Frozen Supply Chain Optimizations

The Case Study of Jerónimo Martins

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Abstract

With the growing concern towards sustainability, many industries have been incorporating this trend into their behaviour, through the integration of this concept in their processes, considering the reduction of negative environmental impacts and promoting its surrounding society. Hence, companies aim to optimize their supply chains in order to satisfy consumers, which are increasingly concerned with the sustainable future.

The present problem arises in this context, in which Jerónimo Martins intends to optimize its supply chain towards a better fitting in the current demanding reality. In particular, the frozen supply chain in Portugal, in order to enhance efficiency, reduce costs and promote a healthy relationship with environment and society.

This problem is analysed in this paper, starting by case study characterization. A Multi-Objective Mixed Integer Linear Programming model is proposed and solved using the GAMS software, assessing the supply chain's performance evolution in the economic, environmental and social dimensions. With this model, several scenarios are analysed, in order to define the implemented warehouses' dimension and location, the product flows and the supplying stores' region for each warehouse, by considering the supply chain's performance.

The current work aims to support the strategic and tactic decisions for the frozen supply chain of JM and possible suggest supply chain's designs after analysing the results of the several modelled scenarios.

Key words: Sustainable supply chain; frozen retail; optimization; modelling.

1. Introduction

With the growing importance given to the sustainable thinking and practices, many sectors have been incorporating this concept into their activities, promoting the surrounding society and reducing their environmental impacts. In line with this trend, companies seek to optimize their supply chain in response to the more conscious and demanding consumers.

Alongside with the changing industrial environment, resulting from the decreasing resource availability, smaller product life cycle, market globalization, increasing demand on economic performance without neglecting environmental and social responsibilities, and internal and external pressures concerning the activities impact on the surroundings, the concept of supply chain (SC) has been evolving (Seuring et al., 2008; Boukherroub et al., 2015; Mota et al., 2015).

Being defined as the network of facilities and distribution options, SC includes all the processes from raw material to the delivery of the end product to the consumers, going through its procurement, transformation and transport (Ganesh & Harrison, 1995). Seuring & Martin (2008) also define SC as a set of material and information flows that circulate in opposite directions.

With this concept, the supply chain management (SCM) definition came into light and it has been evolving in order to focus on several issues concerning the SC's activity, such as associated risks, performance, integration, connection between its internal and external networks and legal regulation (Ahi & Searcy, 2013).

One of the major issues, nowadays, concerns the integration of sustainability in SC's activities. Defined by Tascioglu (2015) as the intersection of the economic, environmental and social objectives, sustainability considers the efficient and effective stakeholders' needs satisfaction, with minimization of waste, reduction of pollutant emissions and resources protection, without disregarding workers' health and safety, as well as, the human rights of the general population.

Merging the two previous concepts, sustainable supply chain (SSC) presents the integration of several concerns related to the economic, environmental and social dimensions into its activities. In such SC, the members are obliged to fulfil environmental and social criteria in order to be part of it, while maintaining its competitiveness through client and economic objectives satisfaction (Seuring et al., 2008). Regarding the implementation of this type of SC, Seuring (2012) refers that the balance between the three pillars offers the major challenge in any level of decision (from strategic to operational), with the social dimension being the less researched and developed, and predicting a long way to achieve the SSC as previously defined.

Considering the modelling of SSC, Tang & Zhou (2012) have shown that the main research focus on the company exclusively and on the environmental dimension. They criticize the measures used to evaluate the environmental performance, which are based on regulation, not taking into consideration the consumers pressures towards greener products and processes. Similar aspects are pointed out by Seuring (2012), who also highlights the lack of study on the social dimension given the difficulties on measuring and modelling the impact on society.

This author depicts that the environmental dimension is mainly assessed through Life Cycle Assessment (LCA) methods; the economic aspects are portrait based on total costs or profits; the social dimension does not present a common pattern in terms of measures followed; and, when several dimensions are combined, the solutions are achieved through trade-offs analysis. Eskandarpour et al. (2015) reinforce those ideas adding the need to create more general indicators for the environmental performance evaluation and to elaborate measures for the social dimension assessment.

Seuring (2012) verifies the minor investigation on green thinking integration into traditional (forward) SC, being mainly applied in the closed-loop ones.

The majority of the models presented in the literature are multi-objective, with Multi-Objective Mixed Integer Linear Programming (MOMILP) being the most common approach. Also, the models focus mainly on strategic and tactical decisions, like network design and material flows definition.

Regarding food SC modelling, and, in particular, for frozen food, it is noticeable the lack of literature. Despite the importance of the food industry on the global economy, its performance and impacts have been understudied (Turi et al., 2014).

Concerning the previous research limitations pointed out, in this paper the model presented by Mota et al. (2016) is adapted in order to analyse the case-study considering several scenarios. This work is chosen since it uses more general measures for the various performance dimensions and it allows the support of decisions on network design and material flow, considering many supply chain characteristics, through a MOMILP model.

The present paper intends to analyse the economic, environmental and social performances of a SC given the proposed configurations. The paper is structured as follows: in Section 2, the case study is presented. Then, in Section 3, the mathematical model is described. Followed by the results in Section 4. Lastly, in Section 5, the main conclusions are drawn.

2. Case-study

This paper addresses a case-study of Jerónimo Martins (JM), which is an international group based in Portugal and presents itself as a wholesaler and retailer, with focus on food retail. Without being an exception to the sustainability trend, JM has been trying to optimize its SC. In particular, the group is looking for ways of improving its frozen supply chain in Portugal, through network design and planning restructuration, aiming for higher efficiency, lower costs and a healthier relationship with the environment and the concerning society. Hence, new locations and configurations for the warehouses (WH), as well as the respective flows, are brought to light, without forgetting the need to satisfy the demand.

Currently, JM's frozen supply chain includes three WHs, in the districts of Porto, Lisbon and Faro and a assortment of almost 2000 products. In detail, those warehouses differ in terms of dimensions, stores supplied and products stored, as so:

- Porto: the only WH that stores all the assortment, with $6000m^2$, it supplies all the stores with slow movers and with fast movers the stores in the northern region;
- Lisbon: it mainly stores fast movers in order to satisfy the demand from the stores in central Portugal for such products and receives, through transhipment from the previous WH, the slow movers which, later, delivers to the same set of stores; this facility has $1600m^2$ and it is the only that does not belong to JM, being an outsourced warehouse;
- Faro: the smaller facility, with $1250m^2$, it only stores fast movers to satisfy the demand on those products from the southern stores, receiving the slow movers from the northern WH, like in the Lisbon's warehouse.

The presented configuration the SC is being challenged with the reach of its own capacity as well as the increasing number of stores to satisfy. Hence, on the present paper new configurations are put to test considering changes in:

- Location, contemplating the existing ones and the new ones selected based on geographical distribution of demand and stores;
- Assortment stored, where each warehouse can include the complete assortment or allowing transhipment;
- Dimension, depending on the flows and inventory at the warehouse;
- Stores satisfied, allowing different sets of stores assigned to each implemented warehouse.

Such configurations are assessed based on SC's performance at economic, environmental and social dimensions.

3. Mathematical model

3.1. Description of the mathematical model

The mathematical model presented in this work models exclusively the forward SC, since the reverse chain is not considered relevant for decisions intended to support.

Concerning the entities modelled, only WHs and stores are considered, since the activities regarding the WH supplying are responsibility of the suppliers. These entities are defined by its geographical location and related to each other by the distance between them.

As the support of strategic and tactical decisions is intended, it is considered a ten years' interval divided in one year periods.

The products modelled are obtained through item clustering, since it is not computationally possible to model the complete assortment. They are characterized by its dimensions, weight, demand and minimum stock requirements.

The contemplated costs regard the WHs' implementation and operation as well as the distribution of the products.

The model intends to propose a SC configuration in order to satisfy the demand and minimize costs and environmental impacts while also maximizing the social benefits. So, the problem is based on the following data:

- Entities geographical locations;
- WH areas' bounds for each location;
- Distances between the entities;
- Land price at each location for warehouse implementation;
- WH construction costs;
- Operational costs;
- Labour costs and numbers;
- Demand for each representative product;
- Inventory and transportation costs per product unit;
- Dimensions and weight per product unit;
- Distance deviation factor;
- Dimensioning factor considering the products modelled in comparison with the complete assortment;
- Social and environmental indicators.

And seeks to support the following decisions:

- Number, location and dimension of the SC's WHs;
- Products stored at each WH;
- Stores supplied by each WH.

3.2. Model Formulation

3.2.1. Indices

In the present model, for the set definition, were considered the following indices:

- i, j – entities;
- m – products;
- t – time units;
- c – ReCiPe Midpoint impact categories;
- p – PEF impact categories.

3.2.2. Sets

In order to establish the SC superstructure, the sets were defined. Such structure allows the further model development, implying the objective functions, as well as the problem imposed constraints.

Entities

The modelled supply chain divides the entities into warehouses and stores. All the entities are included in the set I, which is subdivided into:

- I_w – locations of the WH, $i \in I_w \subseteq I$;
- I_m – locations of the stores, $i \in I_w \subseteq I$.

Products

Each representative article is identified by the m index, belonging to the M set.

Time

The elements of the time scale are defined by the t index and belong to the T set.

Environmental Impacts

For each LCIA methodology analysed were defined the following categories sets:

- C – impact categories for ReCiPe Midpoint methodology, $c \in C$;
- P – impact categories for PEF methodology, $p \in P$.

Allowed entities connections

In order to establish the relations between the several entities modelled the following sets were defined:

- U – connections allowed between WH belonging to I_w and stores from I_m, $U = \{(i,j): i \in I_W \wedge j \in I_m\}$;
- A – the assumed supplying activity, as result of the suppliers' omission, is defined as connection within each WH, $A = \{(i,i): i \epsilon I_w\}$;
- R – transhipment activity performed between WH, $R = \{(i,j): i,j \epsilon I_w, i \neq j\}$:
- Q – connections allowed between all entities, $Q = U \cup R$.

Allowed product-entity connection

The possible connection between entities and products are defined by the following sets:

- V – allowed connection between WH from I_w and products of M, $V = \{(m,i): m \epsilon M \wedge i \epsilon I_w\}$;
- S – allowed connection between stores from I_m and products of M, $\{(m,j): m \epsilon M \wedge j \epsilon I_m\}$.

Allowed flow of products between entities

The flows established between the several entities are presented by the following sets:

- F – connection between the possible link WH-store and the link between such entities and the products, $F = \{(m,i,j): (m,i) \epsilon V \wedge (m,j) \epsilon S \wedge (i,j) \epsilon U\}$;
- B – assumed set that connects each WH to itself and the allowed links WH-product, $B = \{(m,i,i): (m,i) \epsilon V \wedge ((i,i) \epsilon A\}$;
- O – flow associated to transhipment activity, $O = \{(m,i,j): (m,i) \epsilon V \wedge (m,j) \epsilon V \wedge (i,j) \epsilon R\}$;
- N – connection between all the entity-entity and entity-product links, $N = F \cup O$.

3.2.3.Parameters

Entity

- $ia_i^{máx}$ – maximum area for WH implementation in location $i, i \epsilon I_w$;
- $ia_i^{mín}$ – minimum area for WH implementation in location $i, i \epsilon I_w$;
- $il_m^{máx}$ – maximum stock level allowed for product $m,\ m \in M$;
- $il_m^{mín}$ – minimum stock level allowed for product $m, m \in M$;
- it_i – cost of land per square meter of location $i, i \epsilon I_w$;
- ic – construction cost for a warehouse per square meter;
- w – number of non-specialized workers needed per square meter;
- wc_t – cost per non-specialized worker, for unit time $t, t \in T$;
- $staff$ - number of specialized workers needed per square meter;
- fwc_t – cost per specialized worker, for unit time $t, t \in T$;
- uc_t – operational costs per square meter installed, for unit time $t, t \in T$;
- $dimprod$ – warehouse dimensioning factor based on the flows volume considered;

Product

- dem_{mjt} – demand of product m at the store j, for unit time t, $j \epsilon I_m,\ m \in M\ and\ \ t \in T$;
- apu_m – required storage area per unit of the product m, $m \in M$;
- $apuh_m$ – required handling area per unit of the product $m, m \in M$;
- $mass_m$ – unit's weight of the product m, $m \in M$;
- inc – inventory cost per product unit;
- ctr– transportation cost per product unit and kilometre (with only one driver per truck);

Environment

- iat_c – impact characterization factor for transportation activity, considering the ReCiPe Midpoint impact category c, $c \in C$;
- iai_c – impact characterization factor for warehouse implementation, considering the ReCiPe Midpoint impact category c, $c \in C$;
- η_c – normalization factor for ReCiPe Midpoint impact category c, $c \in C$;
- iat_p – impact characterization factor for transportation activity, considering the PEF impact category p, $p \in P$;
- iai_p – impact characterization factor for warehouse implementation, considering the PEF impact category p, $p \in P$;
- η_p – normalization factor for PEF impact category p, $p \in P$.

Social

- Em_i – normalized indicator for unemployment rate in location i, $i \epsilon I_w$;
- Pop_i – normalized indicator for population density in location i, $i \epsilon I_w$;

Others

- d_{ij} – distance between the locations' entities i and j, $(i,j)\epsilon I_w$;
- $distmax$ – maximum distance allowed per driver;
- $cond$ – percentage of transportation cost increase due to use of extra driver per truck;
- $desvio$ – distance deviation factor.

3.2.4.Variables

Binary variables

- $x_i = 1$ if a WH is implemented at the location i and $x_i = 0$ otherwise, $i\epsilon I_w$.

Continuous and non-negative variables

- AI_i – installed area for the WH implemented at location i, $i\epsilon I_w$;
- CI_{it} – installed capacity for the WH implemented at location i, at the unit time t, $i\epsilon I_w$ and $t \in T$;
- IP_{mit} –product m inventory in the WH implemented at the location i, at the unit time t, $(m,i) \in V$ and $t \in T$;
- $IPin_{mi}$ – product m initial inventory in the WH implemented at the location i, $(m,i) \in V$;
- Z_{ijmt} – flow of the product m moved between the entities i and j, at the unit time t, $(m,i,j) \in O$ and $t \in T$;
- E_{iimt} – assumed flow of the product m supplying the warehouse i, for unit time t, $(m,i,i) \in B$ and $t \in T$;

Auxiliary variables

- y – supply chain's total costs considering the decisions achieved with the proposed model;
- $ctransp_{i,j}$ – transportation cost per product unit and kilometre, depending on the distances between i and j;
- $ImpAmb$ – environmental impact indicator for the modelled supply chain;
- Emp – social performance indicator based on unemployed rate;
- Pop – social performance indicator based on population density

3.2.5.Mathematic Formulation

Taking into account the problem's characteristics and using the above sets, parameters and variables, the model is formulated below.

Objective functions

As a sustainable supply chain model, for each dimension of the sustainability one or more objective functions were defined:

Economic dimension:

$$\min y = \sum_{i\in I_w}(it_i \times AI_i + ic \times AI_i) + \sum_{\substack{i\in I_w\\ t\in T}} w \times wc_t \times AI_i + \sum_{\substack{i\in I_w\\ t\in T}} staff \times fwc_t \times AI_i + \sum_{\substack{i\in I_w\\ t\in T}} uc_t \times AI_i + \sum_{\substack{(m,i)\in V\\ t\in T}} inc \times IP_{mit} \times dimprod + \sum_{\substack{(m,i,j)\in N\\ t\in T}} 2 \times \frac{d_{ij}}{1-desvio} \times ctransp_{ij} \times Z_{mijt} \times dimprod \quad [1]$$

$$ctransp_{ij} = \begin{cases} ct, & se\ 2 \times \frac{d_{i,j}}{1-desvio} \le distmax, \\ (1+cond) \times ct, & se\ 2 \times \frac{d_{i,j}}{1-desvio} > di. \end{cases} \quad [2]$$

- Environmental dimension:

$$\min ImpAmb = \sum_{c\in C}\eta_c \left(\sum_{t\in T}\sum_{(m,i,j)\in O} iat_c \times mass_m \times 2 \times \frac{d_{ij}}{1-desvio} \times Z_{mijt} \times dimprod + \sum_{i\in I_w} iai_c \times AI_i\right) \quad [3]$$

- Social dimension:

$$\max Emp = \sum_{i\in I_w} Em_i \times staff \times AI_i + \sum_{i\in I_w} Em_i \times w \times AI_i \quad [4]$$

$$\max Pop = \sum_{i\in I_w} Pop_i \times staff \times AI_i + \sum_{i\in I_w} Pop_i \times w \times AI_i \quad [5]$$

Subject to

$$\sum_{i\in I_w} IPin_{mi} = il_m^{mín}, m \in M \quad [6]$$

$$E_{iimt} + IP_{mi(t-1)} = \sum_{j\in I_m} Z_{ijmt} + IP_{mit}, i \in I_w \wedge m \in M \wedge t \in T \quad [7]$$

$$\sum_{i\in F} Z_{ijmt} = dem_{mjt}, j \in I_m \wedge m \in M \wedge t \in T \quad [8]$$

$$\sum_{i\in V} IP_{mit} \le il_m^{máx}, m \in M \wedge t \in T \quad [9]$$

$$\sum_{i\in V} IP_{mit} \ge il_m^{min}, m \in M \wedge t \in T \quad [10]$$

$$AI_i \le ia_i^{máx} \times x_i, i \in I_w \quad [11]$$

$$AI_i \geq ia_i^{min} \times x_i, i \in I_w \quad [12]$$

$$AI_i \geq \frac{CI_{it}}{dimprod}, i \in I_w \wedge t \in T \quad [13]$$

$$CI_{it} = \sum_{m \in V} apu_m \times IP_{mit} + \frac{\sum_{(m,j) \in O} apuh_m \times Z_{ijmt}}{52}, i \in I_w \wedge t \in T \quad [14]$$

$$\sum_{t \in T} \sum_{(m,j) \in O} Z_{ijmt} \geq x_i, i \in I_w \quad [15]$$

The economic performance of the modelled SC is assessed in equation [1], where the SC's total costs are minimized. The costs included in the previous equation are:

- First and second terms: the costs due to WH implementation (land purchase and installation construction) depending on the implemented area;
- Third and fourth terms: determine the costs with the non-specialized and specialized workers, respectively, which depends on the WHs dimensions;
- Fifth term: the operational costs are calculated depending on the WH implemented area, as well;
- Sixth term: the inventory costs are represented, with base on the several inventories registered over time;
- Seventh term: describes the costs with the transportation activity, depending on the flows, the cost of transportation per product unit and the distances travelled. The equation [2] determines the cost of transportation depending on the distance between the entities.

The SC's environmental impact is evaluated in the equation [3], where the impacts of the WHs implementation and transportation activity is taken into account. On the presented model, only the ReCiPe Midpoint approach is represented. However, a similar structure is applicable to the other methodologies analysed in this work, concerning the categories and normalization factors.

The equations [4] and [5] measure the social impact considering the unemployment rate and population density indicators, respectively. Both of them depend on the number of workers employed at the implemented WHs.

The remaining equations define the imposed constraints. The equation [6] guarantees the minimum stock established for each product in the sum of all the implemented WHs.

The equation [7] defines the material balance, where the sum of all inbound flows and the existing stock must be equal to the sum of the outbound flows plus the remaining stock.

The constraint [8] assures that all the demand in each unit time is satisfied. In this problem, non-satisfied demands aren't allowed.

The following constraints, [9] and [10], establish the upper and lower bounds, respectively, to the allowed stock at the WHs for each modelled product at each time period.

The equations [11] and [12] define the maximum and minimum limits to the WHs' implemented area.

The constraint [13] guarantees that the implemented area supports the maximum capacity needed through all the time periods. This equation also takes into account the dimensioning factor, which allows the conversion of the calculated area to the real needed area, considering not only 80% of the flows, but the entire assortment.

The equation [14] determines the WH capacity (area) needed for each time period, depending on flows and inventory and space occupied per unit in each case.

Lastly, the constraint [15] assures that a WH might only be opened if there are material flows going through it.

4. Results

The model described above was applied to the case study presented in section 2. In order to study possible optimizations to the SC, several sets of scenarios were analysed and compared, including: scenarios considering exclusively the current locations; scenarios with total costs minimization and all locations possible; environmental impact minimization scenarios; social benefit maximization scenarios. The three last sets of scenarios consider not only the current locations, but also those obtained through a procedure based on geographic distribution of demand and stores and squared meter costs criteria, establishing 6 new possible locations for WH implementation.

4.1. Real case and adaptation scenarios

These scenarios intend to represent the current situation and possible modifications to it, considering exclusively the three existent locations. As so, three scenarios were modelled, considering cost minimization:

- Scenario A: the real SC, described by the table 1. However, as the model must satisfy all the demand and since the current areas are not enough, it was discussed with JM the increase of capacity in MARL, as it works over its capacity and it is an outsourced installation.

Table 1: Scenario A supply chain design.

WH	Vila do Conde	MARL	Algoz
Area (m^2)	6.000	1.800	1.250
Stores supplied	39%	52%	9%
Products stored	All	Fast movers	Fast movers

- Scenario B: by considering the current WH locations and excluding their area and supplied stores restrictions, through costs minimization, it was obtained the supply chain design presented in table 2. In this element it is noticeable the dimensions and percentage of supplied stores difference between the WHs Vila do Conde and MARL, when compared with scenario A. The rationale behind this result is the minimization of the distances between WH and stored supplied by it, as well as the storage of the complete assortment at every WH, in order to diminish/eliminate the transhipment, resulting on a more cost effective supply chain design.

Table 2: Scenario B supply chain design.

WH	Vila do Conde	MARL	Algoz
Area (m^2)	3.332	4.220	1.344
Stores supplied	42%	49%	9%
Products stored	All	All	All

- Scenario C: by considering the same dimensions and stores supplied by each WH as in A, but allowing MARL to store the complete assortment, instead of only fast movers, it was obtained the same design as presented in table 1. Such result is justified by the fact that it considers the same areas as in A, in particular, in MARL, which, even without the fast movers restriction, only stores this type of products, as it doesn't have enough space to store all products. The model allocates the fast movers to MARL, as it minimizes the total costs and these products have a higher impact on the transportation costs due to the higher flows associated to them.

Comparison among A, B and C:

By analysing the performance of the previous scenarios in the several dimensions, presented in table 3, it is clear that B performs better in the economic and environmental dimensions. This fact is a result of the absence of the area and stores supplied constraints in B, allowing the SC design's restructuration to minimize the transportation impact on the first two dimensions, through travelled distances reduction. In the social dimension, A/C have a greater benefit considering the unemployment rate indicator, since it has WH with bigger areas in regions with higher unemployment rates. However, B presents a higher social benefit in terms of population density as it installs higher areas in MARL and Algoz, which have lower densities.

Considering exclusively the economic dimension, table 4, it is visible the greater impact of the transportation costs for all scenarios, since the current analysis considers a ten years' period, devaluing the implementation costs impact. So, the present work unveils that a higher initial investment due to more expensive regions or more WH installed, can compensate on the long term if it allows a transportation costs reduction.

Table 4:Performance of scenarios A, B and C.

Scenarios	A/C	B
Total cost (€)	70.836.039	54.078.721
Environ. Impact (ptos)	61.990,56 (=48.657,56 + 13.333,00)	38.413,51 (=28.255,19 + 10.158,32)
Social Benefit (unemploy. rate)	100,738	96,020
Social Benefit (pop.density)	36,856	41,638

In the table 4, it is highlighted the reduction in B's activity costs (2 to 6) due to total WH area and travelled distances reduction, allowed by its supply chain design. In particular, B allows a reduction by 45% of the transportation costs present in A and C.

Table 5: Economic performance of A, B and C.

Costs (€)	A/C	B
1.Implementation	7.044.451	7.057.926
2.Non-specialized workers	6.219.794	6.113.460
3.Specialized workers	4.022.639	3.953.868
4.Operational	9.233.715	9.075.855
5.Inventory	8.046.281	8.046.281
6.Transportation	36.269.160	19.831.330

4.2. Economic dimension scenarios

These scenarios consider all locations possible and the total costs minimization, differing by the use of dimension and maximum number of WHs constraints.

- Scenario D: without considering any extra constraint, the obtained design is presented in table 5. It is noticeable the implementation of 7 WHs and that all store the complete assortment. Also, it is clear a proportional relation between WH area and the percentage of stores and demand supplied. Such supply chain design is justified by the minimization of travelled distances performed by the model, reducing the impact of the costs of this activity, which has the greatest impact on the total cost.

Table 3: Scenarios D and E supply chains' design.

Scenario	WH	Aveiro	Braga	Sintra	Barreiro	MARL	Vila do Conde	Algoz
D	Area (m^2)	1200	1000	1057	1486	1734	1418	1000
	Stores supplied	15%	11%	11%	16%	20%	18%	9%
E	Area (m^2)	-	1000	1063	1236	6000	1600	1250
	Stores supplied	-	13%	12%	15%	32%	18%	10%
D,E	Products stored	All	All	All	All	All	All	All

- Scenario E: by fixing the real areas of the existent WHs, precluding their expansion, the design obtained is presented in table 5. As visible, the considered supply chain includes 6 WHs, including the current ones, with the complete assortment, in response of the model's minimization of the transportation costs.

In this scenario, the current WHs store all the products, but supply a smaller number of stores, resulting in capacity excess at these WHs. Furthermore, with the imposed areas for the current WHs and a minimum area of 1000 m2 for any WH, in this scenario, the transhipment is amplified, when compared with the remaining, to allow a more efficient space use.

- Scenario F: considering the restriction of a SC with 3 WHs at maximum, the SC's design is described as presented in table 2, since it is the same as the obtained in B.

Such constraint was modelled, since the current model doesn't consider any constraint from suppliers like minimum quantity order or in which WH they deliver to. Also, with the transportation costs between suppliers and WHs being supported by the firsts and the lack of interest from JM in implementing more than 3 WHs, it is considered unrealistic, for a near future, the implementation of more than 3 WHs.

The obtained SC design considers only the current locations, among all possible, meaning that for the present SC those locations are the more suitable, when minimizing costs, but with different dimensions and stores supplied.

Comparison among D, E and F:

Regarding the performance of these scenarios in the different dimensions, table 6, scenario D presents the best performance in the economic and environmental ones, since it considers less constraints, allowing a further cost minimization, through travelled distance and so transportation impact reduction. In the used modelling, the cost minimization favours the environmental impact reduction, as transportation represents the biggest factor in both, when ReCiPe Midpoint methodology is considered.

The scenario E has the highest social benefit in both indicators, since it contemplates the greatest implemented area in total, employing more workers. In contrast, D has the lowest social benefit, due to implementation of greater WHs in regions with lower unemployment rates and higher population density.

Focusing in the economic performance, table 7, D has lower overall costs, opposing to E, which presents the highest values for most costs. The reasoning behind D's costs is the greater distance reduction, which further reduces transportation costs. On the other hand, the results from E are due to the higher implemented area in the SC.

Table 6: Performance of scenarios D, E and F.

Scenarios	D	E	F
Total costs (€)	48.191.592	59.093.911	54.078.721
Environ. Impact (ptos)	30.241,54 (=20.083,22 + 10.158,32)	35.957,95 (=22.084,03 + 13.873,92)	38.413,51 (=28.255,19 + 10.158,32)
Social benefit (unemploy. rate)	94,627	133,134	96,020
Social benefit (pop.density)	34,229	41,765	41,638
Nr. of WHs	7	6	3

However, E has a lower transportation cost than F, which, in the long run, can overcome the implementation costs impact, turning E more favourable than F in terms of costs and environmental impact.

Table 7: Economic performance of D, E and F.

Costs (€)	D	E	F
Implementation	6.904.470	9.412.070	7.057.926
Non-specialized workers	6.113.460	8.349.573	6.113.460
Specialized workers	3.953.868	5.400.069	3.953.868
Operational	9.075855	12.395.520	9.075.855
Inventory	8.046.281	8.046.281	8.046.281
Transportation	14.097.660	15.490.400	19.831.330

4.3. Environmental dimension scenarios

In these scenarios are considered two LCIA methodologies: ReCiPe Midpoint and Product Environmental Footprint (PEF), in order to analysed the SC design variation with their use.

- Scenario G: considers the ReCiPe Midpoint, with a hierarchical perspective, which is the neutral scenario as it guides the environmental impact criteria decisions based on experts' opinions.
- Scenario H: differs from the previous scenario, since it follows the egalitarian perspective, where nature is seen as fragile and ephemeral, assuming a preventive management style.
- Scenario I: assumes an individualist perspective, which is prone to risk and uses an adaptive management style, believing in the nature beneficial behaviour.
- Scenario J: considers the PEF methodology, which intends to facilitate the results interpretation, by focusing in certain impact categories.

Table 8: Scenarios G, H, I and J supply chains' design.

Scenario	WH	Aveiro	Braga	Sintra	Barreiro	MARL	Vila do Conde	Algoz
G	Area (m^2)	1232	1000	1080	1157	1917	1509	1000
	Stores supplied	15%	10%	11%	15%	22%	18%	9%
H	Area (m^2)	1238	1000	1089	1163	1902	1502	1000
	Stores supplied	15%	10%	11%	15%	22%	18%	9%
I	Area (m^2)	1235	1000	1083	1163	1908	1505	1000
	Stores supplied	15%	10%	11%	15%	22%	18%	9%
J	Area (m^2)	1200	1000	1046	1138	2015	1450	1046
	Stores supplied	15%	10%	11%	15%	22%	18%	9%
G,H,I,J	Products stored	All	All	All	All	All	All	All

Comparison among G, H, I and J:

The SCs' configurations obtained with the minimization of the environmental impact for the previous scenarios are summarized in table 8. With this element, it is noticeable the similarity of SCs' design among scenarios, registering only small area variations. These results are motivated by the minimization of the transportation environmental impact, since, for G, H and I, it is the greatest impact, and for J, although is not the main impact, it is the only one that can be further reduced, since the implementation impact reaches its minimum as the required capacity (area) is implemented. The small area variations for the different WHs are due to model liberty when minimizing this dimension, since the optimum can be reach by several SC's configurations.

Lastly, it is evident the environmental impact increase from I to G and G to H, according to the perspective assumed. As the SC's design is similar, the performance in the remaining dimensions is identical across all scenarios.

4.4. Social dimension scenarios

To analyse the impact of social benefit maximization in the SC's design, it was implemented a constraint allowing an increase by 5% in the total costs, in order to avoid unrealistic scenarios. Since the impact in each indicator is not comparable, it was defined the following scenarios:

- Scenario K: considers the maximization of the social benefit based on the unemployment rate indicator.
- Scenario L: considers the maximization of the social benefit based on the population density indicator.

The configurations obtained for both scenarios are presented in table 9.

The element above presents a design with 8 WHs for scenario K, which maximizes the social benefit by installing greater areas in regions with higher unemployment rates. Also, in K, the implemented area surpasses the one in D by 8,5%, since this indicator is also maximized by more workers employed, which are associated with the increased area.

For L, only 7 WHs are implemented and as VNGaia is one of the locations with higher population density, it is not included. This scenario maximizes the social benefit by implementing greater WHs in regions with lower population densities such as MARL and Algoz.

However, both scenarios decrease the SC's efficiency, as they implement excessive area that is not use, increasing the total costs without need, and the greater WHs may not correspond to regions with higher demand, like Algoz in L.

4.5. Comparison between scenarios

To conclude this analysis, it is established a comparison between the scenarios with the best performances and the real case, which means, the A, B/F, D and G scenarios. The best social scenarios are not evaluated due to the needless cost increase associated.

Focusing on the economic performance (figure 1), dimension with greater weight in JM's decision making process, it is noticeable the similarities between all costs, with exception of the transportation costs, which are the smallest in D and G (economic and environmental optimums), leading to 30% total cost reductions, when compared with scenario A.

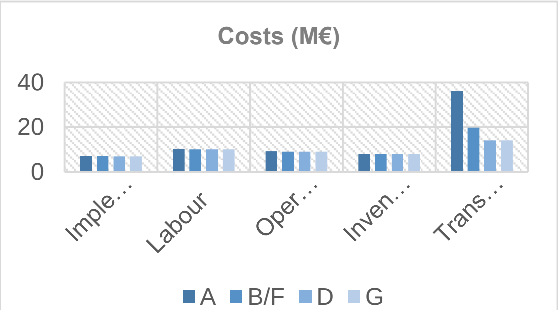

Figure 1: Economic performance for A, B/F, D

However, the SC design in D e G includes 7 WH, which may not be applicable to the real situation due to limitations imposed by suppliers and the reticent JM's perspective on such design. So the scenario B/F comes to light by considering only 3 WHs, although it represents a total costs increase of 12%, when compared with D's, B/F still allows a decrease of 24% of the real case, which is achieved through WH resizing and stores redistribution.

Table 9: Scenarios K and L supply chains' design

Scenario	WH	Aveiro	Braga	Sintra	VNGaia	Barreiro	MARL	Vila do Conde	Algoz
K	Area (m^2)	1088	1000	1000	1348	1796	1284	1143	1000
	Stores supplied	14%	11%	11%	3%	21%	16%	15%	9%
L	Area (m^2)	1225	1000	1000	-	1019	1936	1258	2210
	Stores supplied	15%	12%	10%	-	13%	22%	17%	11%
K,L	Products stored	All	All	All	All	All	All	All	All

Nevertheless, with the majority of the SC designs obtained being characterized by a large number o WHs, it is obvious that such design is encouraging by allowing the reduction of the transportation impact. So, knowing suppliers' limitations, similar designs can be applied if an efficient backhauling system is available, allowing the existant truck empty space rentability for JM and advantageous transportation costs for the suppliers.

4.6. Sensitivity Analysis

In this analysis, the effects of variation in the demand and unitary transportation cost parameters were studied, separately, in order to understand the impact of such parameters in the SC's design. They were selected, since they represent the values with higher uncertainty, due to the global economy and political instability and trends.

For both parameters, its variation doesn't alter the number and location of implemented WHs in D, varying only their dimensions, with exception of Algoz and Braga, that remain with the minimum area, since the capacity is not exceeded. With demand increase the implemented area increases proportionally, as well as the impact on the different dimensions. For transportation cost variation, the total implemented area remains the same. However, with the increase of this cost, the areas change between WHs, to achieve a more efficient SC by reducing the transportation impact.

5. Conclusions

In this paper the redesign of the frozen supply chain of a Portuguese retail company is analysed.

An optimization model was proposed, based on the work developed by Mota et al. (2016).

The developed model intends to support strategic and tactical decisions as number and location of WHs, and which products stored and stores supplied by them.

The results obtained suggest a SC contemplating 7 WHs to satisfy the current needs with the lowest total costs and environmental impact. Nevertheless, if not favourable for suppliers and the company itself, it is highlighted the beneficial results obtained considering a maximum of 3 WHs, which implements 3 WHs in the current locations, proposing, however resizing and store redistribution for each WH, following the demand and store distribution, in order to reduce the transportation impacts.

For future work development a few suggestions arise concerning: suppliers' consideration, products aggregation, transportation model integration and possible scale effects.

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