Redesigning a global supply chain with reverse flows

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ABSTRACT

In recent years much attention has been given to global supply chains. However, the emphasis has been on forward chains, with reverse flows been insufficiently studied. In this work, we study closed-loop supply chains and analyse the impact caused by the introduction of new facility sites into an already existing supply chain. The model considers both strategic and tactical decisions allowing for the design of a global supply chain with reverse flows. The impact of the network redesign is analysed and the associated costs calculated. The obtained MILP is solved using a standard Branch and Bound solver. The results obtained prove that the proposed model handles satisfactorily the network redesign problem.

KEYWORDS: Optimization, global supply chain, reverse flows, retrofit.

INTRODUCTION

In recent years, society's attitude towards product return issues has been changing, leading to a growing significance of reverse logistics, whereby all fields covered by traditional logistics operations (forward logistics) were extended to address the recover/remanufacture of used products (reverse flow).

One question that is often discussed amongst the scientific community, in relation to this matter, is whether or not such structures should be studied in an integrated form (Goetschalckx et al., 2002). The relevance of this, in a strategic perspective, is related to the somewhat uncertain advantage of considering these two flows simultaneously.

In spite of the growing awareness regarding the issues related to product return, companies and researchers still view reverse logistics as a collection of isolated issues, thus disregarding its associated business opportunities (Guide et al., 2003).

As an immediate consequence, very few strategic models have been published. As the most generalized published models, one should refer to: Fleischmann et al. (2001), who propose a model where a single product was considered and where forward and reverse flows are integrated, with no limiting capacities in the involved facilities and flows; Jayaraman et al. (2003), who studied the reverse distribution problem without taking into account the forward flow; and Fandel and Stammen

(2004), who propose a MILP general model for extended strategic supply chain management based on a two-step time structure, but where no testing of adequacy to any example/case is performed. In all mentioned models, there is no product differentiation and thus the same product flows in both networks.

In this work, we try to analyse the impact caused by considering new facility sites for an existing closed-loop supply chain. The study is based on a model previously developed by the authors (Salema et al., 2004), where the design of the global supply chain with reverse flows is achieved along with strategic and operational decisions. The model results into a Mixed Integer Linear Programming (MILP) formulation, which minimizes the supply chain total cost while determining simultaneously the network structure and the associated production, storage and distribution planning. This is done in a dynamic environment where two time scales are considered: a macro time, where the network structure is designed and a micro time where all production and storage planning is accomplished. A multi-product formulation was adopted, allowing for the differentiation or non-differentiation of returned products when compared to the original products.

Based on a previously published case, the impact of the network redesign is analysed through two different perspectives: physical and financial. In the former the analysis is focussed on facility locations, network flows and production and storage planning, while on the latter the emphasis is placed on costs and revenues.

This paper is organized as follows. Next the problems are described in detail. Then, the case study is presented so as to evaluate network and cost changes and finally, some conclusions and future research directions are drawn.

The MILP model was solved by GMAS/CPLEX (built 21.1), in a Pentium 4, 3.40 GHz.

PROBLEM DESCRIPTION

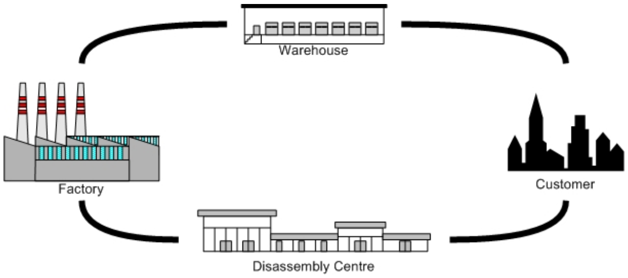

Figure 1: Network structure.

The network considered in this work connects four different entities: factories, warehouses, disassembly centres and customers. The forward chain is composed by factories, warehouses and customers and the reverse chain by customers, disassembly centres and factories. No direct link is allowed between factories and customers in either chain. Figure 1 gives a schematic representation of the described network.

The products flowing in the forward distribution network may be different from products on the reverse chain. This assumption allows the modelling of products that loose their identity after use and, thus, may be grouped into a larger category (for instance, used paper products are simply classified as paper). However, if so required the same product may be tracked down in both networks. Another assumption made is related to the disposal option where each disassembly centre may send collected products to actual disposal, if these are found to be unsuitable for reuse.

Within this framework, two levels of decisions are taken in two interconnected time scales. The one related to network structure is defined at the "macro" time scale, while all other decisions concerning production, storage and distribution planning are taken in the "micro" time scale. These scales can be years/months, years/trimesters, months/days or whichever combination suits the problem. The chosen facilities will remain unchanged throughout the time horizon while the throughput may undergo changes.

Travel times are modelled between network levels. They are defined as the number of "micro" time units needed for a product to flow from its origin to its destination. If travel times are set to zero then a multi-period location/allocation network model is obtained.

Lastly, a profit function is maximized. Transfer and selling prices plus salvage values contribute towards revenue, while several cost terms are considered: opening and operational costs, production, storage, distribution, disposal and penalty costs (for non-satisfied demand or return).

In short, the proposed model can be stated as follows.

Given:

- the opening and operational costs,
- salvage values,
- the amount of returned product that will be added to the new products,
- travel times between each pair of network agents,
- the minimum disposal fraction,
- a cost actualization rate,

and for each macro period and product:

- customers' demand and return values,
- the unit penalty costs for non satisfied demand and return,

and in addition, for each micro period:

- the unit transportation cost between each pair of network agents,
- the maximum and minimum flow capacities,
- the factory production unit costs,
- the facilities unit storage costs,
- the maximum and minimum production capacities,
- the maximum storage capacities,
- the initial stock levels,
- the transfer prices between facilities,
- customers' purchase and selling prices.

Determine the network structure, the production and storage levels, the flow amounts and the non-satisfied demand and return volumes.

So as to, maximize the global supply chain profit.

CASE STUDY

This case was created based on a company that operates in the Iberian Peninsula, whose supply chain is facing demand and return changes in some Portuguese customers and that, as a consequence, needs to examine the possibility of chain structure modifications.

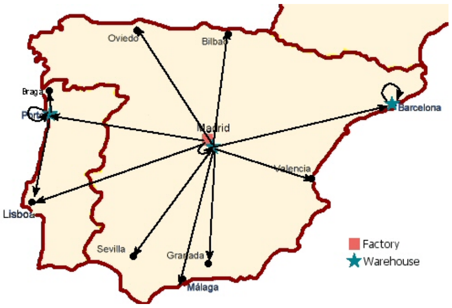

Figure 2: Existing forward chain.

Existing Chain

The company has an already established supply chain with forward and reverse flows that involves a single factory located in Madrid, three warehouses (Barcelona, Madrid and Porto) and two disassembly centres (Madrid and Porto). These facilities serve 11 clusters of customers located in 11 cities. In figure 2 and 3 are shown, respectively, the forward and reverse chains.

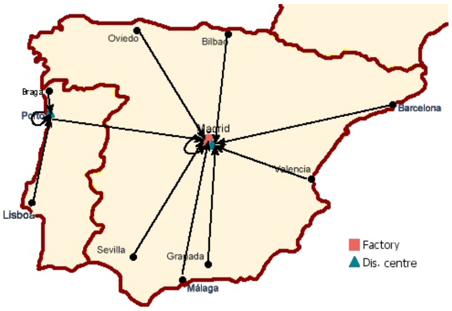

Figure 3: Existing reverse chain.

The supply chain accounts for two forward (F_1 and F_2) and one reverse (R_1) products.

In terms of time scales, the macro time is defined over 5 years and the micro time over 4 trimesters per year: macro time = “year” and micro time = “trimester”.

Since the model considers a horizon of five years, some data has to be estimated. These include the demand and return volumes as well as variations in costs over the years. These estimates were based on some assumptions: transportations costs are proportional to the distance between each city and after the first year an actualization rate of 3% is applied to these and all other costs; if flows cross borders, a tax is applied to the corresponding transportation cost namely, 6% from Portugal to Spain and 3% from Spain to Portugal; in the first year, customers’ demand is made equal to a fraction of the city inhabitants (a value between 0.5 and 0.6) while in the remaining years a variation factor (ranging from 0.98 to 1.05) is considered, allowing for an increase or decrease in the demand value; in each year, customers’ returns is set as a 0.8 fraction of the corresponding total demand. The problem also assumes zero initial stock levels. For product recycling, F_1 and F_2 incorporate each 0.5 of product R_1. The disposal fraction is set to zero and minimum and maximum capacities are defined for production ($11*10^5$ and $9*10^5$, respectively). No limit is imposed on flows and travel times are set to nil. This latter assumption seems reasonable, since travel times between the two countries are of a much lesser order of magnitude than the chosen time scales (years/trimester).

Retrofit Design

As referred to above, the company is facing demand and return changes in some Portuguese customers. On one hand, new contracts have been negotiated with customers located in Coimbra and Lisboa and, as a consequence, a new demand and return site has appeared in Coimbra and Lisboa's demand and return have increased. On the other hand, some customers located at Porto have cancelled their agreements and consequently Porto's demand and return volumes were reduced.

Due to these changes, the company considers a prospective modification in the existing structures. Thus, two new locations, Coimbra and Valladolid, are now being considered for new warehouses and/or disassembly centres. The latter, however, is not a customer location and thus no demand or return is associated to it.

Three scenarios will be considered for this network retrofit study. In scenario I, changes are allowed on warehouses, with both new locations and the possibility of closing existing facilities being contemplated. In addition, the closing of existing disassembly centres is also permitted. In scenario II, the study focuses on disassembly centres modifications and, by analogy with warehouses, new locations and the possibility of closing existing centres is considered, while the closing of existing warehouses is now also allowed. Finally, in scenario III, changes in the number of opened and closed warehouses and disassembly centres are considered. For every scenario the network continues to operate with one single factory whose location remains unchanged.

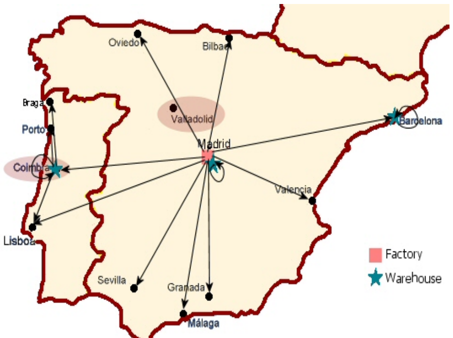

Figure 4: Retrofitted forward network.

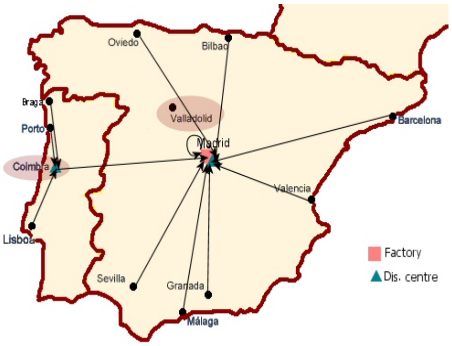

Figure 5: Retrofitted reverse network.

The obtained results are discussed below. Due to paper length limitations, the tactical plan associated with production and storage is only briefly mentioned.

Scenario I

A major change has been observed in the Portuguese forward network: the warehouse located in Porto is closed and all its connections are redirected to a new warehouse located in Coimbra (see Figures 2 and 4). The reverse network structure remains unchanged.

Scenario II

When considering two new locations for disassembly centres, the forward network remains structurally unchanged. On the other hand the reverse network undergoes some changes within Portugal, since the centre located in Porto is closed and its customers redirected to the new centre opened in Coimbra (see Figures 3 and 5). However, as it can be noted, there is no direct connection between this new centre and the customer located in the same city (round arrow). The reason is that, for economical reasons, the products to be returned from Coimbra's customer are not collected.

Scenario III

When simultaneously considering the opening of warehouses and disassembly centres, both forward and reverse networks undergo changes. These changes are analogous to the ones already described for warehouses and disassembly centres. The retrofitted supply chain has the forward and reverse networks depicted respectively in Figures 4 and 5.

Revenue and cost analysis

In Table 1 changes for revenue and costs (operational, transportation, penalization, production and stock costs) are shown as a percentage. These percentages were computed in relation to the original network values.

	Revenue	Costs						Profit
		Oper	Transp	Penal	Prod	Stock	Total	
Scen. I	1.8 ↑	2.4 ↑	1.6 ↑	0	*3.1* ↓	*100* ↓	2.3 ↑	0.5 ↑
Scen. II	6.3 ↑	*0.4* ↓	*0.6* ↓	0	*3.1* ↓	*100* ↓	0.6 ↑	18.8 ↑
Scen. III	8 ↑	2.4 ↑	1.1 ↑	0	*3.1* ↓	*100* ↓	2.9 ↑	19.1 ↑

Table 1: Revenue and costs comparison (%).

In all three scenarios, the revenue is found to increase. The largest increase (8%) is achieved in scenario III, where changes in warehouses and disassembly centres are considered simultaneously. In terms of costs, it should be noted that penalization costs have not changed, implying that the customers' degree of satisfaction was not affected. On the other hand, stock costs are reduced to zero and thus zero stock policy is observed. Overall, the simultaneous retrofit ensures the largest increase in network profit.

	Variable		Constraints	CPU (secs.)	Iterations no (*10^3)	Opt. value (*10^6)
	Total	Binary				
Scen. I	5781	1867	6463	10	11	1316
Scen. II	5301	1907	6513	8	8	1555
Scen. III	6943	2429	8193	11	13	1565

Table 2: Computational results.

The computational results are shown in Table 2. Note that the models although based on reasonably large formulations, require solution times acceptably small (between 8 to 11 seconds).

CONCLUSION

In this paper, a model for the retrofit of existing supply chains is proposed. The study of an existing network in Iberia is performed where structural and cost analyses are carried out. As a main result, a modified network structure is obtained where some existing facilities are closed and new ones opened. Additionally, the production, storage and distribution planning is obtained.

The computational results prove that the proposed model deals satisfactorily with network redesign problems. Consequently, it appears as a promising decision support tool to help the decision-making process in the redesign and tactical planning of multi-product capacitated closed-loop supply chains.

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