into account.
- **Machinery:** The cost of acquiring and maintaining the vehicles, as well as any repairs or upgrades, must be included in the cost calculation.
- **Materials:** The resources associated with the vehicles, such as fuel, oil, tires, and other supplies.
- **Minutes:** This includes the time spent driving, loading and unloading cargo, and performing any other tasks associated with the transport operation.

2.3 Warehouses

In today's supply chains, warehouses play an essential role as they are involved in several stages of the sourcing, production, and distribution of goods. Warehouses facilitate the handling of raw materials, work-in-progress, and finished products. As the last point before dispatching products to the next customer, they are crucial to maintaining high levels of customer service (Rushton et al., 2022).

The location, design, and management of warehouses are essential components of any successful supply chain design and management strategy. Without careful consideration of these factors, a supply chain cannot be fully optimized, and its efficiency and effectiveness will be compromised. Therefore, it is imperative to pay close attention to the location, design, and management of warehouses to ensure a well-functioning and cost-effective supply chain (De Koster et al., 2017).

Warehouses can be classified based on several criteria, such as their area and height, equipment, function, geographic area, ownership, product type, and the stage in the supply chain (Rush-ton et al., 2022).

Most companies rely on warehousing to achieve the lowest possible logistics costs while still maintaining a certain level of customer service, taking into account the trade-offs outlined. A variety of factors influence company's warehousing strategies, such as the industry it operates in, the company's beliefs and values, available capital, the characteristics of its products (e.g. size, perishability, product lines, substitutability, and obsolescence rates), economic conditions, competitive pressures, seasonal demand patterns, use of just-in-time programs, and the type of production process utilized (Lambert et al., 1998). Warehousing is the most expensive operational cost in an organization's supply chain, accounting for 2 to 5% of total selling costs (de Oliveira et al., 2022).

2.3.1 Third Party Logistics

Third Party Logistics (3PL) in warehousing refers to outsourcing warehousing and distribution services to a third-party logistics provider specialized in the corresponding field (Eydi and Rastgar, 2022). Receiving and processing inventory, managing storage and inventory levels, picking and packing orders, shipping and transportation are all examples of such services (Wang et al., 2023). In Figure 2.4 a schematic diagram illustrates the functioning of Third-Party Logistics (3PL) for product storage.

3PL relationships are typically on a contract basis with a long-term commitment. Having an organized process for selecting and communicating with potential 3PL vendors is the key to successful outsourcing relationships (Green et al., 2008).

Outsourcing to a 3PL provider can often be more cost-effective than investing in establishing and maintaining their own logistics infrastructure for small or medium-sized businesses with limited logistics needs. Companies can benefit from economies of scale and access to advanced technology and networks by leveraging the resources and expertise of a 3PL (Balakrishnan and Mohamad Khan, 2018).

While outsourcing can reduce costs, empirical evidence suggests that plants do not always experience consistent improvement in financial performance (Kenyon and Meixell, 2011).

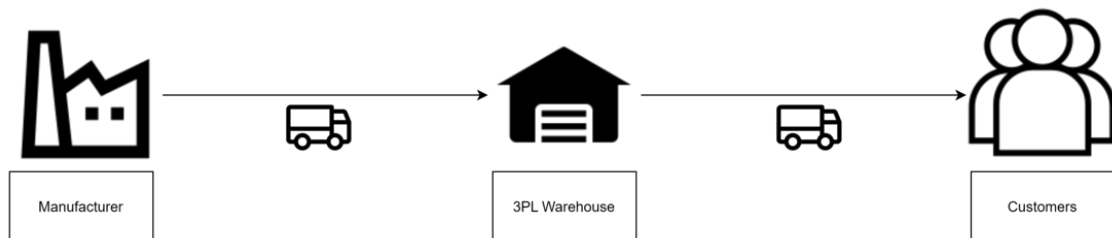


Figure 2.4: 3PL Logistics

As all, Third Party logistics has a lack of advantages and disadvantages.

Advantages:

- **Focus on core competencies:** By outsourcing logistics, businesses can concentrate on their core competencies and strategic initiatives while leaving logistics operations to specialized 3PL providers (Li et al., 2012).
- **Capital investment savings:** Outsourcing logistics to a 3PL eliminates the need for significant capital investments in physical distribution centers and information networks, lowering the company's financial risks (Njoroge and Nyamwange, 2017).
- **Economies of scale:** Utilizing a 3PL can result in cost savings through economies of scale, leveraging the provider's large truck fleets, warehouses, and other resources (Vasiliauskas and Jakubauskas, 2007).
- **Expertise and Specialization:** 3PL providers are logistics experts with specialized knowledge and experience in managing supply chain activities. They stay updated with industry trends, regulations, and best practices, allowing companies to benefit from their expertise and focus on their core competencies (Thi et al., 2022).

Disadvantages:

- **Control loss:** Outsourcing logistics to a third-party logistics provider means giving up direct control over certain aspects of the supply chain. Concerns about transparency, decision-making authority, and responsiveness to changing business needs can arise as a result of this loss of control (Green et al., 2008).
- **Concerns about service quality:** The quality of service provided by a 3PL can vary, affecting customer satisfaction and overall supply chain performance. Inconsistent service levels, late deliveries, or poor handling of goods can all harm the company's reputation and customer relationships (Huang et al., 2019).
- **Data Security and Confidentiality:** There are inherent risks in sharing sensitive business and customer data with a 3PL provider. Companies must ensure that appropriate data security measures and confidentiality agreements are in place to protect proprietary information and comply with data protection regulations (Chen and Zhao, 2012).
- **Limited Customization:** 3PL providers frequently offer standardized services that may not perfectly align with a company's unique requirements. Customization options may be limited, and businesses may be required to adhere to the 3PL provider's practices and processes. Because of this lack of customization, the company may be unable to differentiate its logistics services or meet specific customer demands (Borgström et al., 2021).

2.3.2 Warehouse Operations

Warehouse operations include a variety of activities, as shown in Figure 2.5, that are required for a warehouse to run smoothly and can vary from one warehouse to another depending on specific requirements and the characteristics of the company or industry involved (Rushton et al., 2022).

- **Receiving:** Goods arrive in a truck at a warehouse and are unloaded at the receiving docks (Gu et al., 2007). It is critical to inspect the quality and quantity of incoming goods during the receiving process and to prepack them for easier handling (Kembro et al., 2017).
- **Reserve storage:** Most warehouses transfer goods to the reserve or backup storage area, which often takes up the most space in the facility. The majority of the warehouse inventory is housed in this dedicated area, which is organized in specific locations for easy identification (Rushton et al., 2022).
- **Order picking and sortation:** Order picking involves the tasks carried out to retrieve products from their designated storage locations in order to fulfill specific customer orders (Silva et al., 2020). After the picking process, it is essential to perform sortation to separate the picked orders into individual units, especially when orders are picked in batches. Subsequently, the packed orders need to be properly stacked and organized on the appropriate units or pallets (Custodio and Machado, 2020).
- **Collation, added value services and packing:** This procedure entails placing the items in outer cartons designated for dispatch, labeling them, and using shrink and stretch wrapping techniques to ensure load stability and protection (Khan and Yu, 2019).
- **Marshalling and dispatch:** Dispatching entails coordinating shipment departure, generating necessary documentation (such as shipping labels or invoices), and communicating with carriers to ensure timely delivery (Gerháťová et al., 2021).

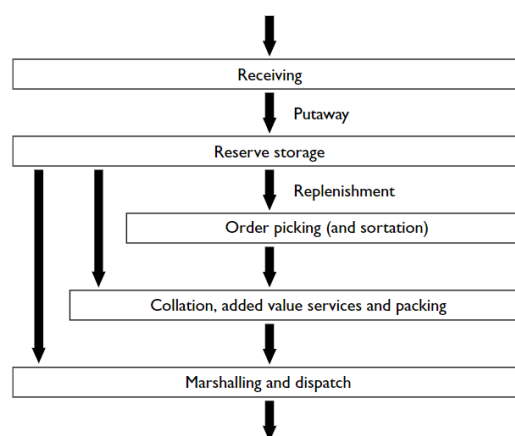


Figure 2.5: Warehouse Operations (Rushton et al., 2022)

2.3.3 Warehouse Costs

Several factors must be considered when deciding whether to buy or build a warehouse, as shown in Table 2.1. Evaluating these factors can assist businesses in determining the best option for their specific needs (Ackerman, 1997).

Table 2.1: Construct vs Buy a Warehouse

Aspect	Constructing a warehouse	Buying a warehouse
Initial Costs	Higher	Varies based on market
Customization	High	Limited
Timeframe	Longer	Quicker
Location	Flexibility	Limited options
Condition	New and tailored	Varies
Expansion Potencial	High	Limited
Operationl Efficiency	Optimized layout	May require modifications
Financial Considerations	Upfront Investment	Purchase cost
Flexibility	Flexible desin	Limited flexibility
Risk and complexity	Higher	Lower

In Figure 2.6 it is possible to see different weights of warehouse costs. It refers to the total expenses involved in operating and maintaining a warehouse facility. This includes staff costs, building costs, building services costs, equipment costs and, Information Technology costs (Rush-ton et al., 2022).

- **Staff Costs:** This category accounts for 45% of total warehouse costs. It includes employee salaries, benefits, and training costs. Staff costs cover a variety of warehouse roles, such as managers, supervisors, and forklift operators. It is critical to invest in a well-trained and skilled workforce for efficient warehouse operations (De la Fuente et al., 2019).
- **Building Costs:** Building costs account for 25% of the total cost and include expenses associated with the physical structure of the warehouse facility. This includes the cost of purchasing or leasing the facility, as well as property taxes, insurance, and ongoing maintenance to keep the building in good working order (Richards, 2017).
- **Building Services:** This category accounts for 15% of the total cost and includes expenses for various services required to operate the warehouse facility. It includes utilities such as electricity, water, heating, and cooling, as well as security measures such as surveillance systems, alarms, and access control. This category also includes waste disposal costs (De Marco and Mangano, 2011).
- **Equipment Costs:** Equipment costs account for 10% of total costs and include expenses related to the purchase or lease of warehouse equipment. Forklifts, pallet jacks, shelving systems, conveyor belts, and other necessary tools are included. This category also includes maintenance, repairs, and replacement of equipment (Kay, 2012).

- **Information Technology:** This cost category is critical in modern warehouse operations because it supports functions like inventory management, order processing, and data analysis. While the exact percentage is not specified, investing in information technology systems and software is critical for optimizing warehouse efficiency and accuracy (Faber et al., 2002).

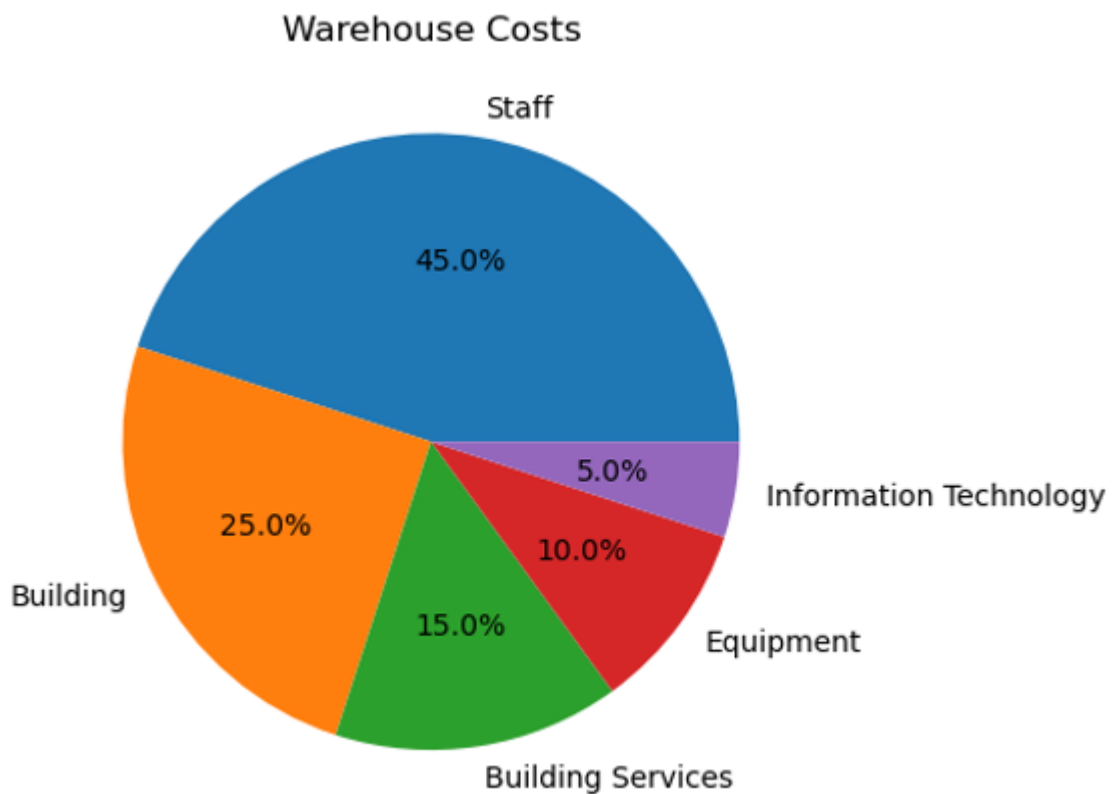


Figure 2.6: Warehouse Costs

2.3.4 Warehouse Sizing and Layout

The price and overall cost of a warehouse are heavily influenced by its size. Size matters when it comes to warehouse facilities. The cost of a warehouse increases in proportion to its size. This is primarily due to the fact that a larger warehouse requires more space, supplies, and resources to construct (Dukic and Opetuk, 2012).

It is crucial to balance the advantages a warehouse offers with the costs involved when determining its size. To find the best size that fits their operational needs and budget, businesses must carefully assess their storage needs, inventory turnover rates, and growth projections (Gu et al., 2010).

Every warehouse has a storage capacity, which is usually measured in square meters, cubic meters, or storage units (Zevgolis et al., 2004).

When a distribution center is underutilized, the cost per unit rises. The rate of utilization will always have an impact on fixed costs (Speh, 2009).

The physical arrangement and organization of different areas within a warehouse facility are referred to as warehouse layouts (Rohit Monga, 2015). A well-designed warehouse layout can not only lower operating costs but also boost efficiency (He et al., 2020).

Dimensioning a warehouse entails determining the optimal size and layout of the facility to accommodate the inventory's storage and handling requirements (Frazelle, 2016).

2.4 Facility Location Problem

The Facility Location Problem (FLP) is a type of optimization problem that involves determining the best location for a facility (such as a warehouse, distribution center, or manufacturing plant). This problem is important for businesses and organizations that need to determine the optimal location of their facilities in order to reduce costs, increase customer satisfaction, and improve overall efficiency (Ángel Corberán et al., 2020). In Figure 2.7 it is possible to see the flow of stock from a plant to a warehouse and then to a customer.

Different approaches, such as mathematical programming models, heuristic algorithms, simulation models, and data-driven methods, are used to determine the optimal location of facilities (Klose and Drexler, 2005).

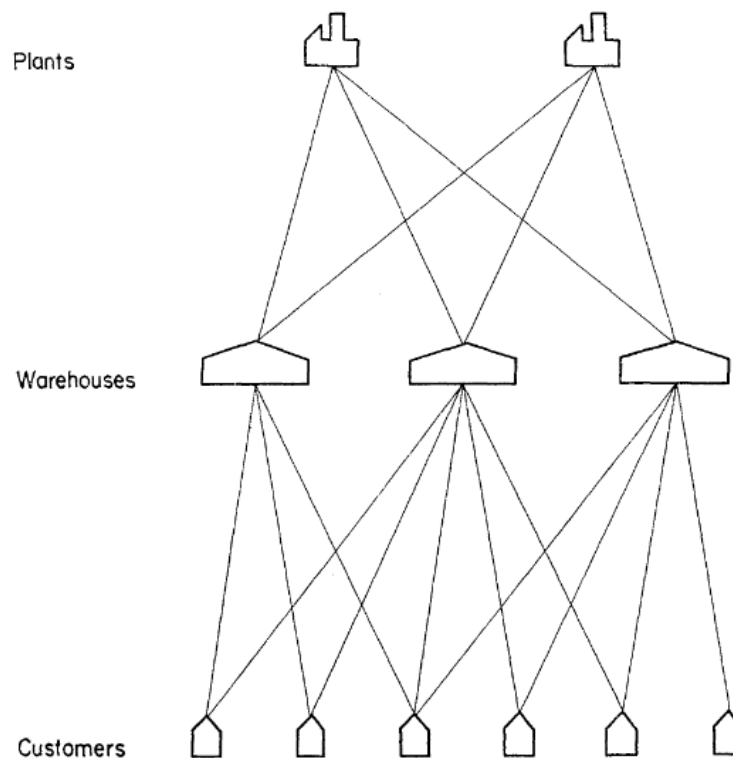


Figure 2.7: Flow of Stock (Elson, 1972)

2.5 MILP - Mixed Integer Linear Programming

MILP has several important supply chain management applications, including facility location, inventory management, and transportation planning. MILP, for example, can be used to determine the optimal number and location of warehouses, the best inventory allocation across multiple locations, and the most efficient transportation routes (Aslam and Amos, 2010).

The model involves a list of candidate installations. These approaches are based on the premise that, rather than dealing with an unbounded space with infinite possibilities, the model operates on a finite set of potential locations. This is based on the idea that it is impractical to consider sites where a facility cannot be established or locations where a company may not want to pursue for other strategic reasons (Palomino et al., 2022).

According to Alberizzi et al. (2020), it is essential to formulate the problem by identifying the following components:

- **Decision variables:** These are the variables that represent the quantities or options in the problem. Symbols are commonly used to represent them. The decision variables, for example, would be the number of products to produce or the amount of resources to allocate if the problem involved determining the number of products to produce or the amount of resources to allocate (Meng et al., 2022).

Binary variables are decision variables that can take only two possible values: 0 or 1 (Korkmaz et al., 2018). Binary variables are frequently represented as x_i or y_i , where i denotes the variable's index.

If the variable x_i satisfies the following constraint, it is binary:

$$x_i \in \{0, 1\}$$

Binary variables are especially useful for representing decisions such as choosing or deselecting specific options, activating or deactivating constraints, or indicating the on/off status of a specific condition (Liu et al., 2021).

- **Constraints:** Constraints must be written as linear combinations of the Decision Variables. MILP solvers can find the optimal solution that satisfies all of the constraints while optimizing the given objective by combining equality and inequality constraints with the objective function (Jing et al., 2019).
- **Objective function:** The objective function in Mixed-Integer Linear Programming (MILP) represents the goal or objective of the optimization problem (Sangaiah et al., 2020). The goal can be to maximize (i.e., find the highest possible value) or minimize (i.e., find the lowest possible value) the value of the objective function (Bellendorf and Ádám Mann, 2020).

For example, the objective function in a production planning problem could represent total profit, and the goal would be to maximize it. The objective function in a cost minimization problem could represent the total cost, and the goal would be to minimize it (Leung et al., 2003).

MILP formulation:

According to (Elson, 1970), the next example defines a general model for transportation problems.

Equation 2.1 minimize total transport costs between origin i and destination j . Equation 2.2 defines supply constraints, and Equation 2.3 defines demand constraints. Obviously the number of units transported have to be higher or equal to zero, as shown in Equation 2.4.

Data:

$c_{ij} \rightarrow$ Cost per unit transported from origin i to destination j ;

$d_i \rightarrow$ Supply availability at origin i ;

$n_j \rightarrow$ Demand at the destination j .

Decision variables:

$x_{ij} \rightarrow$ Number of units transported from origin i to destination j .

Objective:

$$\min \sum_i \sum_j c_{ij} x_{ij} \quad (2.1)$$

$$\sum_j x_{i,j} \leq d_i \quad \forall_i \quad (2.2)$$

$$\sum_i x_{i,j} \geq n_j \quad \forall_j \quad (2.3)$$

$$x_{i,j} \geq 0 \quad (2.4)$$

Chapter 3

Problem description

Through strategic investments, BA Glass company, a leading manufacturer in the glass packaging industry, has achieved consistent growth. BA Glass, like many other businesses in this industry, faces seasonal challenges. During periods of low demand, the company's stock levels rise, while periods of high demand result in lower stock levels.

While BA Glass already operates warehouses with different capacities, the accumulation of substantial stock volumes necessitates the utilization of external warehouses. However, the significant costs associated with these external warehouses prompt an important question: would BA Glass benefit more from establishing other own warehouse and potentially reducing dependence on some of the currently utilized external warehouses?

The level of stocks to be stored is directly affected by effective production planning. Businesses can strike a balance between meeting customer needs and minimizing excess inventory by aligning production with demand, resulting in improved operational efficiency, lower costs, and increased customer satisfaction.

It is important to note that transportation is critical in the operation of warehousing. Maintaining an optimized supply chain requires the efficient movement of goods between manufacturing facilities, warehouses, and distribution channels.

Data from the last three years (2020, 2021, 2022) and one year of forecast (2023), were used in the study. The program used in BA for data storage is SAP (Systems, Applications and Products).

3.1 BA Warehousing

Today, BA Glass has a total of 17 warehouses in Iberia to support its operations. This includes five proprietary warehouses, one for each of the company's plants. BA Glass relies on 12 external warehouses in addition to its proprietary warehouses. As shown in Figure 3.1, these warehouses are strategically located to allow for the efficient storage and distribution of glass products manufactured at the respective plants.

BA Glass can effectively manage their inventory and respond to customer demands in a timely manner by co-locating the five proprietary warehouses with their plants. Because these warehouses

are close to the manufacturing facilities, they can seamlessly integrate production and storage processes. It allows for the direct transfer of glass products from plants to adjacent warehouses, reducing transportation time and optimizing operational efficiency.

BA Glass also makes use of additional 12 external warehouses strategically located throughout Iberia. These warehouses will supplement the co-located proprietary warehouses and improve BA Glass' supply chain operations. BA Glass is able to streamline their supply chain processes and maintain a consistent flow of glass products to the market thanks to the strategic distribution of warehouses.

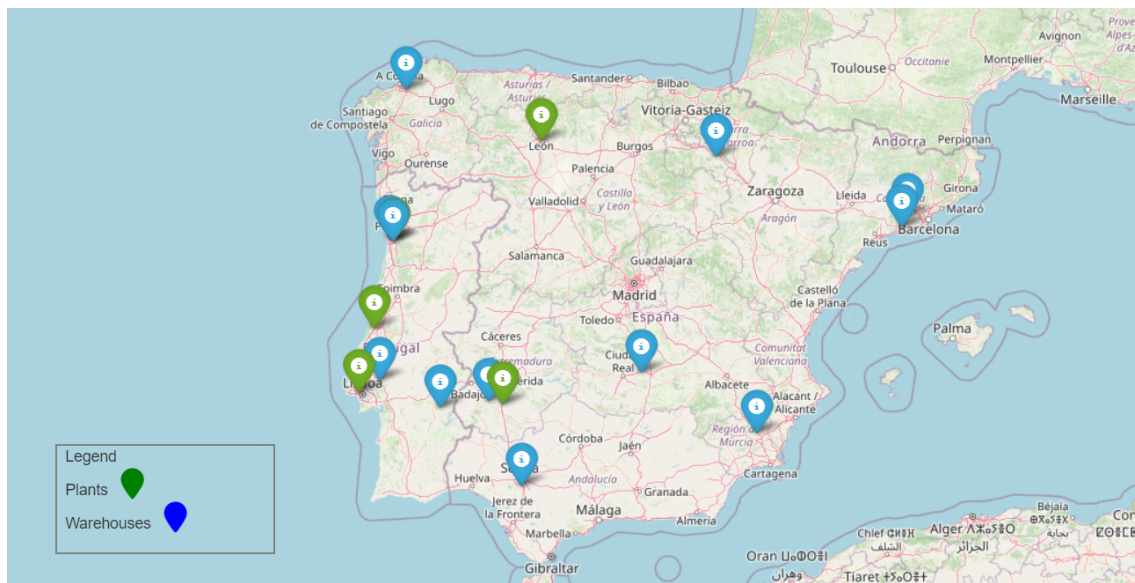


Figure 3.1: BA Glass Plants and actual External Warehouses in Iberia

Table 3.1 provides a detailed overview of the Transport Regions assigned to BA Glass's plants in the Iberian region. This table is a great resource for understanding about the geographical distribution of BA Glass's production facilities and their corresponding Transport Regions (T.Region).

Table 3.1: T. Region of each Plant

Plant	T.Region
AV - Avintes	PT44
MG - Marinha Grande	PT24
VF - Villafranca de los Barros	ES06
LE - León	ES24
VN - Venda Nova	PT27

BA Glass heavily relies on a mapping system that categorizes regions into T.Regions. T.Regions are defined by specific postal zone code numbers, as shown in Figure 3.2. BA Glass can effectively manage and organize its operations across multiple areas thanks to this mapping system.

BA Glass' use of T.Regions allows it to have a clear understanding of the geographic coverage and distribution of its operations in the Iberian market, allowing for more effective decision-making and resource allocation.

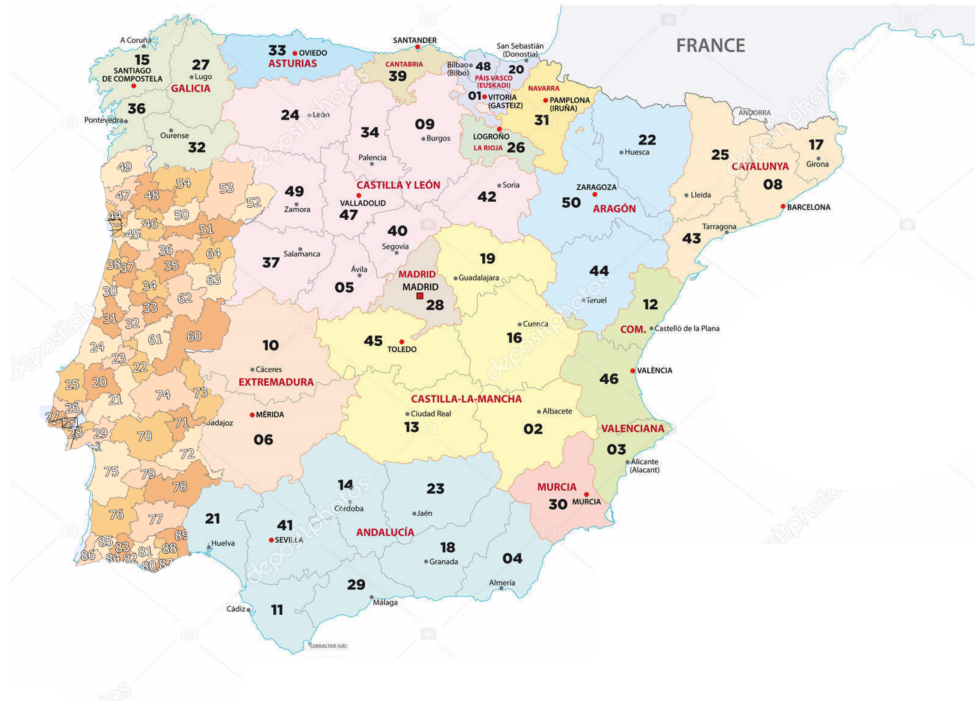


Figure 3.2: Map of Iberia by Postal Code

External Stock

In the context of BA Glass, external stock refers to inventory or goods stored in external warehouses.

External warehouses are frequently used due to a need for additional storage space, or safety stocks near key markets or customers and ensure optimal availability of products throughout Iberia.

In Figure 3.3, it is possible to observe the stock levels in the Iberian region over the past years. Simultaneously, the total stock and the stock in external warehouses are represented. The monthly representation allows for a better understanding of the seasonality in the glass packaging industry. There are periods in the year when stock levels are higher than others, leading to a correspondingly higher utilization of external warehouses.

Third-party logistics (3PL) providers working with BA Glass must follow the company's specific rules and guidelines for warehousing operations. These rules are in place to ensure that the 3PL provider manages their warehousing activities effectively and in accordance with BA Glass's specific requirements and standards.

By following BA Glass's rules and guidelines, 3PL providers can ensure a consistent and harmonized approach to warehouse management. This includes complying with specific protocols related to inventory management, handling and storage procedures, quality control, safety regulations, and other relevant aspects of warehouse operations.

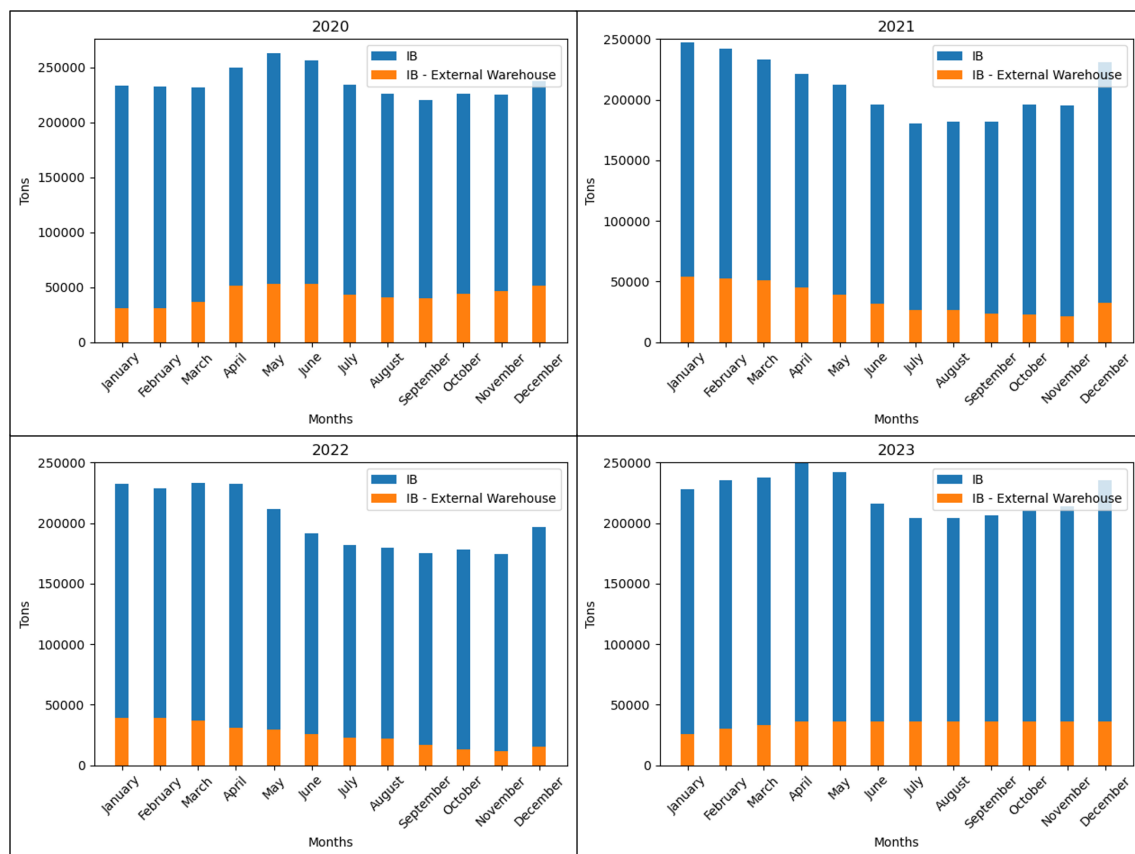


Figure 3.3: External Stock of Iberia over the years

Based on information from previous years, Figure 3.4 shows the percentage distribution of the average stock levels in both internal and external warehouses for each factory. It is clear that the factories in Villafranca de los Barros and Venda Nova store a higher percentage of their inventory, 19% and 18% respectively, in external warehouses.

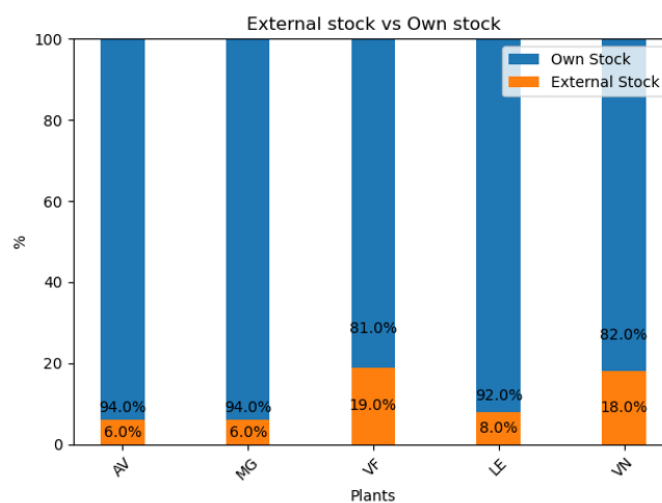


Figure 3.4: Percentage of External Stock per Plant

3.2 Production Planning at BA

Stocks are heavily influenced by production planning. Effective production planning has a direct impact on a warehouse's efficiency, utilization, and overall performance. Production planning at BA Glass entails several critical aspects. Here are a few key points to consider:

- **Demand Forecasting:** BA Glass analyzes market trends, historical sales data, and customer demand patterns to forecast the demand for glass bottles. This helps in estimating the future requirements and adjusting production accordingly.
- **Capacity Planning:** BA Glass assesses its production capacity, taking into account factors such as available resources, equipment capabilities, and workforce availability. This enables them to determine the maximum production output that can be achieved within a given time frame. This allows for obtaining a daily production for each factory.
- **Scheduling:** Once the demand forecast is established and the production capacity is determined, BA Glass creates a production schedule. This involves determining the quantity and types of glass bottles to be produced, as well as the sequencing of production runs.
- **Resource Allocation:** BA Glass allocates resources such as raw materials, energy, machinery, and labor to different production lines or manufacturing facilities. Efficient resource allocation helps ensure smooth production operations and timely delivery of glass bottles.
- **Inventory Management:** BA Glass manages its inventory of glass bottles to ensure an adequate supply for customer orders while avoiding excess stock. This involves optimizing inventory levels, monitoring stock turnover rates, and coordinating with suppliers to ensure a continuous supply of raw materials.
- **Continuous Improvement:** BA Glass continually seeks ways to improve its production processes. This may involve implementing new technologies, optimizing production workflows, or adopting lean manufacturing principles to enhance efficiency, reduce waste, and increase overall productivity.

By effectively planning production, BA Glass can meet customer demands, optimize resources, maintain product quality, and ensure timely delivery of glass bottles to its clients.

3.3 Iberian Market

BA Glass places a high value on the Iberian market, which is critical to the company's overall business strategy. BA Glass is active in the Iberian Peninsula, which includes both Spain and Portugal, and strives to establish a strong presence and capture market opportunities in this region. In Figure 3.5 it is possible to see that the percentage of products produced in Iberia and consumed within Iberia has been increasing year after year, which reinforces the growth of consumption in this region.

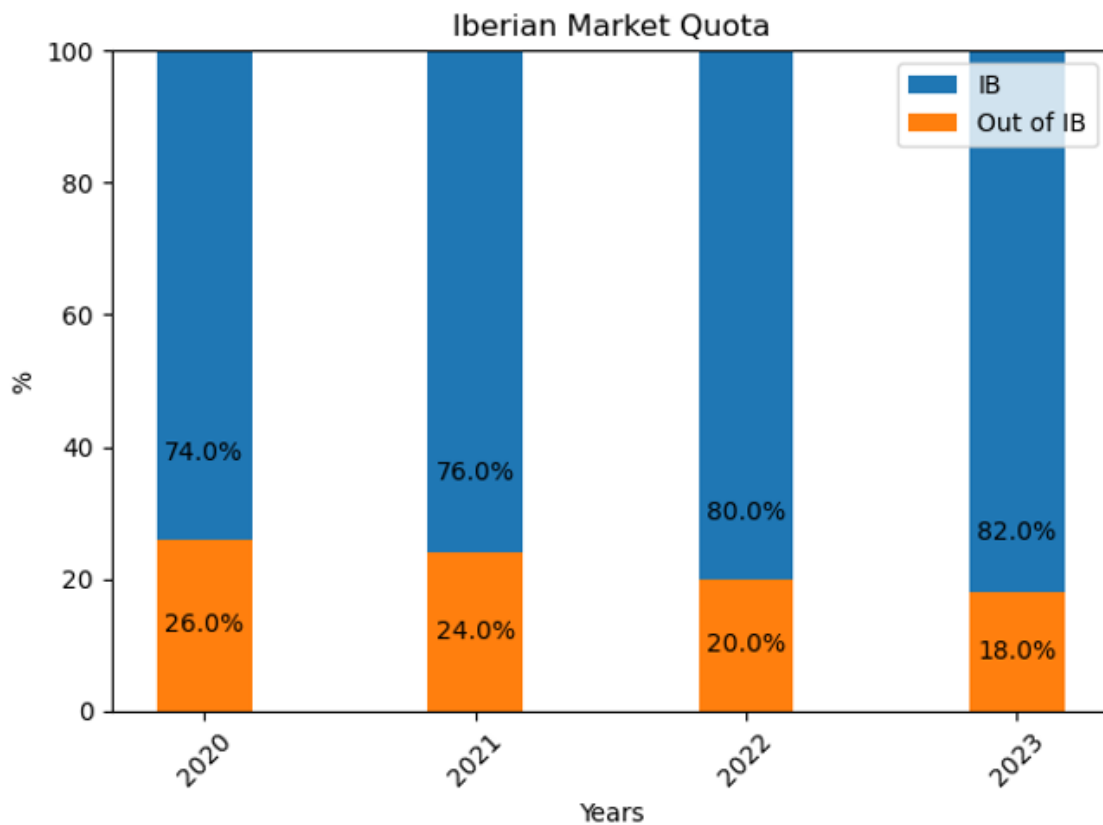


Figure 3.5: Iberian Market Quota

In Figure 3.6, using the Power BI tool, dashboards featuring an Iberian Map were created. The size of the bubbles on the map represents the total number of trucks utilized by each region annually. To provide a clearer visualization of BA Glass's key clients' locations, a filter was applied to display only regions receiving 500 or more trucks annually.

The regions where BA Glass's main customers are situated have remained consistent over the years. However, there has been a noticeable increase in customer consumption within these areas. This growth can be attributed to both the expansion of BA Glass's customers' businesses and the increasing trust in BA Glass as a reliable supplier of glass packaging.

The market share of each factory in the Iberian market can also be observed. By clicking on different T.Region Origins in the donut chart, the map dynamically displays the number of deliveries based on the location where the material was produced and subsequently delivered to each region.

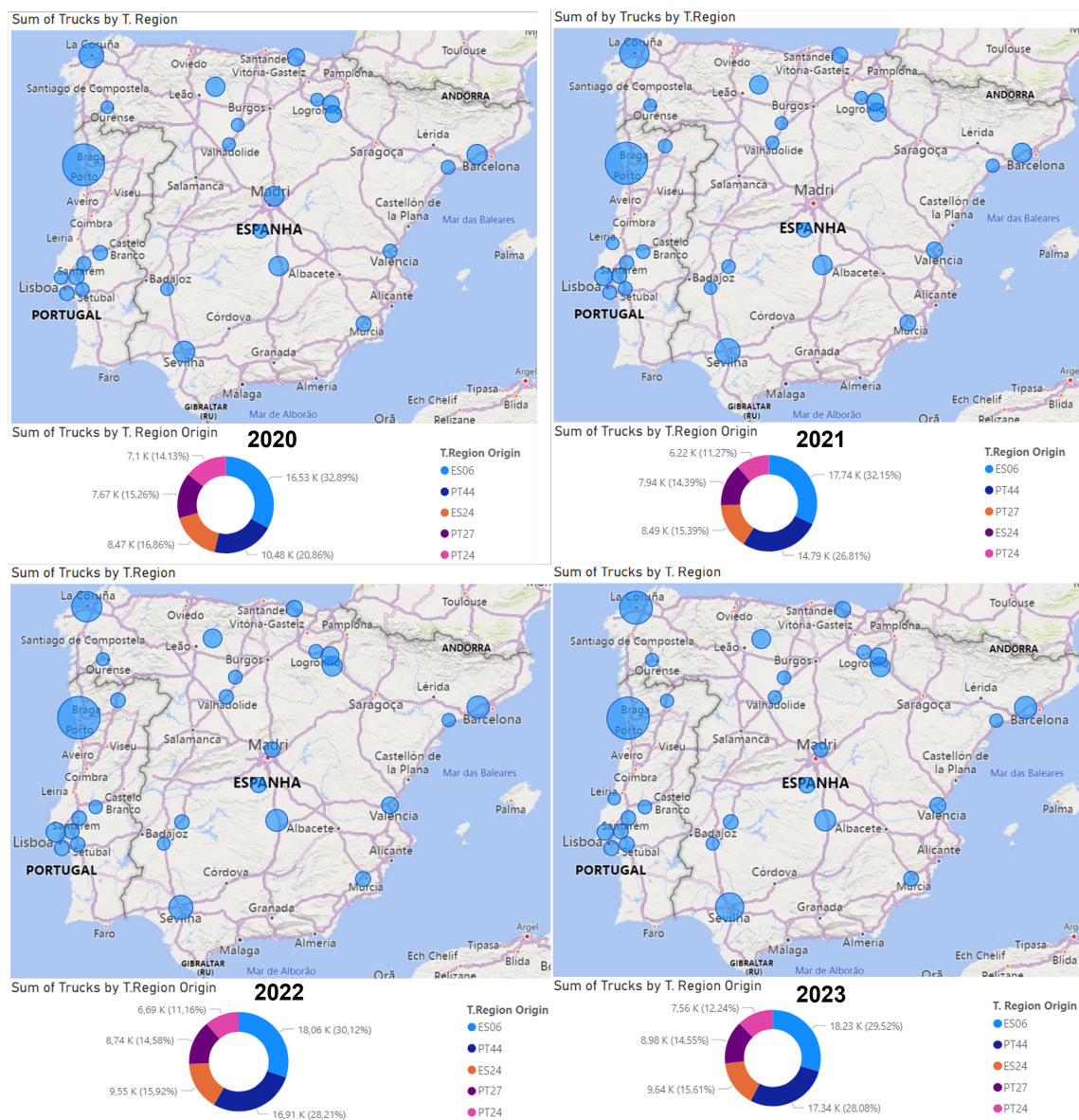


Figure 3.6: Demand over the years

3.4 Transports in BA

According with the data presented in Figure 3.7, there is a projected increase of around 10,000 trucks being consumed in the Iberian region from 2020 to the end of 2023. This suggests a growing demand for glass packaging within this period.

This reinforcement in the Iberian market highlights the work that the entire structure has been developing. All the investments made in the factories contribute to enhancing this growth and making the operation increasingly efficient. From technology to sustainability, there is a clear commitment from BA to secure the future and meet all customer demands.

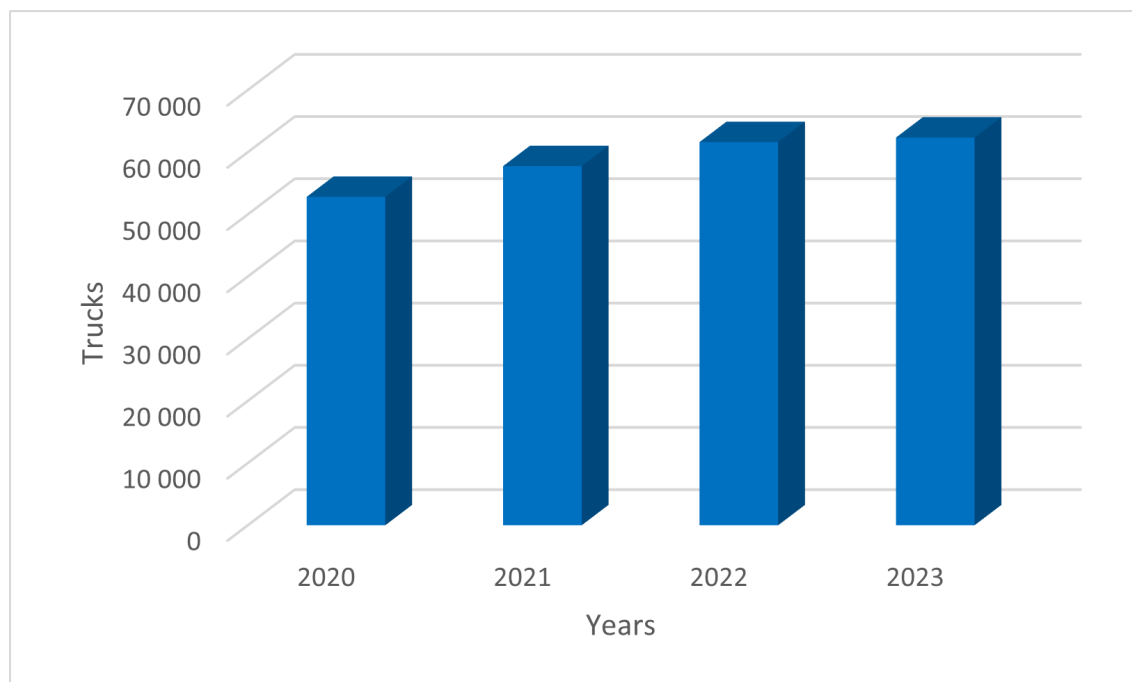


Figure 3.7: Deliveries per year in IB

BA Glass relies on trucks as the primary mode of transportation for ground deliveries. BA Glass has entered into contractual agreements with transportation companies to ensure the efficient and secure transportation of its products. These agreements ensure that BA Glass has access to a dedicated fleet of vehicles as well as logistics services to meet its transportation requirements.

When discussing transportation, it is essential to comprehend the dimensions of a truck. According to Table 3.2, a truck is capable of transporting either 26 high pallets or 52 low pallets. In both scenarios, an average value of 17 tons of finished product per truck is considered.

Currently, BA Glass exclusively utilizes full truck load transportation for its operations. By carrying an average of 17 tons of finished goods on each truck, the maximum amount of transport capacity is used, and goods are delivered quickly.

Table 3.2: Dimension of a truck

Number of trucks	Tons	Number of Pallets
1	17	52 / 26

Strategy of division by T.Regions based on postal codes greatly aids in the organization of BA Glass's logistics operations. Each distinct region is identified by its unique postal code number, facilitating the identification and location of delivery and collection zones. Such an approach enables the company to allocate resources effectively and optimize transportation routes.

BA Glass has a robust transportation network that is critical to its operations. With a firm commitment to efficiency and dependability, the company has built a strong system to transport its

glass containers to various locations around the world. In Figure 3.8, it is possible to see the main routes for main clients in Iberia.

The price of transportation is influenced by the origin and destination regions, and consequently by the distance.



Figure 3.8: Top 10 routes from each Plant

Each plant in the BA Glass network specializes in producing different products to meet the needs and requirements of specific customers. As a result, the key customers of each plant are geographically distributed, allowing BA Glass to effectively serve a diverse range of markets.

In Figure 3.9 it is possible to see the number of trucks that are consumed in Portugal and Spain.

In recent years, the percentage of trucks consumed in Spain has consistently been higher than the number of trucks consumed in Portugal. Within the Iberian Peninsula, Spain has a higher share of truck consumption than Portugal. Spain, in particular, absorbs approximately 63% of the region's total truck production, while Portugal absorbs approximately 37%.



Figure 3.9: Number of Trucks from IB in Portugal and Spain

3.5 Difficulties with External Warehouse Operation

There are several common difficulties that can arise in warehouse operations:

- One of the problems that BA Glass may face when operating with external warehouses is the restriction imposed by some logistics operators who have warehouses and also provide transportation services. In these cases, they may require that the transportation to and from their warehouses be exclusively handled by them. This limits BA Glass's flexibility in choosing the most suitable carrier and can result in higher transportation costs, as the company is obligated to use a specific carrier regardless of the price.
- Communication Issues: Working with external warehouses brings challenges in communication, timely stock control, and photo sharing. These issues can hinder operational efficiency and require effective communication channels, real-time stock monitoring, and streamlined photo documentation.
- BA Glass encounters challenges when using external warehouses, as some operators may not have SAP integration. This lack of SAP compatibility can lead to difficulties in data synchronization, information sharing, and overall coordination between BA Glass and the external warehouses.
- One of the challenges BA Glass faces when working with external warehouses is that their employees may not have the same level of experience handling fragile materials like glass as BA Glass employees. This lack of expertise in handling delicate glass products can lead to an increased risk of breakage or damage during storage.

Chapter 4

Implementations and Results

In the implementation and results section, a mathematical formulation for Mixed-Integer Linear Programming (MILP) was developed to minimize the cost in the different scenarios considered. The mathematical formulation was programmed in Python, as shown in Appendix A. In the mathematical model, the fundamental unit of work was defined as the number of trucks. The mathematical model aims to minimize transportation costs, and for that purpose, a Python model was developed to calculate the distances, by road, between different locations. After implementing the distance calculation model, a cost per kilometer was assigned to reflect the expenses associated with transportation.

The capacity of the new warehouse was determined based on estimations derived from historical data.

Four scenarios were formulated and analyzed to provide meaningful insights for the company.

In all scenarios it was considered three external warehouses that are mandatory to continue due to proximity to important clients. For mathematical model the new warehouse location can not be in locations where BA already has own or external warehouses.

4.1 Mathematical Model

Model Variables:

x_{fik} $\longrightarrow$ Number of units of product f sent from source i to warehouse k (in trucks)

y_{fkj} $\longrightarrow$ Number of units of product f supplied from warehouse k to demand region j (in trucks)

$$I_k = \begin{cases} 1 & \text{if warehouse } k \text{ is opened} \\ 0 & \text{otherwise} \end{cases} \quad (k \in K', \text{ the set of potential new warehouses})$$

Model parameters:

A_{fi} $\longrightarrow$ Number of units of product f which can be made available from source i (in trucks)

D_{fj} $\longrightarrow$ Number of units of product f required by demand region j (in trucks)

C_k $\longrightarrow$ Capacity of warehouse k (in trucks)

CS_{fik} $\longrightarrow$ Unit cost of transporting product f from source i to warehouse k (per truck)

CT_{fkj} $\longrightarrow$ Unit cost of transporting product f from warehouse k to demand region j (per truck)

Model Constraints:

In Equation 4.1, the total quantity of products flowing to the warehouses must be higher than or equal to the quantities available from the sources:

$$\sum_k x_{fik} \geq A_{fi} \quad (f \in F, i \in I) \quad (4.1)$$

In Equation 4.2, the total quantity of products flowing from the warehouses to the demand areas must satisfy the demand:

$$\sum_k y_{fkj} \geq D_{fj} \quad (f \in F, j \in J) \quad (4.2)$$

In Equation 4.3, the quantity of products flowing into a warehouse must be higher than quantities flowing out of it:

$$\sum_i x_{fik} \geq \sum_j y_{fkj} \quad (f \in F, k \in K) \quad (4.3)$$

In Equation 4.4, for existing warehouses: Warehouse capacity must be sufficient for the total product throughput:

$$\sum_f \sum_i x_{fik} \leq C_k \quad (k \in K'') \quad (4.4)$$

In Equation 4.5, for potencial new warehouses: Warehouse capacity must be sufficient for the total product throughput:

$$\sum_f \sum_i x_{fik} \leq C_k \cdot I_k \quad (k \in K') \quad (4.5)$$

Model Objective:

In Equation 4.6, minimize the sum of Plant-warehouse transport costs:

$$\sum_f \sum_i \sum_k CS_{fik} \cdot x_{fik} + \quad (4.6)$$

In Equation 4.7, minimize warehouse-customer transport costs:

$$\sum_f \sum_k \sum_j CT_{fkj} \cdot y_{fkj} \quad (4.7)$$

4.2 Warehouse Capacity

The best location for the warehouse, proper sizing and dimensioning are critical. Warehouse dimensioning is crucial for increasing efficiency, improving operations, and achieving cost-efficiency.

The graph in Figure 4.1 has proven to be an excellent tool for determining the capacity of the future warehouse under consideration in this thesis. It was possible to deduce that on average, over these four years under analysis, approximately 29,000 tons were required for external stock.

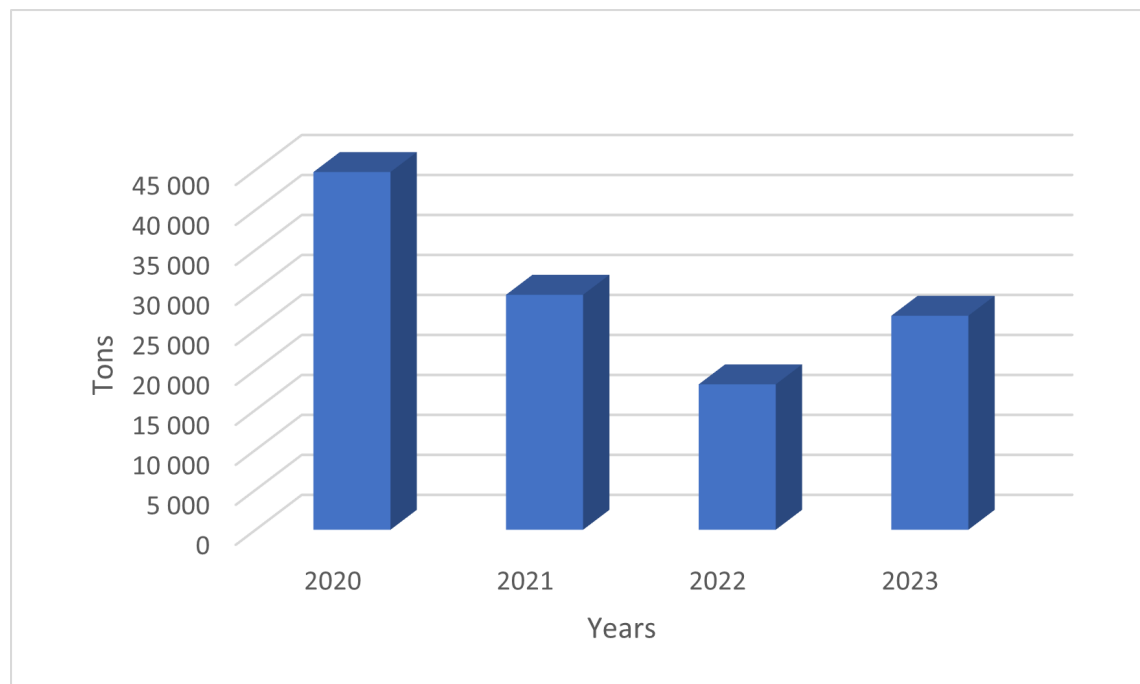


Figure 4.1: External Stock in Iberia

It is known that there are three warehouses, as shown in Table 4.1, that will need to be maintained due to existing contracts with local clients. These warehouses have a total capacity of approximately 9,000 tons.

Table 4.1: T.Region of Mandatory External Warehouses

External Warehouse Region	Capacity (Tons)
PT44	4000
ES08	2500
ES15	2500

Using these three warehouses, it is possible to calculate the capacity of the new warehouse by subtracting 9,000 tons from the total capacity of 29,000 tons. As a result, the remaining capacity is 20,000 tons.

With experience of BA Glass logistics team, it was considered moreless 70% of the 20,000 tons to ensure that the warehouse was always full. It is critical to avoid underutilization because it would result in significant costs.

4.3 Transport Cost

To calculate the transportation cost, the first step was to identify the coordinates corresponding to each postal code zone. With that, all possible route combinations were generated. In other words, using the postal code zones, all origin-destination combinations between them were created.

The distance between regions was calculated using Python programming with the help of API of Open Route Service, which utilized the coordinates of the origin and destination to calculate the road distance, as shown in Figure 4.2. Python code used to determine road distances is available in Appendix B.

Origin	Destination	Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude	Distance
ES15	ES36	43.3526862	-8.420000988	42.23571395	-8.459154257	124.2427
ES15	ES32	43.3526862	-8.420000988	42.34908725	-7.999419581	116.7428
ES15	ES27	43.3526862	-8.420000988	42.5868392	-7.776483566	99.96588
ES15	ES33	43.3526862	-8.420000988	43.3675555	-5.523976488	234.122
ES15	ES39	43.3526862	-8.420000988	43.4443481	-3.459999224	400.8057
ES15	ES48	43.3526862	-8.420000988	43.3194435	-3.001529142	438.1663
ES15	ES20	43.3526862	-8.420000988	43.19332799	-2.056346517	515.3846
ES15	ES01	43.3526862	-8.420000988	42.49607675	-2.441015102	495.9401
ES15	ES24	43.3526862	-8.420000988	42.75093788	-5.137369983	274.9715
ES15	ES49	43.3526862	-8.420000988	41.53361702	-5.301605154	326.1336

Figure 4.2: Distance calculator between T. Regions

It was calculated the estimated cost of the trip after determining the distance between the locations, as shown in Figure 4.3. It was assigned different costs per kilometer based on the distance traveled, taking into account the current transportation market. For distances less than 100 kilometers, it was applied a higher cost per kilometer. This reflects the shorter distances and the costs associated with covering those distances.

For distances greater than 100 kilometers, however, a reduced rate per kilometer has been assigned. This account for economies of scale and efficiencies gained when traveling longer distances.

Origin	Destination	Origin Latitude	Origin Longitude	Destination Latitude	Destination Longitude	Distance	Price
ES15	ES36	43.3526862	-8.420000988	42.23571395	-8.459154257	124.2427	155.3034
ES15	ES32	43.3526862	-8.420000988	42.34908725	-7.999419581	116.7428	145.9284
ES15	ES27	43.3526862	-8.420000988	42.5868392	-7.776483566	99.96588	299.8976
ES15	ES33	43.3526862	-8.420000988	43.3675555	-5.523976488	234.122	292.6524
ES15	ES39	43.3526862	-8.420000988	43.4443481	-3.459999224	400.8057	501.0072
ES15	ES48	43.3526862	-8.420000988	43.3194435	-3.001529142	438.1663	547.7079
ES15	ES20	43.3526862	-8.420000988	43.19332799	-2.056346517	515.3846	644.2308
ES15	ES01	43.3526862	-8.420000988	42.49607675	-2.441015102	495.9401	619.9251
ES15	ES24	43.3526862	-8.420000988	42.75093788	-5.137369983	274.9715	343.7143
ES15	ES49	43.3526862	-8.420000988	41.53361702	-5.301605154	326.1336	407.667

Figure 4.3: Price calculator between T. Regions

4.4 Different Scenarios

Using a mathematical model, four different scenarios that make sense for the company were developed in this study. In all scenarios, three external warehouses were retained in addition to the

warehouses owned by BA due to contractual agreements with specific customers, as shown in Table 4.2.

In some scenarios, the study explored the use of additional optional external warehouses. These optional external warehouses were considered to evaluate their potential impact on cost reduction. The inclusion of these optional warehouses demonstrates that different configurations could optimize the company's operations or not.

The analysis considered factors such as transport costs, customer demand, capacity of the warehouses in study, the capacity that each plant has to put product in the market determine the potential benefits of each scenario. The costs used in this analysis are not real costs in order to maintain the confidentiality of the company's data. To ensure data privacy, a distortion factor was applied to multiply the costs, resulting in values that deviate from reality. This measure was taken to protect sensitive information and maintain confidentiality. The main variable costs were taken into consideration.

Table 4.2: Mandatory Warehouses

External Warehouse Region	Capacity (Tons)	Trucks
PT44	4000	235
ES08	2500	147
ES15	2500	147

First Scenario

Firstly, an analysis was performed with the factory warehouses as well as three external warehouses that must remain operational at all times, as shown in Figure 4.4.

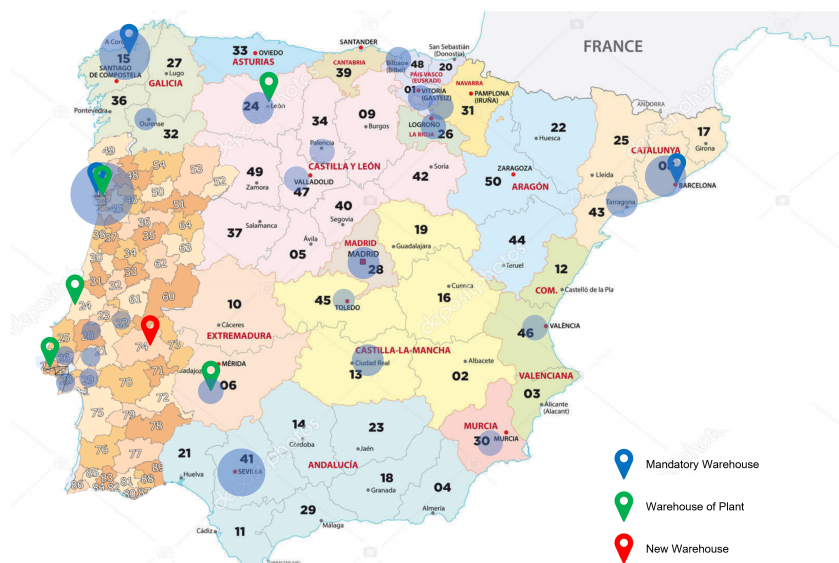


Figure 4.4: Distribution of warehouses - First scenario

In this case, the mathematical model indicated that the most cost-effective location is the PT74 region.

In Figure 4.5, it is evident that the new warehouse will primarily serve to store finished products manufactured at the Venda Nova (PT27) and Villafranca de los Barros (ES06) factories.

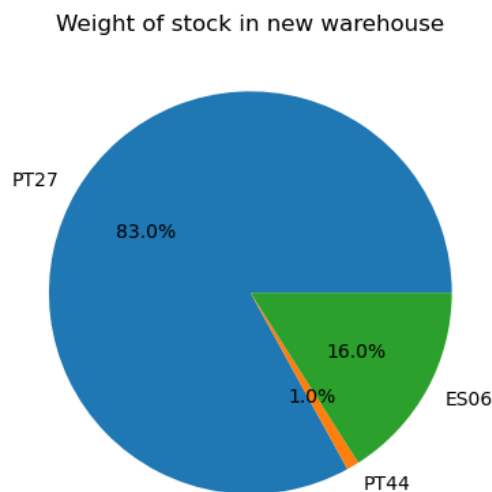


Figure 4.5: Weight of Stock - First scenario

In Section 4.2, it is possible to understand that BA Glass needs, on average, approximately 29,000 tons for external stock. Considering that total capacity of the three mandatory warehouses is 9,000 tons, if 9,000 tons are subtracted from the initial quantity of 29,000 tons, the resulting amount is 20,000 tons.

In this case, it was considered that the new warehouse would require a capacity for 13,804 tons, which corresponds to about 70% of 20,000 tons.

The experience of BA Glass logistics teams confirmed that for each ton of material is needed 1.25 m². When multiplied by 13,804 tons, the result yields an area o, as shown in Table 4.3.

Table 4.3: New warehouse information - First scenario

Region	Capacity (Tons)	Trucks	Area(m ²)
PT74	13 804	812	17 255

The mathematical model was formulated with the aim of achieving the lowest possible transportation cost, both from the factories to the warehouses and from the warehouses to the end customers. In this scenario, the value obtained for the total monthly transportation cost is 2,798,020 euros. In other words, an average annual transportation expense of approximately 33,576,249 euros.

After consulting with BA Glass's investment team, it has been concluded that the average price per square meter of land for construction in the PT74 region is currently around 72 euros.

Considering the required area of 17,255 m², the estimated cost of land acquisition would be approximately 1,242,360 euros. It is crucial to keep in mind that other aspects like negotiation, location, and market conditions might affect the actual cost of buying the land. The current construction cost is approximately 384 euros per square meter. Therefore, for the specific area under analysis, the construction cost would be approximately 6,625,920 euros.

Both the construction cost and the land where the warehouse will be built will be depreciated over a period of 20 years. This depreciation period is in accordance with the standard accounting practices in Portugal.

In Table 4.4 is possible to see the main variable expenses between all scenarios under consideration, per year.

Table 4.4: Expenses - First scenario

Expenses	Euros (€)
Transportation Costs	33 576 249
Price of land	62 118
Price of construction	331 296
Total	33 969 663

Second Scenario

In the second scenario, it was retained the five warehouses of the plants and the three mandatory external warehouses. However, the key difference is that it was introduced an optional external warehouse located in ES06, as shown in Figure 4.6. The purpose of including this optional warehouse is to assess if its utilization brings about improved operational outcomes. With this condition the Mathematical model indicated that the most cost-effective location is PT26 region.

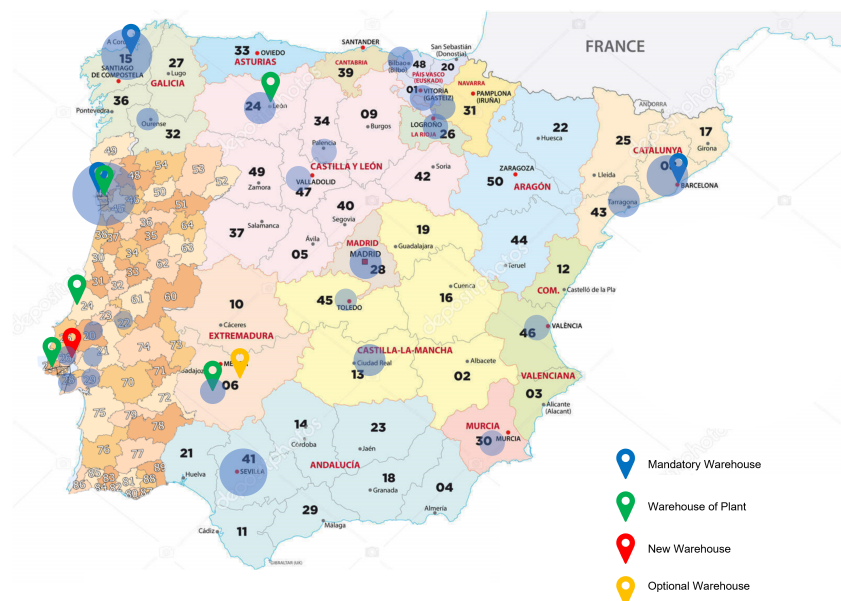


Figure 4.6: Distribution of warehouses - Second scenario

If the optional external warehouse in ES06 provides additional capacity in terms of tons, it would be reasonable to consider reducing the capacity of the new warehouse in the same proportion. This adjustment ensures that the overall storage capacity meets the company's needs while optimizing resource allocation.

The External warehouse in ES06 is an existing warehouse that BA is currently utilizing in its operations, and its capacity is already known, as shown in Table 4.5. Then it becomes crucial to evaluate whether it is beneficial to continue the contract or not.

Table 4.5: Capacity of optional warehouse in ES06 region

Region	Capacity (Tons)	Trucks	Area(m ²)
ES06	3 000	177	3 750

In the previous scenario, the capacity of the potential new warehouse was utilized at 13,804 tons. However, in this new scenario, with the assistance of the external warehouse in ES06, the total capacity of warehousing increased by 3,000 tons. Therefore, to calculate the capacity of the new warehouse in this scenario, it was subtracted the additional 3,000 tons from the previous capacity of 13,804 tons, resulting in a new capacity of 10,804 tons for the new warehouse, as shown in Table 4.6.

Table 4.6: New warehouse information - Second scenario

Region	Capacity (Tons)	Trucks	Area(m ²)
PT26	10 804	636	13 505

According to Figure 4.7, it is evident that the primary purpose of the new warehouse is to store products exclusively from the Venda Nova plant (PT27).

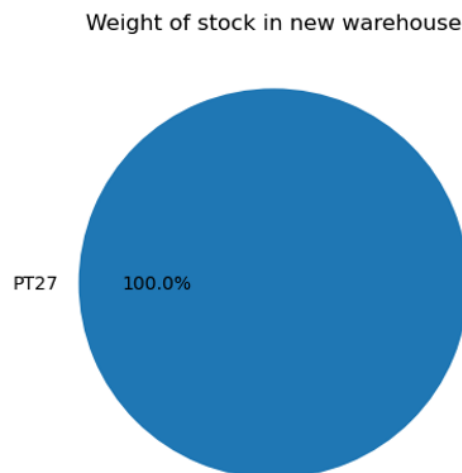


Figure 4.7: Weight of Stock - Second scenario

This can be easily explained by the following reason: In the previous scenario, the stock produced at the Villafranca de Los Barros factory accounted for 16% of the inventory in the potential new warehouse. In the current scenario, the stock has been relocated to the optional external warehouse in ES06, reducing the need for the potential warehouse under study. This adjustment optimizes storage capacity and takes advantage of the proximity between ES06 and the plant.

In this scenario, the total monthly transportation cost is calculated as 2,786,283 euros. This translates to an average annual transportation expense of approximately 33,440,198 euros.

After consulting with BA Glass's investment team, it has been determined that the average price per square meter of land for construction in the PT26 region is approximately 78 euros. Based on the required area of 13,505 square meters, the estimated cost of land acquisition would amount to approximately 1,053,390 euros. Additionally, the current construction cost in the region is approximately 320 euros per square meter. Therefore, for the specific area being analyzed, the construction cost is estimated to be around 5,185,920 euros.

In Table 4.7 it is possible to see the main variable expenses between all scenarios under consideration, per year.

Table 4.7: Expenses - Second scenario

Expenses	Euros (€)
Transportation Costs	33 440 198
Price of land	52 669
Price of construction	259 296
Optional warehouse in ES06	72 000
Total	33 824 163

Third Scenario

In the third scenario, the strategy adopted closely resembles the second scenario. It was maintained the five warehouses of the factories, the three mandatory external warehouses, and introduced an optional warehouse. However, in this case, the optional warehouse is located in the ES13 region instead of ES06, as shown in Figure 4.8.

The PT26 region is the most cost-effective location under these circumstances, according to the mathematical model to install the new warehouse.

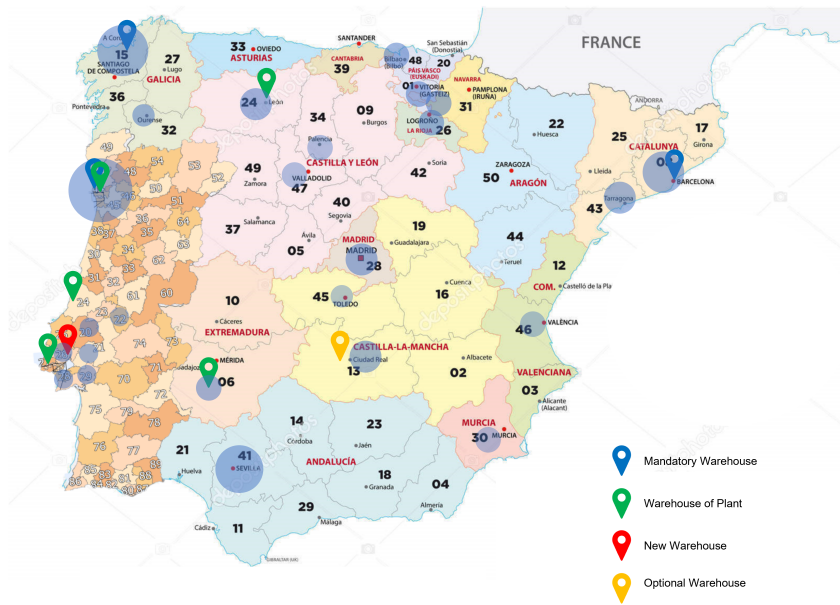


Figure 4.8: Distribution of warehouses - Third scenario

In a similar manner to the previous scenario, the capacity of the potential new warehouse can be proportionally reduced as we are leveraging a third-party logistics provider that is utilized by BA Glass. It is known that External warehouse located in ES13 has capacity for 2,500 tons, as shown in Table 4.8.

Table 4.8: Capacity of optional warehouse in ES13 region

Region	Capacity (Tons)	Trucks	Area(m ²)
ES13	2 500	147	3125

In the first scenario where no optional warehouse was utilized, the capacity used amounted to 13,804. By subtracting 2,500 from the initial capacity of 13,804, the recalculated capacity of the potential new warehouse in this scenario amounts to 11,304, as shown in Table 4.9.

Table 4.9: New warehouse information - Third scenario

Region	Capacity (Tons)	Trucks	Area(m ²)
PT26	11 304	665	14 130

In this case, our potential new warehouse is once again fully utilized for storing stock produced at the Venda Nova factory (PT27), as shown in Figure 4.9. The optional warehouse utilized in this scenario, although located in ES13 instead of ES06, is again utilized for storing any excess stock produced at the Villafranca de los Barros factory.

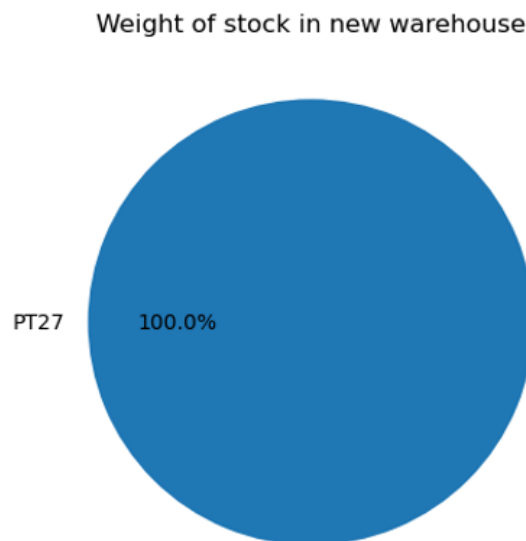


Figure 4.9: Weight of Stock - Third scenario

In this scenario, the total monthly transportation cost is calculated as 2,790,020 euros. This corresponds to an average annual transportation expense of approximately 33,480,245 euros. Consultations with BA Glass's investment team reveal that the average price per square meter of land for construction in the PT26 region is approximately 78 euros. With a required area of 13,505 square meters, the estimated cost of land acquisition amounts to approximately 1,102,140 euros. Moreover, the current construction cost in the region is approximately 384 euros per square meter. Therefore, for the specific area under analysis, the estimated construction cost totals around 4,239,000 euros.

In Table 4.10 it is possible to see the main variable expenses between all scenarios under consideration, per year.

Table 4.10: Expenses - Third scenario

Expenses	Euros (€)
Transportation Costs	33 480 245
Price of land	55 108
Price of construction	271 296
Optional warehouse in ES13	48 000
Total	33 854 649

Fourth Scenario

The fourth and final scenario studied involved a combination of the second and third scenarios. In this scenario, the five warehouses of the factories were retained, as well as the three mandatory external warehouses, and were introduced two optional warehouses located in ES06 and ES13, as shown in Figure 4.10.

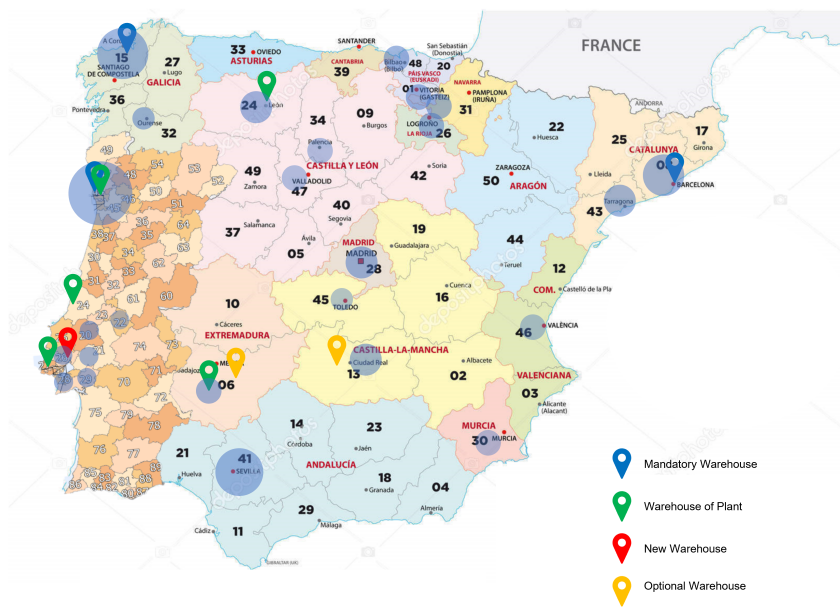


Figure 4.10: Distribution of warehouses - Fourth scenario

The mathematical model once again indicates that the optimal location is the PT26 region.

Similarly to the previous scenario, the capacity of the potential new warehouse can be proportionally reduced considering the involvement of two third-party logistics providers used by BA Glass. It is known that the external warehouses located in ES13 and ES06 have capacities of 2,500 tons and 3,000 tons, respectively, as shown in Table 4.11.

Table 4.11: Capacity of optional warehouses in ES06 and ES13 regions

Region	Capacity (Tons)	Trucks	Area(m ²)
ES06	3 000	177	3 750
ES13	2 500	147	3 125

In this case, the potential new warehouse's recalculated capacity is 8 304 tons, as shown in Table 4.12.

Table 4.12: New warehouse information - Fourth scenario

Region	Capacity (Tons)	Trucks	Area(m ²)
PT26	8 304	489	10 380

In this particular case, the potential new warehouse is once again used to its full capacity for storing the stock produced at the Venda Nova factory (PT27), as depicted in Figure 4.11.

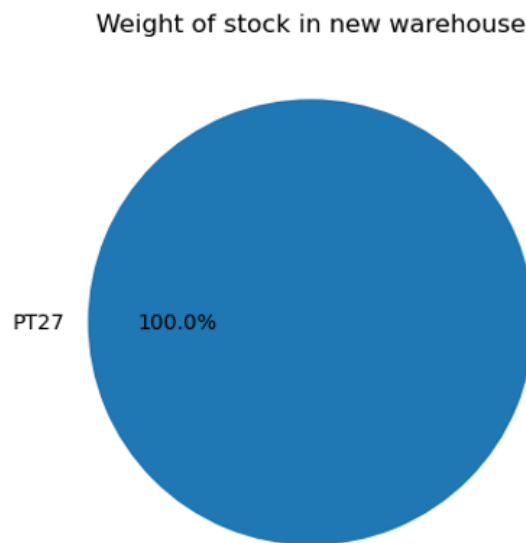


Figure 4.11: Weight of Stock - Fourth scenario

In this case, a total monthly transportation expense of 2,781,461 euros has been determined. This amounts to roughly 33,377,530 euros in average annual transportation costs. . The average cost per square meter of land for construction in the PT26 region, according to BA Glass's investment team, is about 78 euros. The estimated cost of land acquisition is 809,640 euros with a required area of 10,380 square meters. Furthermore, considering the current construction cost in the region of approximately 384 euros per square meter, the estimated construction cost for the specific area under analysis amounts to around 3,985,920 euros.

In Table 4.13 it is possible to see the main variable expenses between all scenarios under consideration, per year.

Table 4.13: Expenses - Fourth scenario

Expenses	Euros (€)
Transportation Costs	33 377 530
Price of land	55 108
Price of construction	199 296
Optional warehouse in ES06	72 000
Optional warehouse in ES13	48 000
Total	33 751 934

4.5 Mathematical Model in Python

The PuLP library and Python programming language were used to implement the mathematical model. Popular open-source library PuLP for Python's linear and integer programming offers a simple syntax and potent optimization tools.

The code gets the capacity that each plant could give (A), as shown in Figure 4.12. The temporal period used in this was on a monthly basis.

Plant	Source	A
PT44	PT44	

Figure 4.12: Capacity of production per plant

The code also had to read the demand (D) in different regions according to where the product is produced (plant), as shown in Figure 4.13.

Plant	Region	D
ES06	ES15	

Figure 4.13: Demands

The code had to read the capacities of existing warehouses in different regions, as well as the capacity of the new warehouse in all other potential locations for installation, as shown in Figure 4.14.

Warehouse	Capacity
PT44	

Figure 4.14: Capacity of warehouses

The code also needed to read the prices of different routes required for the operation, as shown in Figure 4.15.

Origin	Destination	Price
ES24	ES15	

Figure 4.15: Price between regions

Figure 4.16 is divided into three parts. The first part shows the locations where warehouses need to be present. The second part presents the number of trucks between a given factory and a given warehouse. Finally, the last part presents the number of trucks between a given warehouse and a given customer, taking into account where the product is produced.

Variable	Value	Variable	Value	Variable	Value
l_var_ES01	0	x_('ES06','_ES01')	0	y_('ES06','_ES06','_ES06')	2
l_var_ES02	0	x_('ES06','_ES02')	0	y_('ES06','_ES06','_ES09')	7
l_var_ES03	0	x_('ES06','_ES03')	0	y_('ES06','_ES06','_ES11')	5
l_var_ES04	0	x_('ES06','_ES04')	0	y_('ES06','_ES06','_ES14')	6
l_var_ES05	0	x_('ES06','_ES05')	0	y_('ES06','_ES06','_ES16')	1
l_var_ES06	1	x_('ES06','_ES06')	3241	y_('ES06','_ES06','_ES17')	1

Figure 4.16: Results of Mathematical Model

Chapter 5

Conclusion and Future Works

This dissertation was conducted within BA Glass's Iberian Distribution department, which is responsible for managing advanced warehouses. The utilization of the Python based mathematical model played a crucial role in identifying suitable warehouse locations.

Among the different scenarios considered, scenario four was identified as the most economically advantageous option. It is expected to significantly enhance the efficiency and performance of the logistics team. However, the difference in economic benefits compared to other scenarios was not substantial.

The new warehouse will provide substantial support to the Venda Nova factory. By situating the warehouse in close proximity to the factory, BA Glass gains a competitive advantage through optimized logistics, cost reduction, and increased operational flexibility. This strategic placement allows for efficient resource utilization and swift response to evolving market dynamics, ultimately contributing to the overall success and competitiveness of the company.

Looking ahead, incorporating lead times into the analysis is crucial for gaining a comprehensive understanding of operational efficiency and customer satisfaction. By considering lead times, businesses can fine-tune their operations, better manage customer expectations, and enhance overall performance. This focus on lead times enables companies to optimize their supply chains, improve service levels, and remain competitive in the market.

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Appendix A

Python Code of Mathematical Model

```
1 from pulp import *
2 import pandas as pd
3 import itertools
4
5 df = pd.ExcelFile('RUI1.xlsx')
6 s1 = df.parse('Sheet1')
7 s2 = df.parse('Sheet2').dropna()
8 s3 = df.parse('Sheet3').dropna()
9 s4 = df.parse('Sheet4').dropna()
10 s5 = df.parse('Sheet5').dropna()
11 s6 = df.parse('Sheet6').dropna()
12 s7 = df.parse('Sheet7').dropna()
13
14 F = list(s1['Plant'].dropna())
15 J = list(s1['Region'].dropna())
16 K = list(s1['Warehouse'].dropna())
17
18 K_prime = list(s5['Warehouse'])
19 K_double_prime = list(s4['Warehouse'])
20
21 A = {}
22
23 for index, row in s2.iterrows():
24     plant = row['Plant']
25     value = row['A']
26
27     A[plant] = value
28
29 D = {}
30
31 for index, row in s3.iterrows():
32     plant = row['Plant']
33     region = row['Region']
34     value = row['D']
35
36     if plant in D:
37         D[plant][region] = value
38     else:
39         D[plant] = {region: value}
40
41 C = {}
42
43 for index, row in itertools.chain(s4.iterrows(), s5.iterrows()):
```

```

44     warehouse = row['Warehouse']
45     value = row['Capacity']
46
47     if warehouse in C:
48         C[warehouse] += value
49     else:
50         C[warehouse] = value
51
52 CS = {}
53
54 for _, row in s6.iterrows():
55     plant = row['Origin']
56     warehouse = row['Destination']
57     price = row['Price']
58
59     if plant not in CS:
60         CS[plant] = {}
61
62     CS[plant][warehouse] = price
63
64 CT = {}
65
66 for _, row in s7.iterrows():
67     plant = row['Plant']
68     warehouse = row['Origin']
69     region = row['Destination']
70     price = row['Price']
71
72     if plant not in CT:
73         CT[plant] = {}
74     if warehouse not in CT[plant]:
75         CT[plant][warehouse] = {}
76     CT[plant][warehouse][region] = price
77
78 # Create the problem
79 prob = LpProblem("Warehouse_Transportation_Problem", LpMinimize)
80
81 # Define the decision variables
82 x = LpVariable.dicts("x", ((f, k) for f in F for k in K), lowBound=0, cat="
Continuous")
83 y = LpVariable.dicts("y", ((f, k, j) for f in F for k in K for j in J),
lowBound=0, cat="Continuous")
84 I_var = LpVariable.dicts("I_var", (k for k in K), cat="Binary")
85
86 # Set the objective function
87 prob += lpSum(CS[f][k] * x[(f,k)] for f in F for k in K) \
88     + lpSum(CT[f][k][j] * y[(f,k,j)] for f in F for k in K for j in J)
89
90 # Add the constraints
91 for f in F:
92     prob += lpSum(x[(f,k)] for k in K) >= A[f]
93
94 for f in F:
95     for j in J:
96         prob += lpSum(y[(f,k,j)] for k in K) >= D[f][j]
97
98 for f in F:
99     for k in K:
100         prob += x[(f,k)] >= lpSum(y[(f,k,j)] for j in J)
101

```

```

102 for k in K_double_prime:
103     prob += lpSum(x[(f,k)] for f in F) <= C[k]
104
105 for k in K_prime:
106     prob += lpSum(x[(f,k)] for f in F) <= C[k] * I_var[k]
107
108 prob+=lpSum(I_var[k] for k in K_double_prime) == len(K_double_prime)
109
110 prob+=lpSum(I_var[k] for k in K) == 8
111
112 # Solve the problem
113 prob.solve()
114
115 # Print the status of the solution
116 print("Status:", LpStatus[prob.status])
117
118 import pandas as pd
119
120 # Create a dictionary to store the variable groups
121 variable_groups = {}
122
123 # Iterate over the variables and group them based on their prefix
124 for v in prob.variables():
125     prefix = v.name.split('_')[0]
126     if prefix not in variable_groups:
127         variable_groups[prefix] = []
128     variable_groups[prefix].append({'Variable': v.name, 'Value': v.varValue})
129
130 # Specify the Excel file path
131 excel_file = 'solutions.xlsx'
132
133 # Create a Pandas Excel writer using the xlsxwriter engine
134 writer = pd.ExcelWriter(excel_file)
135
136 # Write each variable group to a separate sheet
137 for group_name, group_data in variable_groups.items():
138     df = pd.DataFrame(group_data)
139     df.to_excel(writer, sheet_name=group_name, index=False)
140
141 # Save the Excel file
142 writer.close()
143
144 print("Solutions written to", excel_file)
145
146
147 # Print the optimal solution
148 for v in prob.variables():
149     print(v.name, "=", v.varValue)
150
151 # Print the optimal objective value
152 print("Total Cost =", prob.objective.value())

```


Appendix B

Python Distance Calculator

```
1 import openrouteservice
2 import pandas as pd
3
4 # Read the data from Excel
5 col_names = ['Origin', 'Destination',
6              'Origin Longitude', 'Origin Latitude',
7              'Destination Latitude', 'Destination Longitude']
8 df = pd.read_excel('Coordinates.xlsx', sheet_name='Sheet8', usecols=col_names)
9
10 # Read the data from Excel
11 col_names = ['Origin', 'Destination',
12              'Origin Longitude', 'Origin Latitude',
13              'Destination Latitude', 'Destination Longitude']
14 df = pd.read_excel('Coordenadas.xlsx', sheet_name='Sheet8', usecols=col_names)
15
16 # Define the OpenRouteService API key
17 api_key = 'YOUR_KEY'
18
19 # Create a client for the OpenRouteService API
20 client = openrouteservice.Client(key=api_key)
21 distance = []
22
23
24 # Loop over the pairs of starting points and destinations
25 for i, (start, dest) in tqdm(enumerate(zip(start_points, destinations))):
26     # Calculate the route between the current pair of points
27     # The profile can be change to adjust to different types of vehicles.
28     # driving-hgv stans for heavy goods vehicle
29     route = client.directions(coordinates=[list(start), list(dest)], profile='
30     driving-hgv', format='geojson')
31     # Distance is divided by 1000 to adjust the unit to km
32     distance.append(route['features'][0]['properties']['segments'][0]['distance
33     ']/1000)
34
35
36 # Append to the dataframe
37 df['Distance [km]'] = distance
38
39 df.to_excel('Coordinates_with_distances.xlsx', index=False)
```