Supply Chain Design and Planning with Product Return: An Optimization Approach

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Abstract

This paper addresses the design and planning of supply chains with product return. A graph approach is used as the modelling methodology. Commonly, the application of graph approaches to the design of supply chains, considers nodes as chain entities and arcs as connections between them. These assumptions are extended in the present work where products may also be associated with both nodes and arcs. A multi-product network formulation is obtained which is further generalised to consider the modelling of time, resulting in a dynamic multi-product network model with product return.

This generalisation assumes that any node is a transformation point which allows inbound and outbound products to differ. Considering four different kinds of entities (factories, warehouses, sorting centres and customers), proper functions are defined for each one: production, postponement, usage and selection.

An example, base on a Portuguese industry case, is applied in order to corroborate the model applicability and adequacy to real world problems.

Keywords: Supply chain design, MILP model, forward and reverse flows, graph network.

1. Introduction

In Europe, governments are taking the disposal of end-of-life (EOL) products very seriously. As a result, the responsibility for handling these products has increasingly been shifted from consumers to producers. Thus, EOL products can no longer be ignored by companies which might regard them has either an economic opportunity or an environmental liability. In order to remain competitive while meeting this challenge, companies need therefore to develop adequate strategies and adapt their supply chains accordingly (Geyer and Jackson, 2004).

Changes into existing supply chains open a number of questions which require to be answered: Should collection centres be opened? If so, where to place them? How to plan collection? How to re-organize production when used materials co-exist along with brand-new ones? In what ways the new reverse flow may affect the prevailing forward flow?

Over the past decade, the research community has been proposing different models to help answering those questions. However, most published work either treats design and planning independently or is too case dependent. Fleischmann et al. (2001) integrate the forward and reverse flows of a given product within the context of the supply chain design; Jayaraman et al. (2003) discuss several issues related with reverse distribution and propose a formulation for a version of this problem; Fandel and Stammen (2004) propose a general model for extended strategic supply chain management, based on a two-step time structure.

In this work, we go a step further and propose a model that integrates the design and planning aspects within a single formulation. This is achieved through a multi-period formulation, based on a two-time scale. The resulting MILP is an extension of the work presented by Salema et al. (2005) where three different levels of decisions are considered: facilities site location, demand satisfaction and production, distribution and storage planning. Additionally, the main types of products along the supply chain (forward, returned and sub-assemblies) are accounted for, together with the modelling of their bill-of-materials. However, when dealing with forward flows no differentiation is made between brand-new and used components.

The paper is structured as follows. The problem is first described and the model is briefly presented. Then an example, based on an industrial case, is explored. Finally, some concluding remarks are drawn.

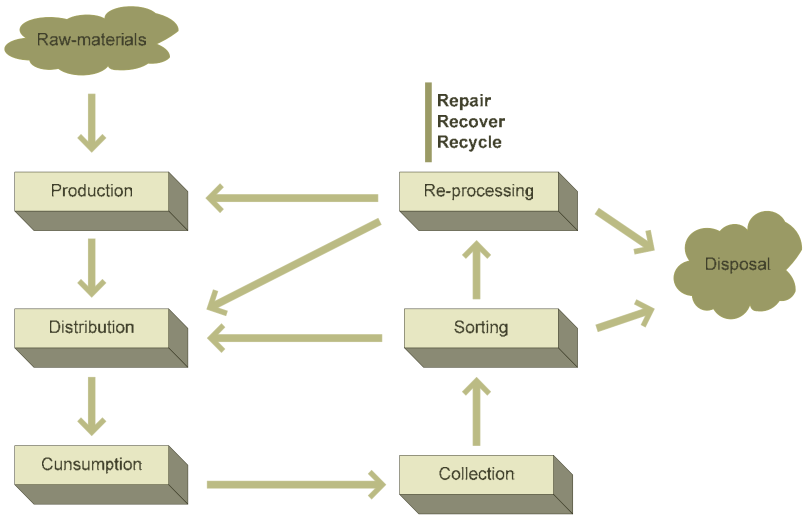

Figure 1: General structure of the supply chain.

2. Problem Modelling

A supply chain structure is formed by different entities with different functions: production, storage/distribution, consumption, sorting, etc (see Figure 1). Each one of these entities involves different material flows and, from their interaction, a multi-product network is obtained.

In this paper, and in order to model such structure, a new graph representation is developed. This representation considers the traditional approach where nodes are network entities connected by arcs and extends it with the addition of time and products.

Products are linked both with nodes and arcs. Acting as transformation points, nodes change inbound products to outbound ones, which mean that they relate two different products. On the other hand, one single product is related to each flow.

Time is modelled considering a management perspective. A given time horizon is divided into strategic time units ("macro" time) for strategic decisions and each macro time unit is then divided into smaller units ("micro" time) where tactical decisions are taken (planning). Therefore, a two interconnected time scale is modelled. For further detail refer to Salema et al. (2005).

The planning considers the production and storage levels along the network flow for each micro period of a given time horizon. Therefore, in each micro time period, a material balance is performed which assures that, in any given entity, the input material plus the existing material in storage must equal the output plus the amount of material that will still remain in storage (Figure 2).

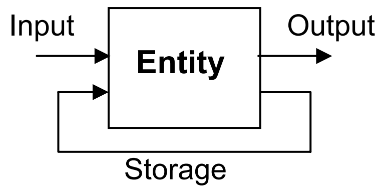

Figure 2: Entity representation.

In traditional deterministic supply chain models, customers have known demand volumes to be satisfied. In this work, since return of material is also considered, customers may also have return volumes to be collected. Therefore, they can be regarded as entities that consume "new" products and produce "returns". After consumption, returns suffer a selection or sorting operation and due to environmental legislation, a fraction of collected products has to be recovered. The model takes this constraint into account.

Summing up, the proposed model can be stated as

Min Global supply chain cost

s.t. Material Balance (for each entity, product and micro time unit)

Demand satisfaction (for each customer, product and macro period)

Returns satisfaction (for each customer, product and macro period)

Environmental constraint (for each sorting centre, product and macro period)

Maximum and minimum production capacities (for each production facility and micro time unit)

Maximum storage capacity (for all entities and micro time unit)

Maximum and minimum flow capacities (for each flow and each micro time unit)

3. Example

This example is based on a supply chain within the glass industry, in Portugal. The supply chain involves four different entities: factories, warehouses, costumers and sorting centres.

Based on the representation presented in the previous section, the supply chain under consideration has the structure depicted in Figure 3.

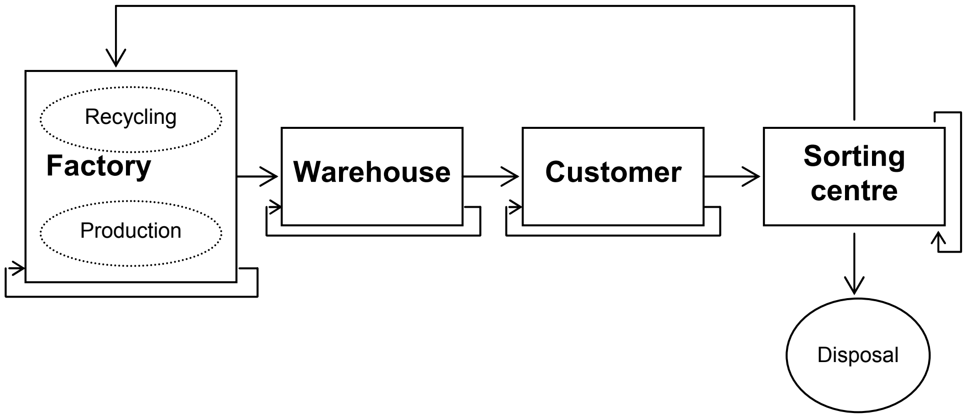

Figure 3: Network schematic structure

Each entity has an inbound and an outbound flow that links it to the previous and the next entity, respectively. Storage is allowed in all entities.

Within the network shown in Figure 3, there are several types of materials:

- M and C, the factory inbound products, which can be either new raw-material products (M) or recovered products from sorting centres (C, eg. glass), i.e., sorting centres outbound products,
- F, the factory outbound products, which are simultaneously inbound to the warehouses,
- A, the warehouse outbound products, which are simultaneously inbound to the customers,
- R, the customers outbound product (or EOL), which is simultaneously inbound to the sorting centres.

Furthermore, in the sorting centres products may be sent back to factories or to undergo to disposal. In the factories apart from the in-coming flow of the sorting centres there is also the suppliers flow associated other raw materials flows.

For the case in study, factories produce three different types of glass recipients, which are differentiated mainly by their colour: green (F_1), white (F_2) and brown (F_3), see Figure 4. These products are sent to associated warehouses where they are subjected to a postponement operation (i.e., packaging) resulting in six different products (A_1 to A_6,). The final products are supplied to customers according to their demand. After use, all products are considered simply as glass (R_1) which is collected by sorting centres. The sorting activity separates glass into white and non-white glass (C_2 and C_1, respectively). Factories or proper disposal are the final destination of these two types of glass.

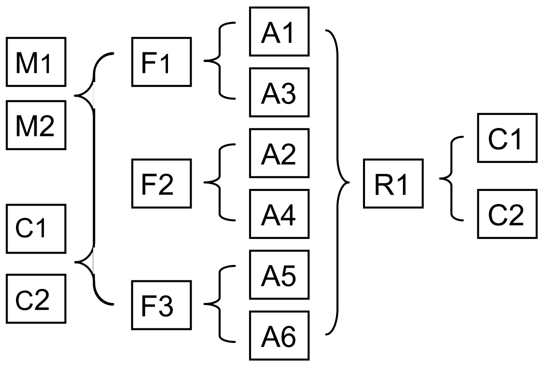

Figure 4: Product relation.

In terms of time, a five year horizon is set as the strategic time. The macro time unit is considered as one year and the micro time as the trimester.

3.1. Data

Due to the strategic nature of the model, customers are grouped into clusters and assign to the district capital. Eighteen customers are considered: Aveiro, Beja, Braga, Bragança, Castelo Branco, Coimbra, Évora, Faro, Guarda, Leiria, Lisboa, Portalegre, Porto, Santarém, Setúbal, Viana do Castelo, Vila Real and Viseu.

Some of these cities are also possible sites to open: factories (Leiria and Porto), warehouses and sorting centres (Braga, Coimbra, Évora, Leiria, Lisboa, Portalegre, Porto, Santarém, Viseu and Vila Real).

Customers have different product needs and, thus, some products are selectively supplied. Demand volumes vary among customers. The maximum and minimum values for the first year are given in Table 1. For the remaining four years an estimated factor, ranging from 0.98 to 1.05, is applied in order to calculate the demand volumes.

Table 1: Maximum and minimum values for the first year demand (in tons).

	A1	A2	A3	A4	A5	A6
Maximum	802	314	748	508	264	207
Minimum	25	18	11	12	49	20

In terms of return, each product has a different return fraction which is given in Table 2. These values remain constant over the time horizon.

Table 2: Products return fraction.

	A1	A2	A3	A4	A5	A6
Return fraction	0.45	0.7	0.5	0.8	0.4	0.9

3.2. Results

The results in terms of network flows are shown in Figure 5 where on the left is represented the forward flow and on the left the reverse flow. The factories are located at the two possible sites provided: Leiria and Porto. These factories supply two warehouses located in the same cities. Four sorting centres are opened: Évora, Leiria, Lisboa and Porto. Warehouses and sorting centres are connected with the factory located in the same city. Évora and Lisboa sorting centres are connected with the Leiria factory.

Comparing the two network flows, the reverse flow appears simpler. The main reason is the different number of products involved in both flows: six different products are supplied, while just one is collected.

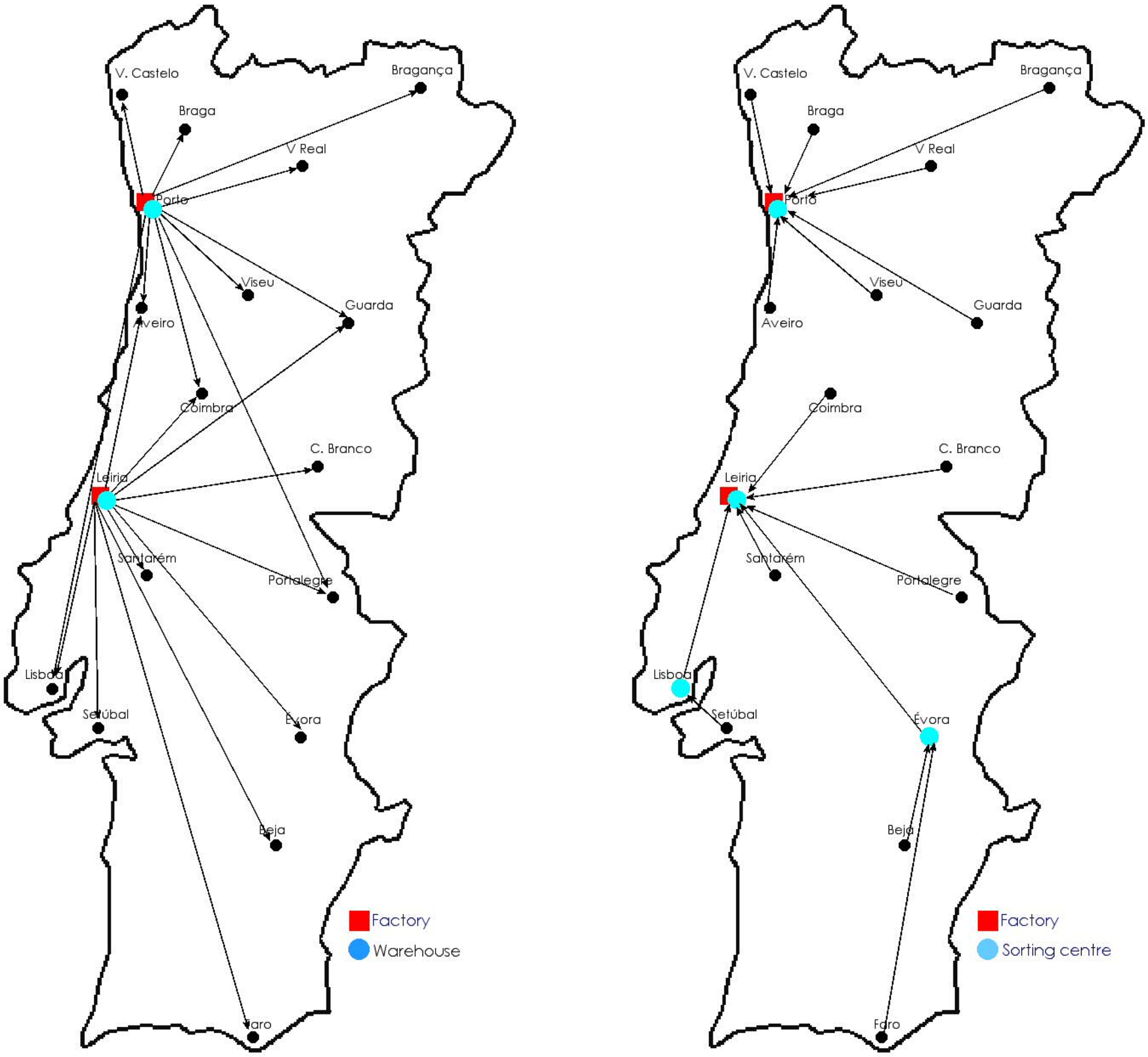

Figure 5: Forward and reverse network flows.

Having described the strategic decisions suggested by the model, there are still several tactical decisions that need to be taken:

1. What is the production plan for the factories?
2. What are the storage police in the factories, warehouses and sorting centres?
3. When, over the time horizon, have customers their needs satisfied? Are these needs entirely satisfied?
4. What is the glass recycling volume and where is it send?

The model gives answers to those questions while simultaneously defines the network. However, as the amount of information is too large only a few examples are given.

The production of each factory is based on two sources of raw materials: the suppliers flow of M1 and M2, as shown in Figure 6 and the return of products from the sorting centres (C1 and C2) as shown in Figure 7

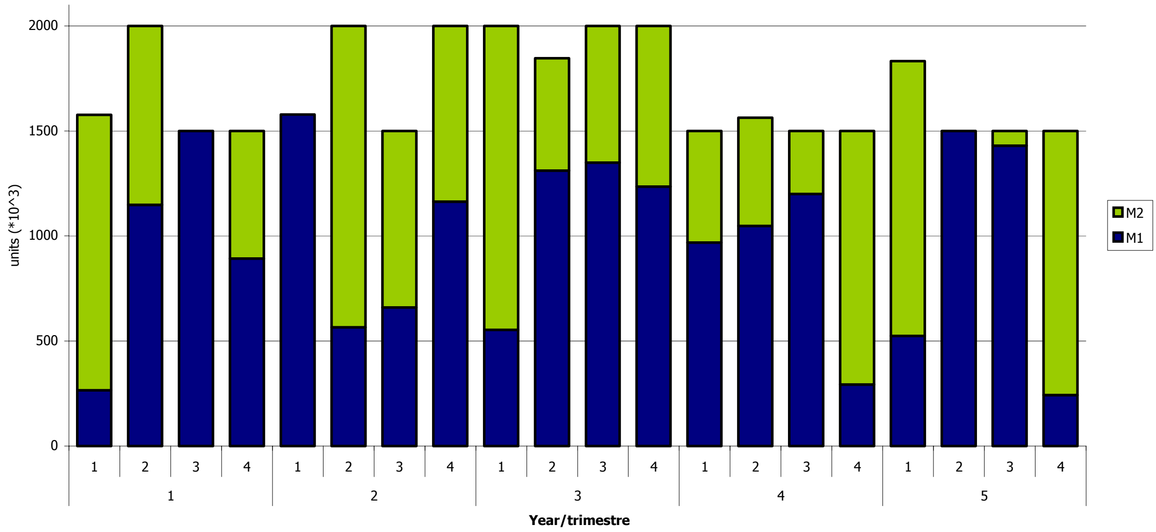

Figure 6: Leiria factory suppliers plan.

In terms of suppliers plan (Figure 6) the contracts are defined between a minimum and a maximum respectively over the fiver year horizon (1500 and 2000 thousand units, respectively). Years 2 and 3 have the higher demand volumes, which lead to the need of higher raw material levels. In years 4 and 5, demand decreases and these level reacts accordingly.

The other component of the inbound flow at the factories comes from the sorting centres located in Évora, Leiria and Lisboa (rEvora, rLeiria and rLisboa, respectively). This flow has an assumed maximum level of 2000 thousand units per trimester and this limit is reached only once (see Figure 7).

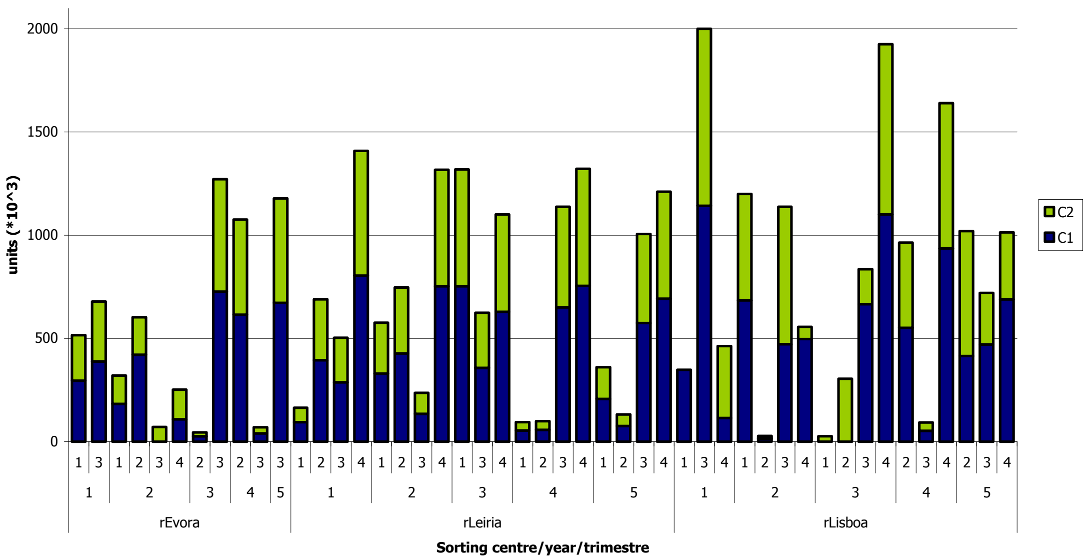

Figure 7: Leiria factory inbound flows.

The flows between factories and warehouses have an assumed maximum level of 2000 thousand units. In Figure 8, and for the case of Leiria one can see that this limit is reached in some years and always stays above 500 thousand units. Due to optimal level of stock in factories being zero and the fact that Leiria factory only supplies Leiria warehouse, the factory production plan is equal to the distribution plan for the only warehouse it supplies (see Figure 8).

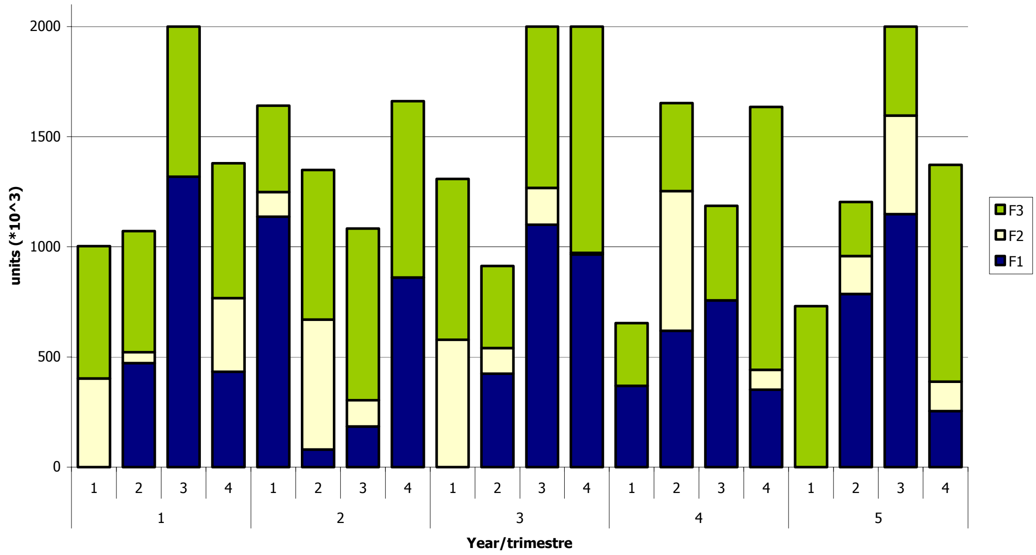

Figure 8: Distribution plan between factory and warehouse located in Leiria.

Because of the postponement activity operated in warehouses, their three inbound products are transformed into six outbound products, whose demand is not equally requested by customers. In Figure 9 two customers supplied by Leiria warehouse are shown: Évora and Lisboa, whose demand is fully met (five and four products, respectively).

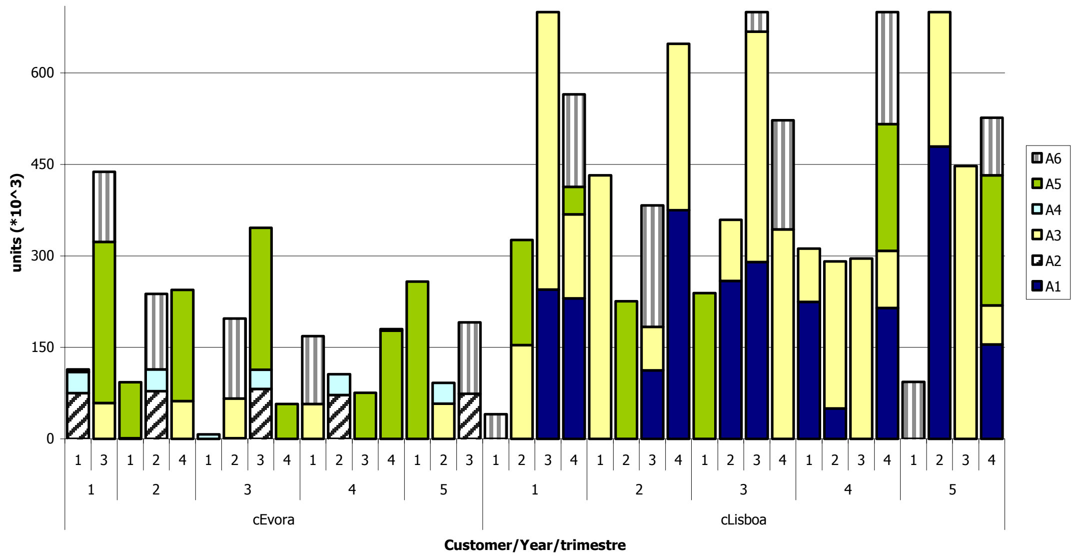

Figure 9: Évora and Lisboa supplying plan.

In terms of EOL return from customers, a single product is considered, glass. Figure 10 shows the collection plan for Castelo Branco and Portalegre customers. The collection plan is different between customers. For instance, Portalegre has returns collected once or twice a year, while Castelo Branco has collections two to three times a year (flow maximum limit is set as 500 thousand units).

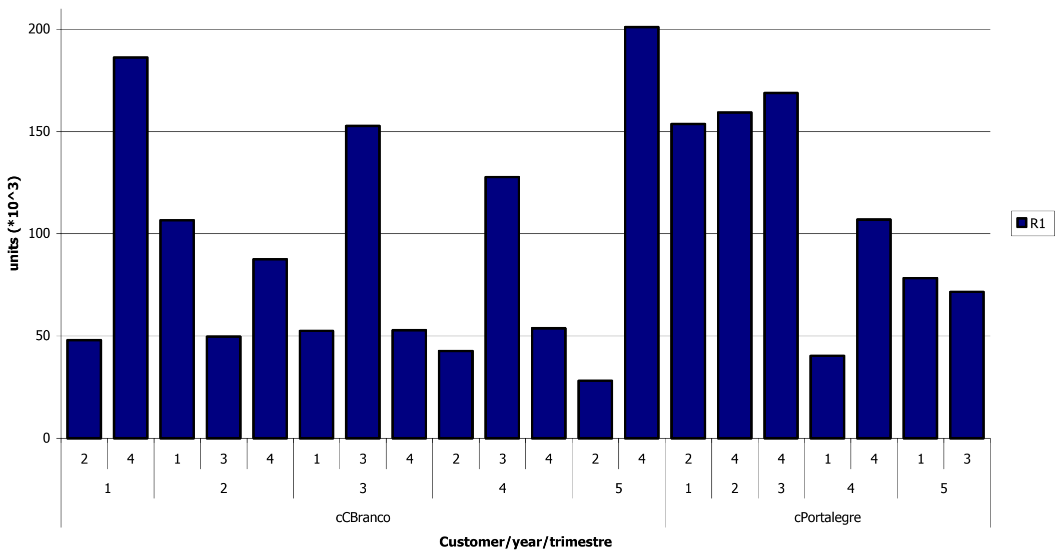

Figure 10: Castelo Branco and Portalegre collection plan.

The last flow that connects the sorting centres to factories and/or disposal is exemplified in Figure 11 . Porto centre recycle all its collected products, while Lisboa sends 20% of each year collected volume to disposal (f0).

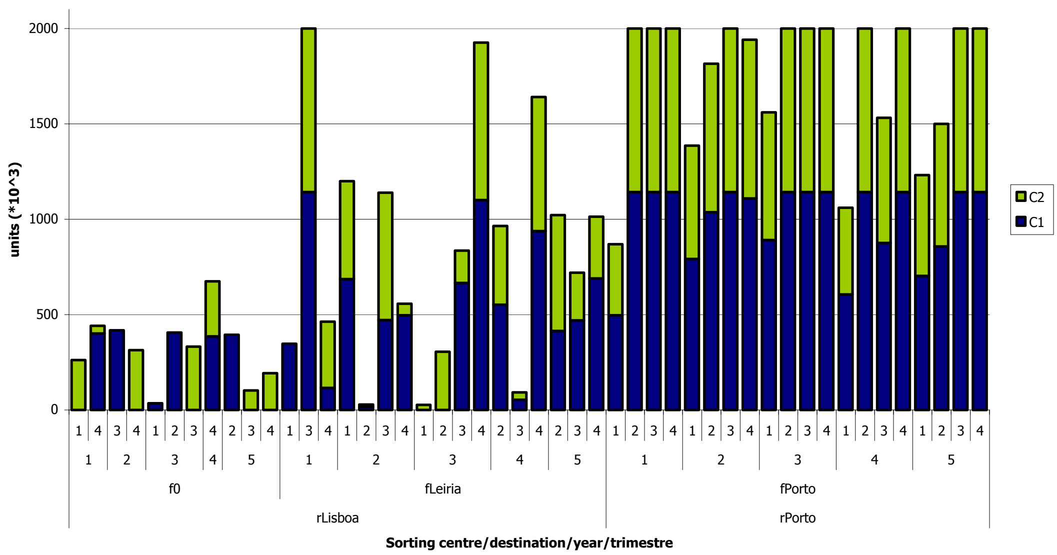

Figure 11: Plan of Lisboa and Porto sorting centre outbound.

In terms of inventory, the model points to a zero stock policy.

Finally, Figure 12 depicts the relation between customers' total demand and the amount not supplied for the case of Faro and Bragança. One can see that, only a small percentage of demand is not supplied to the Faro customer, while Bragança customer demand is only satisfied in about 60 percent.

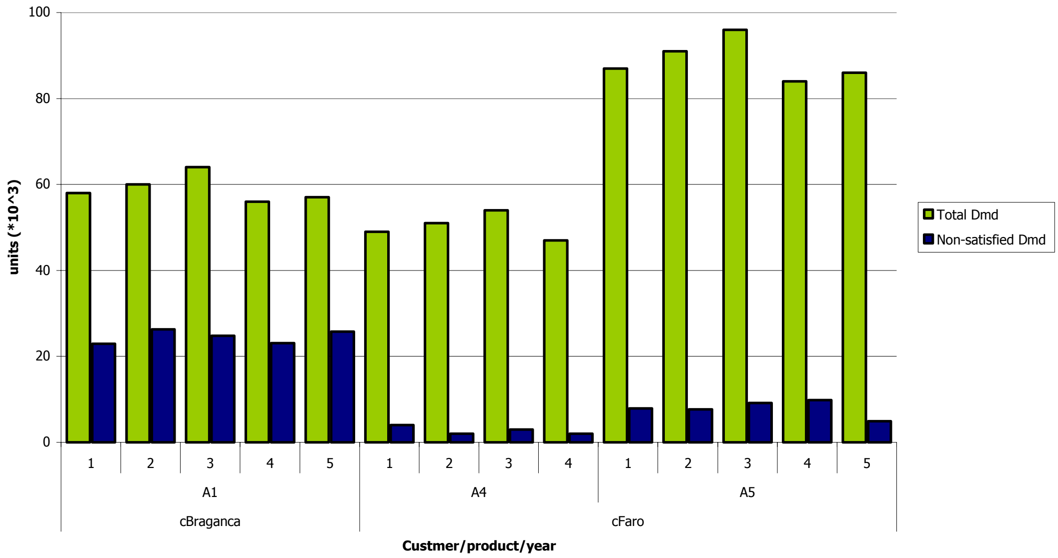

Figure 12: Total demand vs. non-satisfied demand.

The resulting MILP model was solved by GAMS/CPLEX (built 22.0), in a Pentium 4, 3.4 GHz. The model is characterized by 38395 variables (8 022 binary) and 22615 constraints, and took about 240 CPU seconds to solve to optimality. The optimal value found is 7 443*10^3 currency units.

4. Conclusions

In this work, a model for the design and planning of supply chains with returns is proposed. Strategic and tactical decision levels are accounted for. At the strategic level, the network structure is defined while at the tactical level the operations planning (production, warehousing, distribution and sorting) are optimised.

A graph network approach is used to represent both the general supply chain structure and associated planning decisions.

An example, based on a Portuguese industry, is used in order to test the model applicability and adequacy. The results obtained show that the proposed model deals satisfactorily with problems with a considerable degree of detail and complexity.

In conclusion, the proposed model appears as a promising decision support tool to help the decision-making process in the strategic and tactical planning decision levels of multi-product capacitated supply chains with returns. As future work and in order to speed up the solving process, we intend to investigate the application of decomposition methods, either generic or specially developed for the proposed model.

Acknowledgment

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