Optimization of Batteries Sustainable Distribution Network with Reverse Flows

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Abstract

Optimized supply chains, both economically as well as environmentally, are significant instruments to be adopted by companies if they want to succeed in the current competitive world. However, without the support of decision tools to help, at least approximately, the integration of these two aspects in the company's decision making such aim is difficult to reach.

The purpose of this study is to develop a mixed integer linear programming model (MILP), which allows the optimization of closed loop supply chains, considering not only economical aspects, but also environmental ones. The model developed was applied to a Portuguese company where their logistic network structure was redesigned.

Keywords: Close-loop supply chain, economical optimization, environmental optimization, warehouses location.

1- Introduction

Consumers and modern organizations are changing their goals. These are no longer strictly connected to economic factors, quality and level of service. They have also started to look into environmental aspects. The business community increasingly recognizes the significance of products and processes environmental performance. As an immediate consequence, the supply chain management is under transformation process.

Numbers are quite impressive and they represent well this urgency for a change. The increasing emission of GHG (greenhouse gases) into the atmosphere reached menacing and frightening values over the last years. According to the *Stern Report*, in 2006, transportations accounted for 14% of greenhouse gases emissions, from which three quarters are related to road transportation (Stern, 2006). It should be noted there is still a shortness of scientific literature related to the quantification of these emissions for further improvement of supply chains performance (Peacyk and McKinnon, 2009). However, efforts have been made in order to find new ways to optimize supply chains taking this kind of concerns into consideration.

The decrease of products life-cycle, the growing environmental concerns, and a tendency towards the diminishing of profit margins has lead companies to increasingly consider the return of used products. Companies are becoming more aware, or legally obligated, to take responsibility for the entire product life-cycle, including a proper recovery and disposal (Kleindorfer *et al*., 2005).

Literature, concerning the connection of environmental issues with the activities of a supply chain is rather limited. However, this subject has been explored in a some research studies (Bojarski *et al*., 2009). Among the published works, it must be mentioned the work of Duke et al. (2007), which developed a MILP model for the definition of the best supply chain structure transportation routes, taking into account the design of the product process, environmental impacts and economical metrics. Later on, this work was improved, by adding an environmental indicator, the Eco-indicator 99 (EI99), and therefore being able to quantify the supply chain environmental impact. Guillén-Gosálbez and Grossmann (2008) have also proposed a MILP model that considers profits and environmental impacts of a chemical plant supply chain. They access the environmental performance using the Eco-Indicator 99. Neto *et al.* (2007) developed a framework and applied it to the design of a paper industry logistic chain. Profits and environmental impacts of logistic networks are balanced by means of a multi-objective analysis. These authors provide an algorithm for a multi-objective linear problem with three objectives: reduce impacts and costs, and achieve target sets by an EU directive. The CED (Cumulative Energy Demand) was chosen as the environmental impacts indicator.

With the present work, we aim to contribute to the development of a decision tool that allows for the design of supply chains with return flows (*Closed Loop Supply Chains*), taking into account not only the economical aspects, but also the environmental ones. The model developed is then applied to a real case study of a batteries distribution supply chain where reverse flows are also considered.

2- Case Study

The model developed is applied to a Portuguese company, which manufactures and distributes batteries. The company wishes to optimize its logistics network structure considering not only economical performance metrics but also environmental ones.

This logistics network is composed of one factory and twelve warehouses, spread along Portugal. The latter have different features in terms of functions and dimensions. All of these facilities are responsible for the capillary distribution (distribution to costumers from the warehouse) and act as a direct point of sale to the public.

In terms of selling, this company acts as direct points of sale to the public, performs capillary distribution, or sells trough two licensed agents.

Moreover, the company also manages its reverse flow, which means that it collects and sells the end-of-life batteries released by the customers. These reverse flows represent raw materials to produce new batteries.

The transportation of the batteries can be done in two different ways. The primary distribution is outsourced. Subcontracted companies take products between the factory and the warehouses. To deliver batteries to customers, the company uses in-house vehicles (figure 1). By doing this direct supply (and collect when EOL – End Of Life – batteries are available) the company assures that orders are fulfilled within 24 hours after having been placed. This service level is of major importance for the company.

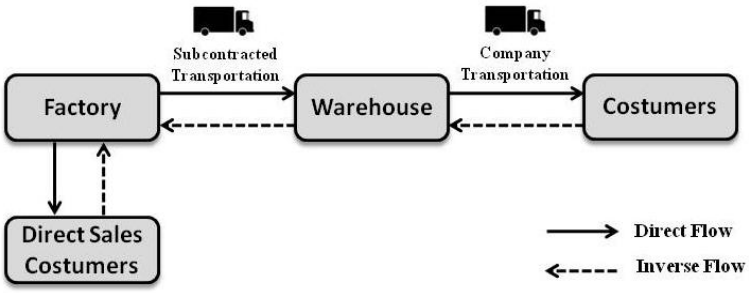

Figure 1: Diagram of company's supply chain.

The current network structure was developed along the years. It now allows the company to achieve their service level targets. However, since this operating structure was not object of a global analysis, the company aims at accessing its economical as well as environmental efficiency. This study will focus on warehouse location while considering the associated activity planning. This will be achieved by means of a MILP model that will be summarized in the next section.

3- Mathematic Model

The developed model was based on the model proposed by Salema et al. (2010). This is a multi-period location model that provides information regarding the supply chain planning. By using a graph representation and since the model integrates both forward (flows from factories to customer) and reverse flows (flows from customers back to factories), it is easily adapted to the context in study. Within this graph representation, nodes act as any entity of a supply chain (factories, warehouses, customers, among others) and arcs establish the link between two nodes, thus defining a flow. The developed model considers three types of entities (factory, warehouses and costumers), each one defined by its geographical location.

The costs and environmental impacts accounted in the model are the following: fixed costs of warehouses and environmental impact associated with its opening, batteries supplying costs and environmental impacts related to their production, costs and environmental impacts associated with the activity of the two fleets (primary and secondary), the amount paid to customers for the EOL products, and transportation costs and environmental benefits to this collecting activity.

The final purpose consists in redesigning the logistic network with the smallest cost and minimum environmental impacts. Therefore two objective functions are defined. On the cost minimization, the objective function considers fixed costs of opening/renting warehouses, the costs of raw materials needed for production, not only acquired from suppliers, but also the raw materials produced by recycling the EOL products purchased from customers. In addition, the transportation costs are estimated differently, depending on the specific flow. For the primary distribution in the forward flow, since it is subcontract transportation, the cost accounts for the distance from the factory to the warehoused and the number of trips performed by the subcontracted company. For the transportation of EOL batteries from warehouses back to the factory, the transportation cost is given by a fraction of its direct cost. In terms of the capillary distribution (between warehouses to the costumers) since the company uses in-house fleet, the cost is proportional to the distance traveled and the number of necessary trips to deliver products. Note that the cost of the vehicle return also adds to this transportation cost. All data used to estimate the above mentioned costs were provided by the company. Due to confidentiality reasons these values can be published. Concerning the minimization of the environmental impacts, the Eco Indicator 99 (Goedkoop and Spriensma, 1999) was the choice for accessing the values. This indicator is based on a Life Cycle Assessment and the final value is a weighted sum of damages in three categories: human health, ecosystem quality and resources.

Each one of the damage categories is analyzed in a similar way to costs. Namely, the environmental objective function considers the effect of entities installation (land-use), the production of batteries, and several terms related with the transportation activity. Since the company does not consider changing the location of the factory, the impact of land-use by the factory is not considered. Regarding the definition of the impacts related to the production of batteries, the impacts considered result directly from the production of batteries having in mind that the recovery of old batteries leads to a reduction in the volume of purchased raw materials. In terms of transportation, the environmental burden comes mostly from gases emissions. All transportation are included, even the primary distributions that is outsourced.

The problem characteristics are modeled through a set of constraints that accounted for:

- Balance of products across all the facilities that represent the supply chain throughout the time;
- Satisfaction of costumers demand;
- Collection of used batteries (limited to a fraction);
- Storage profiles accounting for storage limits;
- Amounts of direct and reverse flows along the chain;
- Installation of new entities when required.

A Mixed Integer Linear Model Program (MILP) resulted. This was implemented in the GAMS software and solved through the CPLEX V.23.5 solver in a Intel (R) Core TM i7 CPU, 6.00 GB, 2.8 GHz. All the values related to the environmental impacts are obtained in the data library of *SimaPro 7.1*.

4- Results

The model previously explained is applied to the case study where both the economical as well as the environmental objectives are considered. Since this the first step of a more deep study, each objective is optimized separately. A bi-objective analysis is the next step to take. Therefore, two scenarios were studied where a distribution network from grassroots was considered. These are compared with the actual network. The first scenario (scenario A1) considered the design of the distribution network for the minimization of an economical function. The second case (scenario A2) designed also the distribution network but in this case the minimization of the environmental impacts was considered. For each scenario, different solutions are obtained. The difference will be below analyzed.

Due to confidentiality reasons, all values presented in this section were modified but they reflect a context similar with the real case.

4.1 Logistics Network

The logistic network achieved in the scenario A1 consists on a logistic structure with 13 warehouses (the same, in number, as the actual network) contrasting with the logistic network in the scenario A2, which has only 8 warehouses.

The location of warehouses for the three networks (current, cost effective and environmental effective) is presented in Figure 2.

The structure of the network A2, compared with the existing network, is rather inferior in the number of warehouses, given the strong environmental impact caused by the opening of warehouses. The opening impact of a warehouse with an average capacity is substantially larger than the impact of other activities, which led the environmental objective function to be extremely sensitive to the opening of such facilities.

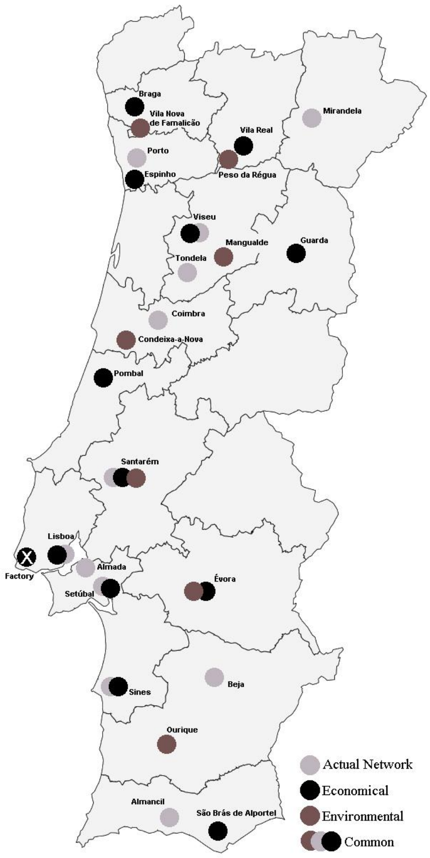

Figure 2: Logistics network obtained

4.2 Costs

As expected, the total cost in the scenario A1 is inferior to the cost of scenario A2. However, the analysis of different types of costs (Table 1) shows some singularities.

Table 1: Cost values for scenarios A1 and A2.

Costs (u.m.)	**A1**	**A2**
Fixed	81404,64	57366
Transp.f1(factory → warehouse)	80348,35	9398,638
Transp.f2+r1 (warehouse ↔ costumers)	177720	791620
Transp.r2 (warehouse → factory)	2630,977	-
Suppliers	1296800	1288800
Bat. Recover	13989,95	17305,95
Total	1652900	2164500

The most sticking aspects are related with transportation costs. The first one is the massive reduction observe in the costs values of Transp. f1, which refers to the forward connection between the factory and warehouses. The value decreases almost 90%. This is explained by the smaller number warehouses open in scenario A2, thus fewer subcontracted vehicles are needed. One second reason not so obvious is related with the supply plans. The scenarios show optimal supplying plans completely different. In scenario A2 (environmental minimization), the warehouse located in the factory processes much more batteries than all other seven warehouses. The reason is the non existence of generation of environmental impacts associated with the transportation between the factory and this warehouse, which for longer distances are associated with large impact values due to the type of transportation used in the primary distribution. This will be later on detailed. Also this connection does not have any cost associated. Since this is the largest warehouse of the company it has enough capacity to serve an enormous amount of demand.

Another consequence is the higher value of the secondary transportation costs (transp. f2 + r1) in the scenario A2 (almost 4 times larger), which is explained again by the smaller number of warehouses opened in scenario A2. Therefore there is a greater need for secondary transportation.

As for the transportation costs from warehouses back to the factory (Transp. r2), we have a curious situation. Apparently, the scenario A2 chooses not to transport the collected batteries from the warehouses to the factory, this essentially due to the environmental impacts as it will be detailed later on. However, costs associated to the collection itself are higher in this scenario, in other words, the company collects more batteries. After analyzing the volume of products sent from the warehouse to the factory in the two scenarios, it is possible to verify that the scenario A2 collects 20% more batteries than the scenario A1. The non-existence of transportation cost related with this flow is explained by the fact that all products are collected by the warehouse located in the factory, which connection has no associated cost.

Finally, the scenario A2 achieves a 1% reduction in raw material costs when compared with the scenario A1, which despite seeming as a residual value, it represents a decrease of 3300 u.m. per year in the company accounts.

4.3 Environmental Impacts

The environmental impact, measured by the eco-indicator 99, in the scenario A2 is naturally smaller than in the scenario A1. However, in order to achieve a 1% reduction in these impacts when compared with the A1 scenario, there was a 30% increase in costs (see Table 2). Cleary this is an unfavorable relation.

Table 2: Environmental impact values for scenarios A1 and A2.

EI99		A1	A2
Warehouses		930	655
Batteries		7890000	7840000
Bat. Recover		- 61110	- 73155
Transp (total)		30180	22500
	Transp.f1(factory → warehouse)	23500	3150
	Transp.f2+r1 (warehouse ↔ costumers)	4350	19400
	Transp.r2 (warehouse → factory)	2330	0
Total		7860000	7790000

The main difference between costs minimization and the minimization of the environmental impacts is related with the extreme importance of the batteries production activity, since the environmental impacts presented by the model in both scenarios are dominated by the impact of production. Although the impact of a single battery is very small when compared, for example, with the impact of opening a warehouse, the total production represents 95% and 99% of the total environmental impact of this supply chain, in the scenarios A1 and A2, respectively.

It is now clear why the scenario A2 collects all the possible EOL batteries. The main difference between the minimization of the two functions lies in this fact. Considering its strong impact in the chain, minimizing the environmental function A2 favors more the collection of batteries than the economical function (A1), therefore the minimization is strongly focused on this reduction. That is why the warehouse located within the factory is essential in scenario A2. The transportation cost for batteries collected at this location is zero since factory and warehouse share the same location. Also the environmental impact between these two points is zero. As a result, the flow of this warehouse is massive and subsequently the secondary distribution increases exponentially, thus creating a huge gap in costs between the two scenarios. Another fact that helps increasing the secondary distribution, rather than the primary, is the small amount of effects that the secondary fleet has (21 times lower than the primary fleet) has on the environmental impacts when compared to the primary distribution.

Regarding the optimal cost scenario, it is possible to achieve a 34% decrease of the transportation impacts in scenario A2. Despite the higher impact created by the secondary fleet in this scenario, the primary offsets it, because it is much less used (flow r2).

In short, scenario A1 privileges the primary transportation with regard to the secondary, since economically that relationship is much more favorable. In scenario A2, one observes the opposite phenomenon due to the associated environmental impacts. Therefore, one may say that it is of advantage to transport less with the sub-contracted fleet in favor the secondary transportation considering its small environmental impact.

Overall it can be said the supply chain when the total cost is at stake has a decentralized structure, while when environmental is the driver, the structure changes to a centralized one.

For a more sustained analysis the values of some parameter should careful analyzed in future work. The above results show that they have a considerable influence on the supply chain structure.

5- Conclusions

The present paper studied the design and planning of a logistics network where both economical as well as environmental aspects are considered. The model is applied to a real logistics network where production, distribution as well as recovery of batteries are considered.

As final results it can be seen that the current operating network can be further optimized not only in terms of costs but mostly in environmental terms. Nonetheless a more deep analysis needs to be performed since both optimal supply chains present very different structures.

The high environmental impact of the primary fleet, combined with the extreme importance of the batteries collected in the model, given the environmental benefits of this activity, entails as the best option the intensive use of the fleet responsible for the secondary distribution. However, these optimal results lead to a supply chain structure that does not favor the service quality policy followed by the company. The agility and flexibility in the delivery of the batteries, key features for the company, could be at risk. Another aspect concerns the costs involved if the optimal environmental structure is chosen. However, the tendency towards centralization without damaging the service level should be considered by the company.

As future work, a bi-objective model is developed to account simultaneously with the minimization of both economical and environmental objectives. Moreover, a careful sensitivity analysis should be performed on several parameters that come out critical in final solutions. Furthermore, given the different structure in both solutions, a bi-objective analysis is the next step to take. This analysis will provide further insight into what is the best compromise solution that the company should follow.

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