Projeto e Planeamento de Cadeias Logísticas Sustentáveis – o caso do *Papel Tissue* na The Navigator Company

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Abstract

An industry's production capacity increase frequently implies strategic and tactical adjustments in several departments, in order to ensure that the product can be competitively delivered in the required amount, by the promised date, to the final client's location.

This paper addresses the supply chain network design of The Navigator Company, for the tissue paper product, which is currently in a phase of expansion in the market. The company's concern for the sustainable development of its operations considers the three pillars of sustainability: economic, environmental and social.

For the resolution of the identified issue, a multi-objective mixed integer linear programming model (MOMILP) is proposed, based on the literature review. The model analyzes different logistics planning scenarios, while targeting minimizing costs and environmental impact and maximizing social impact.

The resolution of the case study indicates that the strategy that better satisfies the interests of The Navigator Company is the weekly shipping of *Jumbo Rolls* from the port of Aveiro until the port of Liverpool, which will then be transported up to the city of Manchester, where they will be converted into *Finished Products*, to be directly delivered to the final clients. The recommended warehouses facilities for the safety stock are in Belfast, Northampton and Manchester.

Keywords: sustainable supply chain network design and planning, sustainability, supply chain modelling, optimization.

1. Introduction

The production cycle of an industry is completed when its products are sold to the end customers in order to be consumed in the quantity, location and time required. For this to happen, it is necessary that companies ensure a distribution network that takes its products from the place of production to the place of consumption. This trip can often be complex, suffering several stops in hub terminals – place where the goods are transferred from one means of transportation to another – go through several entities and complying with rules and regulations that often vary from country to country. These complex operations often lead companies to present high distribution costs that may cause the operation in certain markets to be no longer profitable, forcing companies to abandon some customers. In addition to the associated costs, companies must ensure the quality of the distribution service, which can often be difficult due to the fact that some services are outsourced, what alienate the main company of the events flow. For the eyes of the end customer, a consistent, safe and quality service will transmit the confidence to the business procedures, to be carried out smoothly and with the credibility necessary to create beneficial relations to both parties. With a world constantly changing, where the factor *time* has an important weight in the long-term strategy, it is essential for the operations of a company to be flexible in order to be able to readapt due to changes in some parameters - fuel prices, labour costs or storage capabilities - thanks to natural disasters, international crises, stock market speculation or other factors.

A supply chain involves the activities associated with the flow and the transformation of products from raw materials until they reach the final consumer, as well as the flows of information associated with this path (Melo *et al.*, 2009). According to Min and Zhou (2002) a supply chain is an integrated system with 5 main objectives: 1) Acquire raw materials and components; 2) Transform those raw materials into finished goods; 3) Add value to those products; 4) Distribute and promote those products to clients; 5) Enable the information exchange between the different entities involved in the process.

The network planning seeks to define the supply chain configuration that maximizes the performance of the company in the long run, which involves some important decisions. Chaabane *et al.* (2012) define two levels of planning: (1) Strategic Decisions – decision on the location of entities and their allocation; and (2) Tactical Decisions – dealing with the flow of materials between supply chain entities. The physical supply chain design involves mostly strategic decisions, like the number of entities to install, their locations, capabilities and objectives; as well as the relations with collaborating companies so that customer needs are properly met.

The most recent studies on sustainable supply chains have emphasized the notion that the performance of a logistics chain should not only be measured by its ability to generate profits to the company, but also by its impact on social and ecological systems (Gladwin *et al.*, 1995; Seuring & Müller, 2008). Unfortunately, this ideal chain does not exist, so the goal of the current models focuses on finding the most sustainable solution compared to the alternatives (Wu & Pagell, 2011). This balance between economic development, environmental management and social equality is called the triple bottom line (Elkington, 1997; Society, 2005), shown in figure 1.

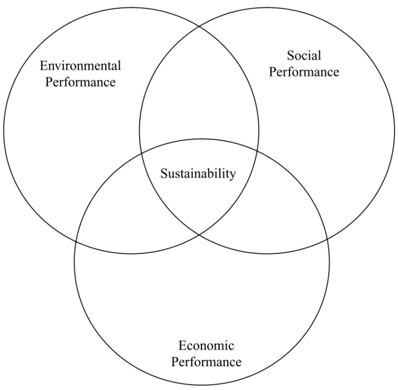

Figure 1 - Triple Bottom Line

Seuring, in his 2013 work, concluded that the majority of the existing supply chain optimization models in the literature analyse the economic dimension of sustainability by minimizing costs. The other option would be the profit maximization. Regarding the environmental dimension, the Life Cycle Assessment (LCA) has been described as the most scientifically reliable method to assess the environmental impacts of a particular product, process or activity (Ness *et al.*, 2007). The European Commission itself has declared in 2003 that the LCA was the best assessment tool of potential environmental impacts, including it in its Sustainable Development Strategy document, in order to standardize methodologies for LCA, facilitating its implementation by companies. This method allows the quantification of the amount of relevant emissions and resources consumed, as well as the health impacts associated with a certain product or service, and takes into account the entire product life cycle, from extraction of resources until recycling, through production and utilisation (European Commission, 2011). Mota *et al.*, in their 2015 model implemented a LCA methodology called ReCiPe 2008, which allows the impact analysis of the products and/or services throughout their life cycle, exploring all impact categories, instead of considering only CO_2 emissions, as it's typically done. Impact categories are the various aspects of the environmental effects to be taken into consideration. The ReCiPe 2008 method uses two types of impact categories: *midpoint* (18 in total) – greater detail, clearer units and more practical sense – and *endpoint* (3, broader) – higher level of uncertainty.

To analyse the social dimension of the sustainability, the article Mota *et al.* (2015) proposes the application of the *Social Benefit Indicator*, which seeks to benefit the less developed regions, using inputs such as unemployment or income distribution by population. This indicator allows the stimulation of job creation in areas most needed over areas that already have a favourable social performance.

2. Case Study

This paper addresses the optimization of the sustainable supply chain of one of the biggest and most important Portuguese companies, with a leading position in the national and international pulp and paper market: **The Navigator Company.** The main goal is to study the best structure for the company's logistics network and to analyse different alternatives, in order to minimize the total costs, minimize the environmental impacts and maximize the social impacts, while guaranteeing high service levels.

The company, that so far only produced paper for office and graphic purposes, in 2015 took the strategic decision of entering in the tissue paper market. The acquisition of the company AMS BR Star Paper was the first step towards this, reinforced with the intention of creating a new production line for this product in its factory in Cacia, Aveiro. The production from this plant will be mostly to export, and this paper analyzes the supply of the United Kingdom customers from the Cacia plant.

The production of tissue paper has an intermediate stage where the Jumbo Rolls are formed before they are converted into the finished and differentiated products. The work in this paper takes into account these two different situations, and estimates which of the products – Jumbo Rolls (*JR*) or Finished Products (*FP*) – must be shipped to the UK. Both products can be transported by ship or by truck to the United Kingdom. In the case of the *FP*, when they arrive to the UK, they can go directly to the clients or be stored in warehouses. In the case of the *JR*, they are transported directly to the converter, where they are converted into *FP*, to be sent to the final customers or to the warehouses. From the warehouses, the *FP* can only be shipped to the end clients. Figure 2 describes all these possible flows. Green arrows represent the flows exclusively of *FP*, the red arrows symbolize the *JR* flows, and blue arrows may represent either the *FP* or the *JR* flows.

2.1. *Company characterization*

2.1.1. Factory

The supply chain on study has only one factory producing, and it is located in Cacia, near the coast in the centre of Portugal. It has a production capability of 70 thousand tons of tissue paper per year.

2.1.3. Customers

The company expects to have 38 retailer customers or delivery points, as can be seen in figure 3. The estimated demand is not the same for every customer. It is assumed that the demand is given by tons of final product.

2.1.4. Products

The product to be delivered to the clients is called *final product (FP)*. There are a lot of final product's forms - with no distinction between the types of products – toilet paper, kitchen roll, paper napkin, *etc*. – but this research does not distinguish them. However, before the formation of the final products, the production process includes an intermediate step in which are formed the *jumbo rolls (JR)*, that tend to be less dense, so easier to transport and store. One of the main strategic decision that this paper is supposed to support is each one of the products should be sent from the Cacia plant. If the model decides to send the *JR,* these must necessarily pass through the converter in order to be converted into the *FP*.

2.1.5. Converter

This entity will only be installed if the product to ship from the Cacia plant is the *JR*. In this case, the converter is located in the city of Manchester, and has a converting capability of 400 weekly tons.

2.1.6. Transportation Modes

The company does not own any vehicle. All the distribution activities are outsourced. It is assumed that the transportation can be performed by road or sea. Depending on the product sent from the plant, the type of vehicle may differ:

- Leaving the plant, regardless of the products that are being shipped, they can be taken to the ports of departure, or directly to the UK by road.
- If it's the *FP* that is being shipped, it goes on a container ship.
- If it's the *JR* that is being shipped, it goes on a regular cargo ship.

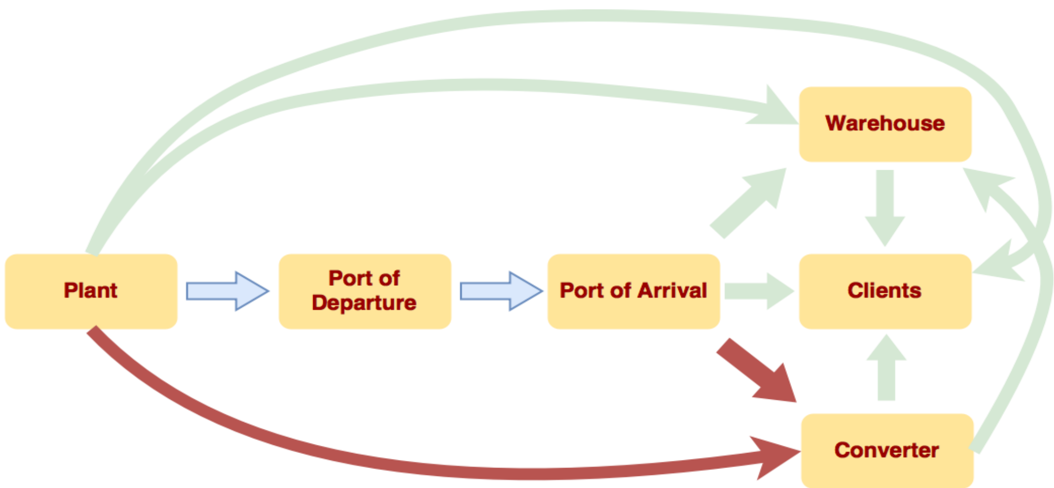

Figure 2 - diagram of the possible entity connections

2.1.7. Sea Ports

As seen in the previous section, the transportation of *FP* is held in a container ship. The Navigator Company intends to consider only two departing ports in Portugal capable of handling containers: Figueira da Foz and Leixões. Regarding the transportation of *JR*, it is assumed that only the port of Aveiro deals with regular cargo ships.

For the arrival of the product to the UK it is only worth taking into account the ports with regular shipping lines from Portugal, at least weekly.

From the port of Leixões, the container ships can travel to the following UK ports: Belfast, Felixstowe, Greenock, Liverpool, Bristol, Teesport e Tilbury. Leaving port of Figueira da Foz, the destinations to consider are only four: Belfast, Felixstowe, Bristol and Liverpool. Regarding the hypothesis of sending *JR* to the converter, the port of Aveiro reported that there are no regular shipping lines, and the transport is usually carried on chartered ships by customers to their port of interest. Therefore, the model will choose the most efficient port, from those seven already mentioned.

2.1.8. Warehouses

The location of the warehouses has no limitations imposed by the company, so they can be located in any UK location that would be beneficial. In order to create a set of realistic locations, it was taken in consideration some parameters such as (1) the proximity to the ports of entry, (2) the proximity to end customers, (3) strategic locations that reduce the distances between entities aiming not only to reduce costs but also to reduce environmental impacts, and finally (4) a warehouse close to the converter.

2.1.9. Model Exception

Northern Ireland is an exception in the case study. The fact that it is separated from the rest of the United Kingdom by the Irish Sea means that there is no road transportation between the entities in this country and the other countries. The product to be delivered to its clients must necessarily be the finished product, and be sent by maritime transportation to the nearest port – Belfast.

2.1.10. UK superstructure

In figure 3 is presented the entire superstructure of the UK's portion of the supply chain.

Figure 3 - UK superstructure

- Ports of Arrival
- Final Clients
- Converter
- Warehouses

3. Description of the mathematic model

The mathematical model used to solve the case-study contemplates a forward supply chain, since the reverse logistic is not strategically relevant to the decision making process of the company.

The problem is modelled through Multi Objective Mixed Integer Linear Programming (MOMILP), and can be described in a summarized form as follows:

Given:

- a superstructure network, with the potential locations of the entities (may differ depending on the product to be sent):
  - factory
  - ports of departure
  - ports of arrival
  - warehouses
  - converter
  - final customers
- production capacities and costs
- distance between entities
- considered products
- estimated demand for each client, in each time interval
- possible transportation modes between each pair of entities
  - capacities
  - outsourcing costs
  - handling costs in the hub terminals
- stock keeping costs
- required storage area for the flow of products
- storage cost per unit of product - (fixed € / m2)
- environmental impacts of entities and transport
- social impacts of entities and transport

Determine:

- the network structure;
- capacity to be installed in each entity;
- transportation modes used;
- type of product to be transported between each level of the network;
- amount of product to be carried in each time interval;
- production and storage levels.

So as to:

- Minimize the total cost of the supply chain, ensuring high level of service
- Minimize environmental impacts
- Maximize social benefits

4. Model Formulation

4.1. Sets

The sets definition allows the characterization of the network superstructure, since it presents all the hypotheses regarding the supply chain.

Entities

Each level of the supply chain is defined by one kind of entity. Each subset represents the possible locations for that entity. The entities to consider are: plant, converter, warehouses, clients and ports.

Transport Modes

There are two main means of transportation: maritime transport and road transport. Depending on the type of product being transported, each transport mode has its specificities and costs associated.

Products

As noted earlier, there are two types of products: finished products and jumbo rolls.

Time

Due to the mathematical modelling, three kinds of time intervals are considered:

- First time interval
- Last time interval
- All the time intervals excepting the first one

4.2. Parameters

Parameters can be defined as the model inputs, and are considered constant throughout the life of the project. The parameter list is large, and it adds no value listing it.

Parameters related to the entities are taken into consideration, such as the minimum and maximum capacities, the costs associated and the distances between them. Regarding the products, parameters related to their production costs, demand, the maximum and minimum levels of storage, or the cost of keeping stock are taken into account. As for the means of transportation, in addition to the possible flows, the costs associated are also inputs of the model. Finally, for the environmental and social dimensions, the impacts of transportation and storage activities are calculated (such as the number of workers needed or the environmental damage caused).

4.3. Variables

The decision variables are the unknown elements of the mathematical programming. They are the output solution of the model.

- Continuous and non-negative variables:

They can assume values on a continuous scale, for which fractional numbers make sense. In this case study two continuous and non-negative variables are used: one of them allows to know the flow of products that is transported between each entity in a certain period of time and by which means of transportation. The other allows to know the stock of each type of product that is stored in each entity.

- Binary variables

These variables can only have two values. 1 if the entity concerned is installed and 0 if the entity is not installed.

- Auxiliary variables

As auxiliary variables, are considered all the costs associated with the supply chain (including the total cost), as well as the area required for storage, and the stock in the first period of analysis, for each product.

- Variables related to the environmental dimension

Are the variables that indicate the impact of transport and storage activities, together with the impact by categories and the total impact.

- Variables related to the social dimension

Indicate the total jobs created with the sum of the two activities taken into account.

4.4. Equations

- Economic Objective Function

Having in mind the sequence of activities the products have to go through to reach the final customers, the minimization of the supply chain costs is achieved with an equation that combines all the potential costs of the network. One of the strategic decisions to implement in the supply chain is related to the type of product that should be shipped from the factory (*JR* or *FP*). Thus, the conversion of the jumbo rolls into finished products can be performed at Cacia or at the converter in the UK. At the time of the decision, the difference in the converting costs in the two different locations should be taken into account.

However, as the analysis relates only to the distribution chain, the total cost considered in the conclusions, shall not include production or converting costs.

- Environmental Objective Function

To determine the environmental impact, the methodology used is the ReCiPe 2008, previously presented in chapter 1.
This methodology might be complex to implement, since it requires a large and detailed data collection. However, the existence of databases and software that contain the parameters corresponding to each kind of activity facilitate its implementation, guaranteeing consistent results.
The objective function that measures the environmental impact, minimizes the impact caused by transport and storage activities.

- Social Objective Function

The lack of available information concerning the distribution of income or unemployment rates by regions, has led to a simplification of the *Social Benefit Indicator*. Thus, the function will use only data on the number of jobs created in the transport and storage activities, maximizing them.

4.5. Constraints

The objective functions recently described are subject to constraints that define the characteristics of the issue being studied, and enable to maintain its integrity. The first category of constraints is the material balance. These equations allow to define the inflows and outflows of materials in each entity, as well as the stock level that can be stored in each one of them. Material balances for the converter, the warehouses and the sea ports are made. The equations concerning the capacity of the entities belong to the second category of restrictions. These constraints seek to ensure that the model does not exceed the maximum capacity of the entities, either in the storage level, or the production level. For storage, the model calculates the area needed in each warehouse. The third category of constraints ensures the accuracy in the storage operation of the finished product in the UK warehouses. These constraints define the maximum and the minimum storage capacities at each individual warehouse and at the sum of all warehouses installed in the UK. The area limitations are also considered, as well the accepted number of warehouses. In the same way that the storage equations were defined for the finished products, it is also necessary to do so for the jumbo rolls. Thus, the minimum and the maximum inventory levels for this product are defined. In the fourth category of restrictions, the volume of flow allowed between each pair of entities is stated. This limits the total flow that the network has ability to move, whether leaving the factory, entering or leaving the ports or the warehouse, for example. Finally, the last constraint ensures that all customers have their demand fully met.

5. Results

5.1. Single Objective Optimization

In this chapter the model developed in the previous section will be applied to the case study described in chapter 2.
Given the different objectives, three main *macro scenarios* were defined – A, B and C. Within each of these *macro scenarios* were created three different hypothesis restricting the type of product that can leave the plant to the distribution network – both products (hypothesis 1), finished product only (hypothesis 2) or jumbo rolls only (hypothesis 3). All the 9 scenarios are described in figure 4.

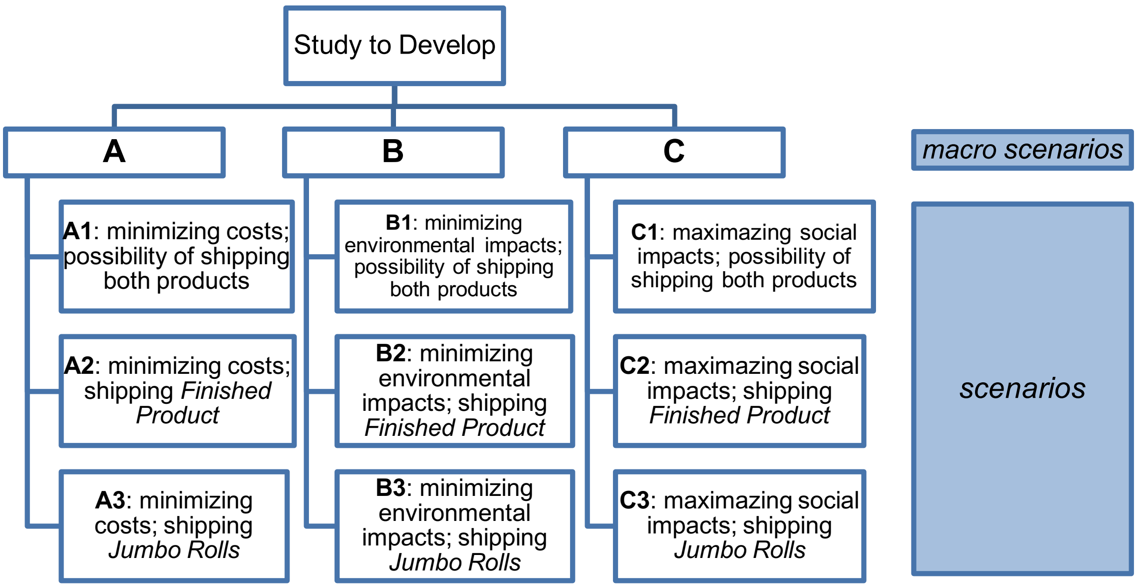

Figure 4 - scenarios under analysis

Each one of the scenarios was solved using the model developed, and the summary of these results is presented in table 1. The *unitary cost* can be described as the distribution cost, per ton, of the supply chain. That is, the cost of the delivering process since it leaves the factory until it reaches the end customers, what naturally excludes the cost of production and the cost of the converting operation. The environmental impact is the normalized sum of all the impacts of each activity considered, and the jobs created regards the number of new jobs that each option allows to create.

As expected, the *macro scenario* A (represented in the first row of the table) is the one with the best results in the economic dimension, especially in cases 1 and 3. The *macro scenario* B shows slightly higher costs, but the environmental impact experienced improvements in the hypotheses 1 and 2. The *macro scenario* C presents extremely high costs and environmental impacts, which will become unreasonable at the operational level.

Scenarios A1, A3 and B3 are highlighted, as they present the best economic result – the cost is about 26% lower than the second best result (B1). The identical values anticipate that the distribution network of these three scenarios have the same structure.

Taking into account the indication that The Navigator Company is planning to ship only one type of product (hypothesis 1 become invalid), one may conclude that it is clearly more efficient to send jumbo rolls through the solutions A1/A3/B3 (37% less expensive compared to the best scenario of shipping only finished product – A2). Besides that, the environmental impact of shipping the *JR* through A1/A3/B3 is 24.5% higher compared to sending *FP* through A2.

5.2. Multi Objective Optimization

Based on the results presented in the previous section, this subchapter aims to combine the individual objective functions in order to achieve a solution by establishing a trade-off between all dimensions of sustainability under analysis. To do so, the Multi Objective Mathematical Programming methodology (MOMP) is implemented, in which the decision on the solution to be implemented is left to the rational decision maker. In the application of the multi objective methodology, the concept of Pareto Frontier is applied, which contains the solutions that cannot be improved in a certain objective function without worsening its performance in at least one other objective function. This paper implements a specific method called *augmented ε-constraint*. This method consists in the optimization of one objective function at a time, using the others as constraints. Thus, it builds up the lexicographic payoff table, from which are obtained the intervals of the objective functions in order to get the Pareto Frontier. Actually, these ranges are the minimum and maximum values of the solutions that the objective function reaches, creating a range in order to quantify all the other intermediate values. This method ensures that the values from these intervals are actually efficient. So, the *augmented ε-constraint* method was implemented to generate Pareto Solutions for the three objective functions (economic, environmental and social), in the three different hypothesis: sending both products (hypothesis 1), sending finished product only (hypothesis 2) and sending jumbo rolls only (hypothesis 3). Through the multi-objective analysis, it is concluded that there are no solutions that improve the social performance without worsening both economic and environmental dimensions. In each of the three hypothesis analyzed, the most interesting results belong to the trade-off between economic and environmental dimensions. Thus, the solutions to be considered end up being those which relate to the single-objective scenarios previously exposed in table 1. Given the multi-objective analysis, a comparison between the supply chains with the best performance in the combination of the three goals is now performed. In figure 5 are shown the physical flows of goods in the logistics networks A1/A3/B3 and B1, as those with the best arrangement between the three pillars of sustainability, and that best suit the interests of The Navigator Company.

Table 1 - results for the single objective optimization

	Both Products	**Finished Product**	**Jumbo Roll**
Minimizing Costs	**A1** Unitary Cost: 221 €/ton Environmental Impact: 5.239 Jobs Created: 85	**A2** Unitary Cost: 350 €/ton Environmental Impact: 4.038 Jobs Created: 84	**A3** Unitary Cost: 221 €/ton Environmental Impact: 5.239 Jobs Created: 85
Minimizing Environmental Impacts	**B1** Unitary Cost: 297 €/ton Environmental Impact: 3.738 Jobs Created: 86	**B2** Unitary Cost: 360 €/ton Environmental Impact: 3.949 Jobs Created: 86	**B3** Unitary Cost: 221 €/ton Environmental Impact: 5.239 Jobs Created: 85
Maximizing Social Impacts	**C1** Unitary Cost: 652 €/ton Environmental Impact: 23.910 Jobs Created: 376	**C2** Unitary Cost: 776 €/ton Environmental Impact: 38.506 Jobs Created: 376	**C3** Unitary Cost: 652 €/ton Environmental Impact: 23.910 Jobs Created: 376

The blue arrows relate to the flow of finished products between the port of Leixões and the arrival ports in the United Kingdom. On the other hand, the green arrows relate to the sending of jumbo rolls from Aveiro to Liverpool. The direct shipping of finished products between the ports of arrival and the final customers are shown in the orange arrows, while the supply of the warehouses is visible in the grey arrows. The black arrow indicates the flow warehouse – customers, and the purple arrow indicates the flow converter – customers. Jumbo rolls traveling from the port of Liverpool to the converter are shown in the yellow arrow.

The logistics chain represented on the left – scenario A1/A3/B3 – send exclusively *JR* to the port of Liverpool, proceeding these towards the converter, where they are converted into finished products. Finally, the finished products are shipped directly to the end customers. On the other hand, the distribution network B1, on the right, reveals a mixed shipping of jumbo rolls and finished products. As it can be seen, finished product is shipped to 5 ports in the UK, and from them to the final customers and one warehouse. There is also a shipment of jumbo rolls to the port of Liverpool, to be then converted and sent to the clients.

Combining the difference in unitary costs between the two scenarios (cost of B1 is 35% higher than the A1), with the greater complexity of distribution chain of B1 (which increases the likelihood of unexpected events along the chain), it can be concluded that not even the greater environmental impact (40%) of solution A1, will hinder it from being the best possible solution to respond to the current case study. Reinforcing this idea is the desire of The Navigator Company to send only one type of product towards the UK – sending only finished product (A2) represent a cost 37% higher).

Due to the excessive costs of warehouse rental and order reception, as well as the large area that the finished product of tissue occupies, in the scenario A1, the model chooses not to use any warehouse for the regular distribution of the product. However, the company's need of safety stock in warehouses in the UK (between one and three) forced the implementation of a strategy to define their best locations. That is, the warehouses must be located in a site that minimizes the inflow and outflow costs when requested. With this option, the model opens a warehouse in Belfast (to provide both customers of Northern Ireland), one in Northampton (supplies 8 clients) and another in Manchester (supplies 28 guests). In the B1 scenario it is not necessary to use this strategy, since the main concern of minimizing the environmental impact is the reduction of transportation distances. Thus, the model will open a warehouse in London, where all the safety stock will be kept.

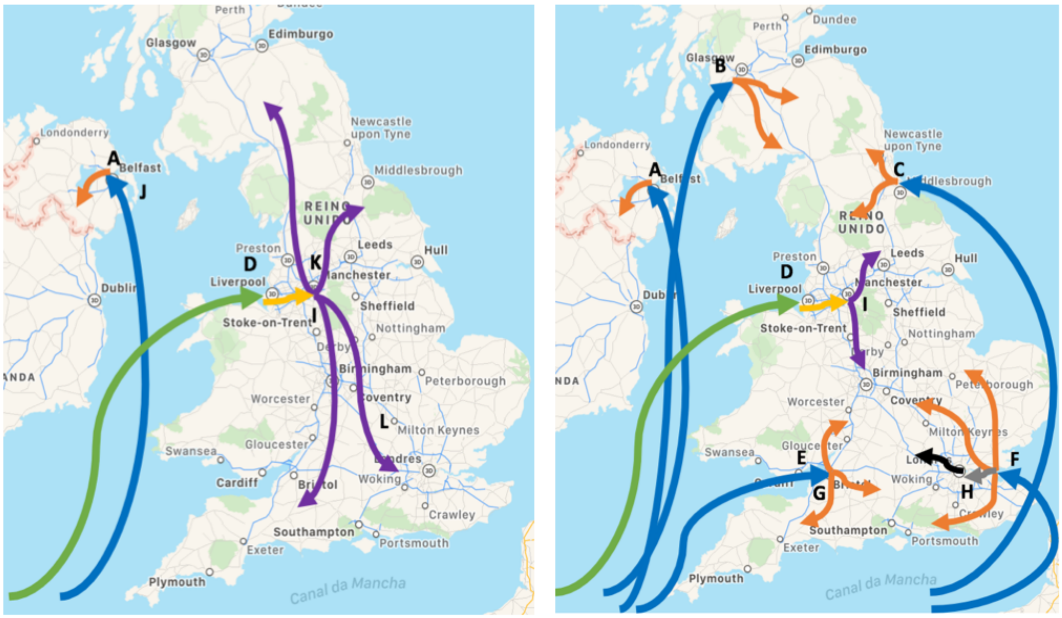

Figure 5 – comparison between the two best network options

A – Port of Belfast
B – Port of Greenock
C – Port of Teesport
D – Port of Liverpool
E – Port of Bristol
F – Port of Tilbury
G – Bristol warehouse
H – London warehouse
I – *Converter*
J – Belfast warehouse
K – Manchester warehouse
L – Northampton warehouse

5.3. Sensitivity Analysis

The parameters included in the mathematical model derived from several sources with different degrees of certainty and precision. Some of them weren't even available, which led to the implementation of assumptions, what may jeopardize the accuracy of the solutions. In addition, these data are likely to change over time, without the influence of the internal operations of the company. For these reasons, a sensitivity analysis for some critical parameters took place, in order to ensure the robustness of solutions and understand what kind of variations may endanger the model results. Thus, the main objective of this analysis involves understanding from the economic and environmental perspectives (since they are the most important dimensions for The Navigator Company), which variations may change the structure of the network – ports to use, routes to perform, warehouses to install – or even the type of product to be transported – Finished Products or Jumbo Rolls. Table 2 summarize the parameters subjected to this analysis, as well as the first variation that will change the physical structure of the supply chain, and the description of the effect caused.

The sensitivity analysis has revealed that, in order to minimize the costs, the *JR* solution is clearly more efficient than the *FP* shipment, being solid enough to withstand major cost increases. Considering the hypothesis that The Navigator Company wishes to send only one type of product to the United Kingdom, the *JR* scenario becomes even more prominent, since all parameter variations continue to suggest the major shipment of this product, remaining the costs of hypothesis 2 (shipment of finished product) much higher.

Table 2 - summary of the sensitivity analysis

Parameter	Variation	First Effect on the Network
Cost of converting in Manchester	+4100%	(1)
Cost of *JR* road transportation	+330%	(1)
Cost of *FP* road transportation	+100%	(1)
Cost of *JR* maritime transportation	+65%	(2)
Cost of *FP* maritime transportation	-40%	(1)
Cost of road transportation in UK	-40%	(2)
Handling costs of *JR* in seaports	+370%	(1)
Environmental impact of transportation	-20%	(3)

Legend:

(1) Part of the product will be sent in the form of finished product from the port of Leixões to the port of Tilbury, and then directly to the nearby customers.
(2) The Jumbo Rolls enter the UK through the Port of Portland.
(3) One of the customers was supplied by the London warehouse starts to receive the finished product directly from the port of Tilbury.

The most critical parameter is the cost of road transportation in the UK, for the reason that if it suffers a decrease of 40%, all production of *JR* must be sent to the port of Portland, rather than Liverpool. Also note that sending the finished product to Tilbury is always the first solution to be taken when there is an increase in costs related to the *JR* activities.

6. Conclusion

This work is intended to design a supply chain, minimizing the costs and environmental impacts and maximizing the social impact that arises from transport routes, the means used, the installed entities and terminals hubs needed in the network. In this regard, this paper developed a mathematical model of optimization, based on the work of Mota *et al.* (2015), testing several scenarios, and thus concluding which one best meets the needs and interests of The Navigator Company.

It is possible to conclude with a high level of certainty, that the strategy that best suits the economic, environmental and social interests of The Navigator Company is the **expedition of jumbo rolls** as exemplified in the diagram of figure 6. As for the warehouses to be installed in the UK, it is suggested the locations of Belfast (35 tons), Northampton (130 tons) and Manchester (435 tons). These warehouses guarantee two weeks of safety stock, not serving as a regular distribution centre. It is noted that this solution is robust to changes in data, as mentioned above.

Finally, some future developments to have in consideration. First, the specification of the type of finished product that must be transported and delivered to the end customers – toilet paper, paper napkins, kitchen roll, etc. – which will increase the complexity of the supply chain, and will involve some operational decisions. In the second place, it may be interesting to explore a link between the two industrial sites of The Navigator Company that produce tissue paper: Cacia and Vila Velha de Ródão. Finally, and certainly relevant is the possible inclusion of the office paper in the supply chain of the tissue paper, or vice versa, in order to take advantage of the transportation synergies of both products.

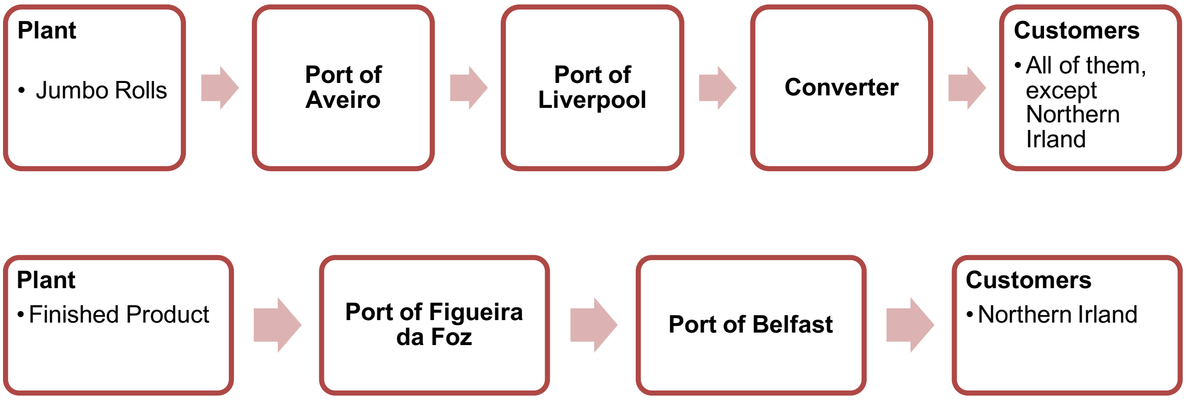

Figure 6 - diagram representing the flows of scenarios A1/A3/B3

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