Transportation problem with plant closure and relocation of machines

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Abstract:
This paper is interested in a food industrial group which produces large quantities of sugar and distributes it to warehouses and customers. The group should review its distribution policy, in particular, to optimize transportation costs and reduce losses caused by the current organization.
In this paper, we propose an integer linear model to optimize the travel of full loaded trucks taking into account respect of the group's peculiarities. We study a second integer linear model taking into account transportation and production costs and allowing the possibility of closing some plants. Finally, the last model aims to review the production capacity of each plant through a redeployment of its production lines.
Keywords: *transportation problem, distribution, plant closure, relocation of machines, integer linear programming, sugar.*

1. Introduction

Transport has long been an important sector of the market economy. Companies encounter permanent transport problems against the development of the globalization of international trade. The needs of carriers are to meet the demands of large shippers, with the greatest operational efficiency at a competitive cost. Accordingly, the transport represents an important component of the national spends of all countries (Crainic and Laporte, 1997).
The researchers, motivated by the economic sector, have early examined the transport optimization problems. These problems are among the most gorgeous success of operational research (applied mathematics, quantitative management methods ...etc.) thanks to collaboration between specialists in Operational Research and transport managers.
The objective of this paper is to provide a substantial answer to a need for optimization of the distribution on behalf of a big company. In fact, the group specialized in the manufacture and distribution of sugar given that it monopolizes the sugar industry in the country. Therefore, the company carries more than one million tons of sugar annually from its mills to its warehouses or directly to customers.

2. Problem description

Sugar is a basic product subsidized by the government, its price is fastened by the latter and it's the same in the whole national territory. So, even if the group operates alone in the national market, it must respect this constraint. Consequently, the distribution costs couldn't be assigned to the final customer and the group must optimize these costs to ensure and increase its profit margin. The company distributes, on full truck load, large quantities of products from its plants to warehouses or to some customers. The company owns eight plants, five products and delivers products to eight warehouses and thirteen customers. The company is confronted by some logistic problems, the most important are:
Transportation problem: enormous costs of distribution are paid and the company can reduce them consequently if every destination is delivered by the nearby plant (Hitchcock (1941)).
Over capacity: the company is on over capacity compared to needs of market, and some plants are very close to each other, so the company is enquiring about the possibility to close some plants to decrease its fixed costs?.
Wrong location of production capacity: plants are specialized in one or more products that cause enormous wastes of distribution costs, if one product is not made by the nearby plant. We study the possibility of redeploying production lines of some products in order to minimize the distribution cost.
The transportation problem was treated alone with interest in inbound or outbound transport (Dantzig, (1951), Klibi et al (2010), Klose (2008), Durai Raj and Rajendran (2012) Kowalski and Levb (2008) Romeijna and Sargut (2011) Crainic (2002)), or with other issues in order to optimize global supply chain, consequently, transport was coupled with production and inventory management.
Therefore, the transport problem was coupled with inventory management by Benjamin, J. (1989) and Burns et al (1985), with inventory management and production (Chen (2004), Blumenfeld et al (1985), Haq et al (1991)) or with the production alone taking into account whether the demand if it is stochastic (Klibi et al (2010)) or deterministic (Jayaramana and Pirkul (2001)). The number of plants and time periods interested several researchers, Blumenfeld et al. (1985) and Benjamin (1989) was interested by direct distribution from several plants in one period while Bloomquist et al. (2002) has treated the same problem

but with multi-periods. Özdamar et al. (1999) was interested by one plant in multi-periods.
The case study that we propose deal with the distribution of sugar, this problem wasn't very developed in the literature, most of papers was interested by procurement and inbound transport (Calvinho (2003) and Salassi et al (2004)), or by supply chain (Gaucher et al (2004)), the main paper near to our object is Van Vliet et al (1992) but it interested by creating an interactive system to establish and adjust daily planning.
The resolution of these problems changes from one author to another though integer linear programming, that we use, is the most used by researchers (Jayaramana and Pirkul (2001), Rönnqvist (2003)).

3. Mathematical Models

The models proposed in this paper take into account the case of direct shipping on full truck load between (n) plants, producing (p) products and (m) destinations. The products are transported by trucks with identical capacity (K) and a truck doing a direct trip full loaded from the factory to the destination and usually returns empty to reload. Examples related to this problem are widespread in the real world: (i) deliveries from factories to warehouses, (ii) deliveries between ports and factories or warehouses and (iii) deliveries between points of exploitation of natural resources and factories or warehouses (such as sugar, wheat, cotton, mining ...etc.)

3.1 Parameters & Decision Variables

Table 1: Parameter definitions for the models

Symbol	Definition
x(i, j, k)	quantity of product (k) transported from plant (i) to destination (j)
open (i)	binary variable informs if the plant (i) is open or n
α (i, o, k)	number of prduction lines of product (k) moved from plant (i) to plant (o)
Cnu (i, k)	new production capacity on product (k) in plant (i
nbv(i)	number of trucks to assign to plant (i)

Table 2 : Decision Variables definitions for the models

Symbol	Definition
c(i, j)	cost of transport from plant (i) to destination (j)
S (i, k)	production capacity on product (k) of plant (i)
D (j, k)	demande on product (k) of destination (j)
n	number of plants
m	number of destinations
p	number of products
Tc(i, j)	cycle time between plant (i)and destination (j)
k	truck capacity
Ts	weekly open time
cf(i)	fixed costs of plant (i)
cd(i, o)	cost of moving production line from plant (i) to plant (o)
Cu(i, k)	current production capacity on product (k) in plant (i)
cap(i, k)	production capacity of one line of product (k) in plant (i)
N	number of weeks by year

Parameters of the models are defined in table 1, and variables are defined in table 2.

3.2 Model 1:

At first, we must decide which plant has to deliver what destination. It's a classical problem of transport (Hitchcock 1941). The goal is to make all deliveries with minimum cost.
The problem can be written as:

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} [\, c(i,j) * x(i,j,k)] \quad (1,1)$$

Subject to:

$$\sum_{j=1}^{m} x\,(i,j,k) \le S\,(i,k) \qquad \forall\, i, k \qquad (1,2)$$

$$\sum_{i=1}^{n} x\,(i,j,k) = D\,(j,k) \qquad \forall\, j, k \qquad (1,3)$$

$$x\,(i,j,k) \ge 0 \qquad \forall\, i, j, k \quad (1,4)$$

The objective function of the model (1,1) aims to minimize the transportation cost besides a proposal about which plant to deliver which destination. The first constraint (1,2) concerns the non-overflow in plant (i). Also, the amount of product (k) leaving the factory (i), must be less than its capacity, $S\,(i,k)$, of this product.

The second constraint (1,3) stipulate that quantity of product (k) delivered to the customer (j) must match its demand, $D(j,k)$, of this product.
Based on the optimized result of this model, we can calculate the number of trucks, $nbv(i)$, to be assigned to each plant (1.5). To make deliveries, we will use trucks with homogeneous capacity (K), in a typical week for a period Ts. The cycle time between the factory(i) and destination (j), $Tc(i,j)$, will include, in addition to trips to / from, the time of loading, unloading, city traffic, maintenance, rest of the drivers etc.

$$\frac{\sum_{j=1}^{m}\sum_{k=1}^{p}(x(i,j,k) * Tc(i,j))}{K * Ts * N} \leq nbv(i)$$
$$nbv(i)\text{: integer} \quad \forall i \quad (1,5)$$

3.3 Model 2:

In many cases, a company invests in production lines that meet market needs and the abundance of raw material (as in mining and agribusiness) but sometimes the raw materials are not as abundant as before or demand has dropped and the company is in excess capacity and therefore seeks to minimize its fixed costs by closing some plants (Diast et al (2006)). To decide which plant to close, we propose a model taking into account transportation costs and fixed costs of factories, cf(i), to provide a tool for decision on plants that company can close. In seeking to minimize the sum of two costs, we will introduce a binary decision variable, open (i), on whether to open a factory. Thus the model has the following form:

$$\min Z = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{p}[c(i,j) * x(i,j,k)] + \sum_{i=1}^{n}[cf(i) * open(i)] \quad (2,1)$$

Subject to:

(1,2), (1,3) and (1,4)

$$\sum_{j=1}^{m}\sum_{k=1}^{p} x(i,j,k) \leq \sum_{k=1}^{p} S(i,k) * open(i) \quad \forall i \quad (2,2)$$

The objective function of this model (2,1) considers both the optimized transport costs and fixed costs related to plants. This model uses the same constraints as the first one by adding the constraint (2,2) which introduces the question of opening or closing a factory. In fact the sum of the quantities leaving a plant must be less than the capacity of the plant provided that the plant is open, if the plant is closed the variable " open (i) " is zero and therefore the quantity that leaves the plant is zero.

3.4 Model 3:

The plants do not necessarily produce all products and it is possible that each factory is specialized in one or more products. We consider that each product is manufactured on a separate line, so the question of change of series does not arise. Nevertheless, it is desirable that each plant manufactures all products to satisfy all customers in minimum of time and cost. The question that will arise is follows: is the current location of the productive capacity by plant and product optimal? It may be that for a given product, the fact that it is not produced by a nearby factory creates transport costs far outweigh the costs of installation, in the factory, of a production line for this product. To better understand this issue we make the capacity as variable and propose a new model that will calculate the ability to have in each plant, by product, for the minimum cost of transport. The easiest way is to keep the same objective function (1.1) and add a constraint (3.2) by stating the capacity per plant and product, $S(i,j)$, as variable to be calculated. The model thus proposed is as follows:

$$\min Z = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{p}[c(i,j) * x(i,j,k)] \quad (3,1)$$

Subject to:

(1,2), (1,3) and (1,4)

$$\sum_{i=1}^{n} S(i,k) = \sum_{j=1}^{m} D(j,k) \quad \forall k \quad (3,2)$$

Certainly, the result given by this model should allow the company to assess the economic issue of a redeployment of its production lines. In practice, even if the result given by this model is often very successful, it is generally difficult to calibrate this result because it provides theoretical capacity that does not reflect the capacities of machines that the company has or may acquire. Therefore, it is absurd to set up a production line that will only work at 10% of its rated capacity, under the pretext of reaching the optimal transportation cost. However this model will help us to identify feasible locations that approximate better the optimal distribution.
Indeed, another way to address this problem, as we now have the theoretical location to be installed in each plant is to be based on net capacity manufacturing lines that the company currently owns and look where we need to install each of these lines for the minimum cost of transport possible, in other words what are the production lines to move from one plant to another without any new investment? This is more interesting because its cost is very low, given that it simply stated the cost of relocation of some machines without any additional investment (Pujo 2001). But this solution will be relevant only if the reduction in transport costs generated by this model deserves the relocation of manufacturing lines and there is sufficient raw material near each plant to response to its new capacity.

3.5 Model 4:

The model 4 takes into account the costs of distribution and the costs of machine moves.

$$\min Z = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{p}[c(i,j) * x(i,j,k)] + \sum_{i=1}^{n}\sum_{o=1}^{n}\sum_{k=1}^{p}[cd(i,o) * \alpha(i,o,k)] \quad (4,1)$$

Subject to:

(1,3) and (1,4)

$$\sum_{j=1}^{m} x(i,j,k) \leq Cnu(i,k) \quad \forall i,k \quad (4,2)$$

$$Cnu(i,k) = Cu(i,k) + \sum_{o=1}^{n}\alpha(o,i,k) * cap(o,k) - \sum_{o=1}^{n}\alpha(i,o,k) * cap(i,k) \quad \forall i,k \quad (4,3)$$

$$\sum_{o=1}^{n}\alpha(i,o,k) \leq \frac{cu(i,k)}{cap(i,k)} \quad \forall i,k \quad (4,4)$$

The cost of relocation of machines is the cost of moving one machine, $cd(i,o)$, multiplied by the number of moved machines $\alpha(i,o,k)$. The constraints to fulfill are (1,3) et (1,4) already seen in the first model and (4,2) stipulate that quantities, $x(i,j,k)$, must be lower than the new production capacity per plant and product $Cnu(i,k)$. $Cnu(i,k)$ must be equal to the current production capacity per plant and product, $Cu(i,k)$, added to number of machines moved to this plant, $\alpha(i,o,k)$, multiplied by the capacity of production line, by product, of source plant, $cap(o,k)$, and minus the number of machines moved from this plant, $\alpha(i,o,k)$, multiplied by the capacity of production line, by product, of this plant, $cap(i,k)$ (constraint (4,3)), the constraint (4,4) stipulate that the number of production lines, by product, moved from one plant must be less or equal than the number of production lines for the same product in this plant.

4. Case study and numerical results:

The case of application of our project meets the need expressed above. The group is specialized in the manufacture of sugar, production capacities are given by Figure 1. The company has eight plants, nine warehouses and five types of products. The plants don't deliver only warehouses but also some customers. A total of 21 destinations are to be delivered from plants in full truck load (Figure 2). Shipments are at full capacity semi-trailers, transport is completely outsourced and the company pays per ton transported. Transport represents 40% of the global logistics cost.

Analysis of the distribution operations of the company showed that there are many points of improvement in the way they are managed, in fact the allocation is done in palliative way and trips between sites and between warehouses, which should not exist, are made with substantial proportions which cause a large amount of unnecessary trips (Figure 3).

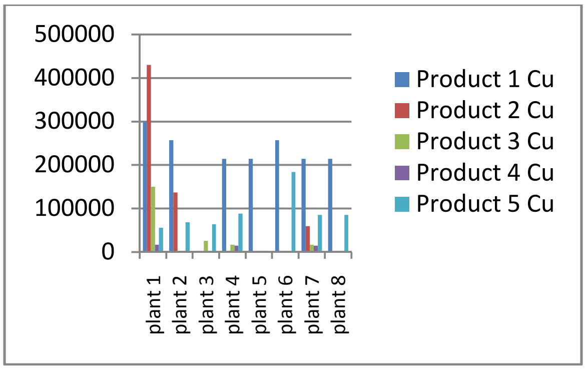

Figure 1 production capacity by product and by plant

The first model has enabled the company to optimize its distribution (Figure 4) which resulted in a reduction in transport costs of around 11% of global distribution cost (Figure 7). The second model, which allows studying the possibility of plant closures on the basis of the costs of production and distribution, shows that it is possible to close plants 5 and 6 (Figure1).

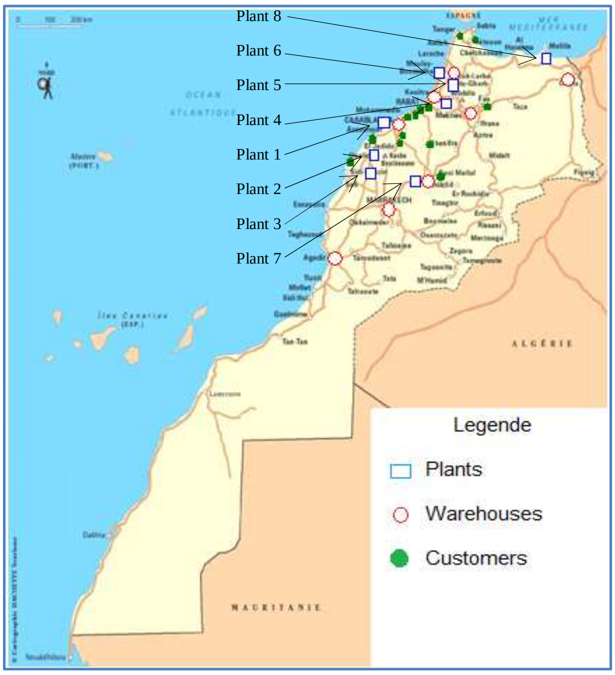

Figure 2: plants, warehouses and customers

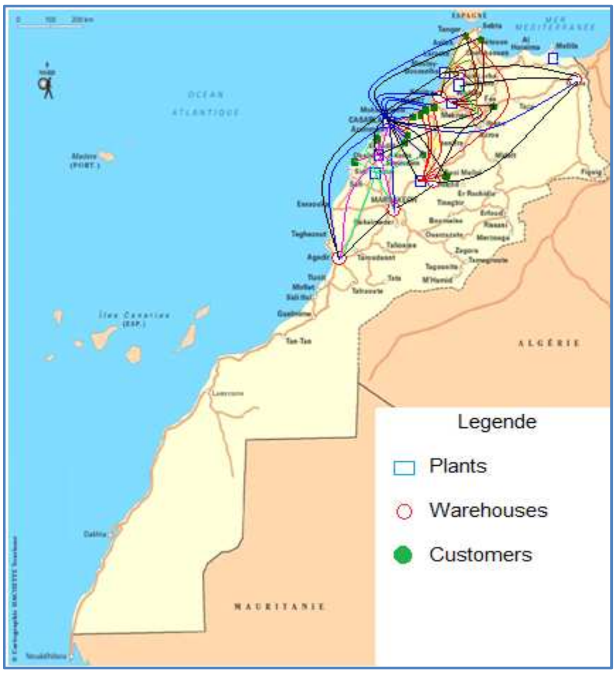

Figure 3: current network

Model 3, where we integrated the issue of searching production capacities to meet the cost of transporting the most optimized, gives more interesting results. Which reduce the annual transport costs of around 30 % in comparison of current situation (Figure 5 and 7), but this will require an investment or a relocation of production lines of the company.

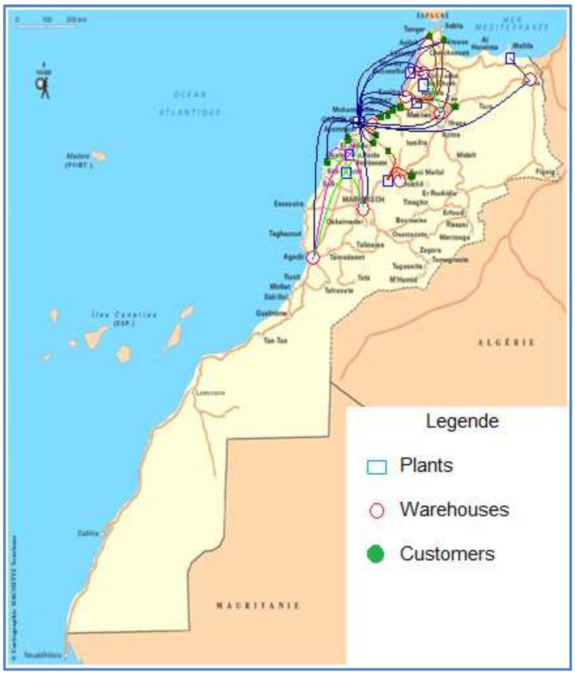

Figure 4 : Optimal network (ON)

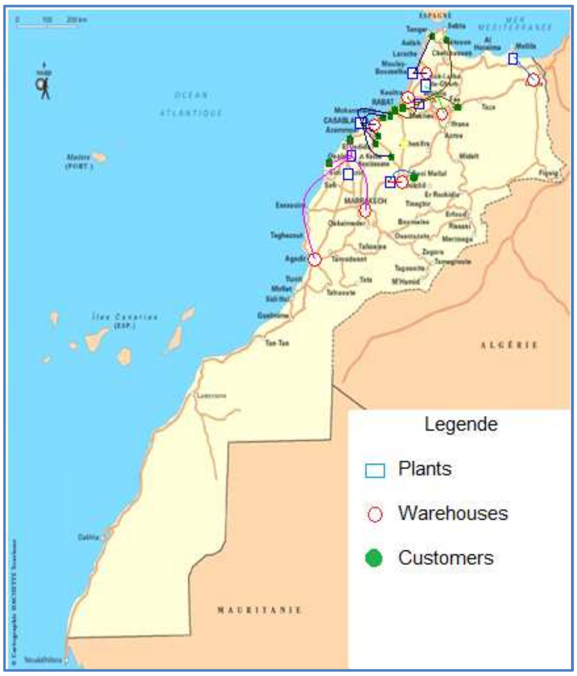

Figure 5: ON with change of capacity

Indeed, the relocation proposed by the model 4 has given some changes in production capacities of some plants (Figure 6) and estimates a reduction on transportation cost of around 27 % in comparison of current situation (Figure 7). This solution is feasible and the company had already achieved the same by moving some production lines from factories already closed to other plants. The reduction given by this model is less than the previous one but it is more realistic and the relocation costs counted just once time (around 2,5 % of current distribution cost). In addition, the results of the models 3 and 4 have shown that we can predict the closure of the plant 3 (Figure 5).

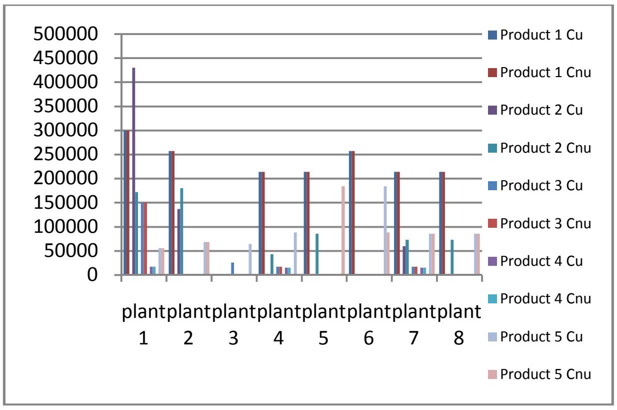

Figure 6: the new production capacity by product and by plant

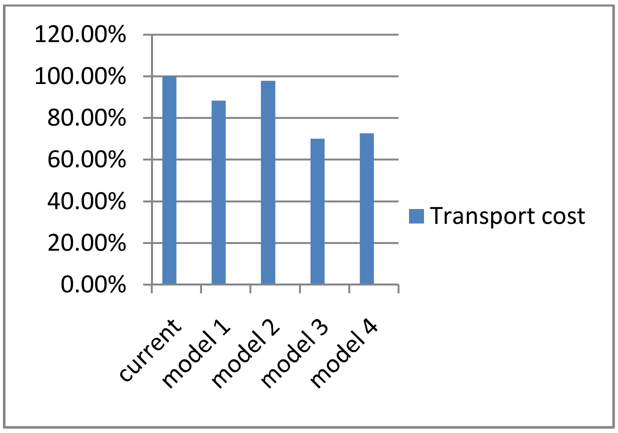

Figure 7: evolution of the transportation cost

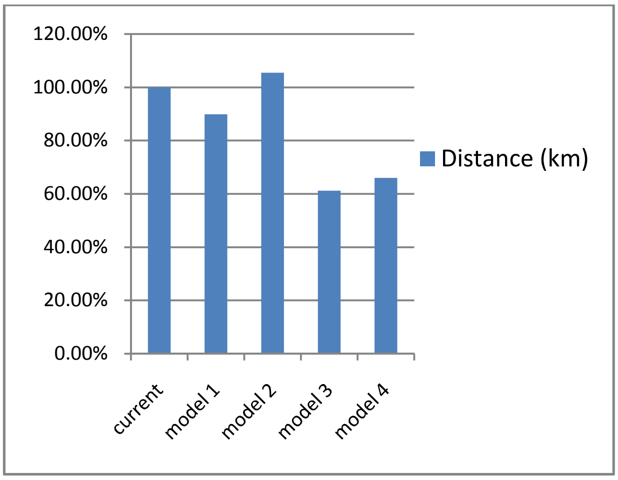

Figure 8: evolution of distance

5. Conclusion and perspectives:

This work has come up with the following results: First it allows a significant reduction in transport costs (around 30 % of current distribution cost). Second, it provides a review of the production capacity in a few plants and examines the possibility of moving some production lines to other plants, the fact which is very relevant given the economic issue that this allows. The possibility of closing some factories and which ones to close is also of a great importance for the group as this will save a significant proportion of fixed costs and transportation costs of the group. The significant reduction in travel (around 35% of current distance (Figure 8)) will allow the company to significantly reduce its carbon footprint especially as the mileage is doubled by the empty returns (a total of 10 million km are traveled by year). As the next track, we will study the routing of trucks to minimize empty trips which certainly has an economic interest for carriers and for the group (renegotiation), but also environmentally friendly because the amount of empty journeys is so immense that if the group does not deal with nobody else will do it. Finally, it will also look at the design of regional warehouses to help them meet the needs of customers at minimum cost. These two tracks can be processed in a single issue known as Inventory Routing Problem.

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