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NETWORK MODEL OF DIRECT AND INDIRECT RAW MATERIAL SUPPLY

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Abstract:
The impact of the distribution of raw materials in a company is a very important topic because the main objective of all enterprises is the customer satisfaction in a timely manner. A correct network distribution involves some key concepts of production which seeks to take care of the efficiency of the raw material supply chain. Among the critical overhaul concepts there are associated logistics costs and restrictions of warehouse capacity and purchase volumes. This model seeks to minimize logistics costs of distribution for the importation of raw materials from different parts of the world until delivery at a specific plant. It also analyzes the point where costs are minimized by separating the proportion of total volume that will be sent directly to the production plant and / or the portion to be stored in an external facility (bonded warehouse) and then consolidate and deliver products at the end at the specific plant.

Key words:
Distribution Network, Costs, Logistics, Warehouse.

INTRODUCTION

Due to globalization it is important that companies develop and monitor whether the design of their distribution networks complies with their needs and budgets. This is in order to increase competitiveness with other companies, to reduce production time, costs and expenses involved in the process, and also to be ready for market changes [1]. In most companies, the supply chain management encompasses all activities related to the flow and transformation of goods, from the stage of raw materials (extraction) to the final user and related information flows. The materials and information flow upstream and downstream in the supply chain, defining the integration of such activities by improving relations in the supply chain to achieve sustainable competitive advantage [2].

First, it is important to visualize the required amount of the manufactured product that the market is demanding. This is in order to plan according to their requirements, since the distribution chain should be planned starting with the customer's need to search for suppliers to be involved in the development of the product. The aim is to ensure that the whole process is mapped with the times of production, transit and delivery of raw materials in the production plant. Then, by having an optimal network distribution of raw materials, lower costs and times can be achieved within the same supply chain, leading to quantitative savings for the companies.

This paper presents a linear model for the development of distribution networks based on balancing of raw material supply sources. Particularly, the model addresses the situation where different raw materials can be directly delivered to a specific plant from a supplier or from an intermediate warehouse. Also, it addresses the most convenient fraction of raw materials that can be delivered from each supplier to the intermediate warehouse and to the specific plant.

1 LITERATURE REVIEW

To better understanding the purpose and functionality of the presented model, the review of related work is necessary. As we mentioned earlier, the world is currently presenting big changes, especially in the minds of the managers of large companies, who are responsible for making important decisions involving gains or losses. In the field of supply chain must of the companies are starting using indicators of logistics and statistics to measure the quality of it process, as an example, there are some of them which are following list: stock coverage rate, transportation cost, delivery performance, etc. [3]. Linear Programming (LP) is a mathematical modeling technique widely used to help the administration team for their decision making processes, mainly with resources allocation [4]. Because LP consists of a mathematical model to describe the problem, it can be defined as a "mathematical technique that addresses the problem of resource allocation among competing activities optimally". The "linear" qualifier indicates that all functions or equations used in the model are of first grade.

LP models seek optimization (maximization or minimization) of a linear function of several variables, called objective function restricted by the need to satisfy a set of equations and / or linear inequalities, called constraints. Thus, LP is a tool for solving optimization problems. In 1947, George Dantzig developed an effective method, the simplex algorithm to solve linear programming problems. Since the algorithm emerged, LP has been used to solve optimization problems in various industries, such as banking, education, forestry, oil and freight [5].

Hence, the main elements of a LP model can be summarized as follows:

a) The linear function (objective function) to be optimized (maximized or minimized) based on the values of decision variables.
b) The values of the decision variables that must satisfy a set of constraints. Each constraint must be a linear equation or linear inequality.

c) Sign restrictions associated with each variable. For any variable X_i the sign restrictions specify that X_i should not be negative ($X_i \geq 0$) or should not have sign restrictions (NRS) [5].

In practice, the use of LP has been very important for the design of distribution networks. In [6] a distribution network model was designed for a two-links distribution chain. This model was integrated within an inventory location problem for distribution centers. The use of mixed integer LP (MILP) was studied in order to determine the appropriate number of distribution centers to be opened, strategically placing them close to supply retailers. In this model each distribution center was supplied by a plant, and each retailer was supplied by only a distribution center. The objective function was defined as the minimization of the total costs within the distribution network.

In [8] MILP model was proposed to solve a supply chain network design problem. This model considered the relationship between product quality, purchasing costs and supply chain design to improve managerial decisions on supplier selection. It is important to mention that the multi-echelon supply chain network does not consider a direct transportation route between non-consecutive entities. In comparison, a complex LP model described in [9] considers additional direct deliveries from suppliers to distribution centers without an intermediate warehouse, and transportation routes between warehouses and distribution centers.

On the other hand, the work described in [7] presented the design of a distribution network for a Colombian company that had a presence in more than 15 countries and more than 200 stores throughout Latin America. The LP model was divided into three phases to build and solve the problem in order to analyze their potential suppliers and / or distribution centers (warehouses) for the supply and distribution of its products to end customers.

In this work we focused on the LP modelling of a distribution network where there are two suppliers and one destination plant. The particularity of this network is that both suppliers can ship raw materials directly to the plant or ship them to an intermediate warehouse where materials will be consolidated and shipped to the plant. Because transportation costs depend of the selected route and the product that is shipped, it is important to determine the quantity (proportion of total volume) of each product that is more convenient to ship to each destination (either directly to the plant, or indirectly to the plant via the intermediate warehouse). This case study was addressed by the use of network flow theory and LP.

In section 3 the details of the proposed model are presented while in section 4 the results on illustrative examples are discussed. Finally, in section 5 our conclusions are presented.

3 METHODOLOGY

Through LP and the SOLVER tool the model for optimizing the distribution network was developed. As discussed, the goal is to minimize logistics costs involved in the distribution of raw material from the supplier's plant to the customer in the country of destination.

Figure 1 outlines the model of the network distribution for the supply of raw materials. This model considers two locations for the supplier of raw material A and B, a fiscal warehouse E for the receipt of the goods for extraction thereof and finally the plant in the country of destination. In addition to the above structure, we define the variables that are involved for differentiating the routes by product:

a) a: fraction of raw material to be transferred from location A to end on plant P;
b) $1-a$: fraction of raw material to be transferred from location A to fiscal warehouse E;
c) b: fraction of raw material to be transferred from location B to end on plant P;
d) $1-b$: fraction of raw material to be transferred from location B to fiscal warehouse.

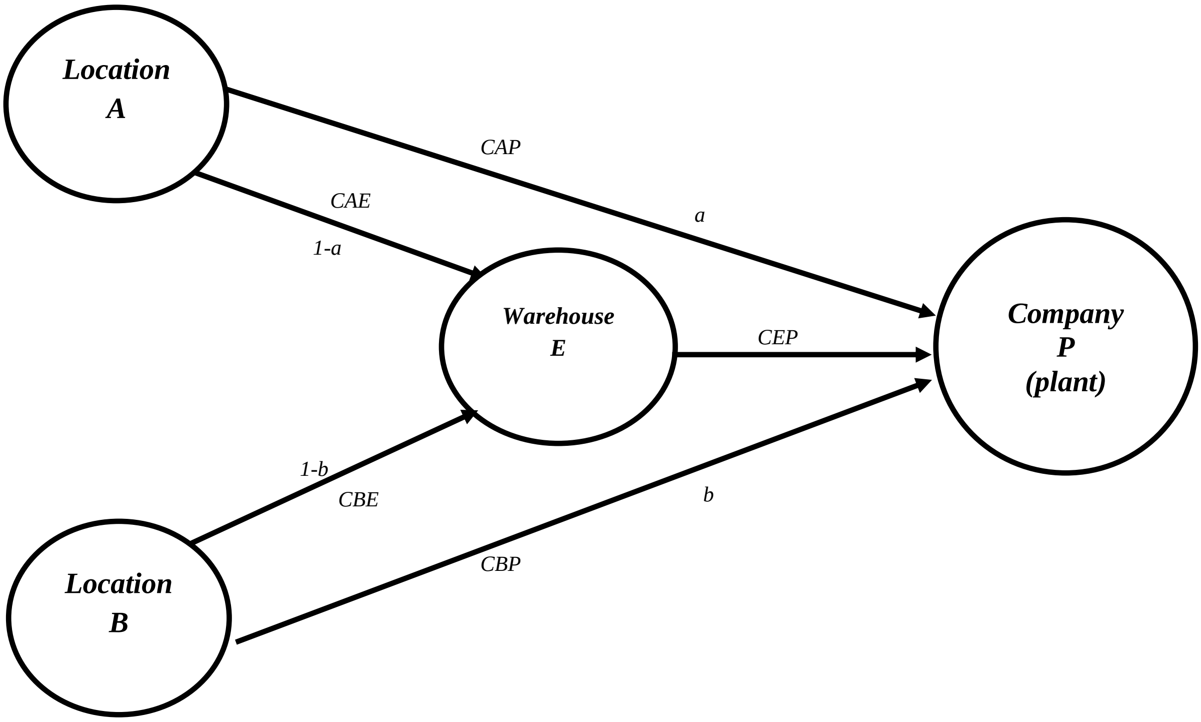

Fig.1 *Distribution Network Model of Raw Material*

Note that a, $b \in [0, 1]$. The warehouse cost variables that are involved in all routes are defined considering that all of them are consolidated in the final plant P. The model starts by defining those entities involved in the distribution chain. As presented, for this case we determined two locations (two raw material suppliers) A and B. We also defined the existence of a fiscal warehouse E in the country of destination, described as the establishment that protects foreign goods in the destination country without generating taxes until the removal of the goods. In this location, the restriction is that the material protected must be sold to a local customer. The final destination, referred as P, represents the plant which is located at the destination country.

In order to define the mathematical model, the following concepts were envisioned:

a) Flows to define the four possible combinations of distributions; location A to plant P, location A to warehouse E, location B to plant P and finally location B to warehouse E.
b) Costs definitions involved in the four possible routes, also one more route is added from warehouse E to plant P.
c) Definition of model variables when fractions or percentages of the total demand of each product (row material) i are to be transported from one point to another.
d) Definition of the variables that intervene in obtaining the costs involved in the four possible routes plus the load consolidation route when the fiscal warehouse is used.
e) Defining the objective function as the total of all costs involved.
f) Definition of the variable p_i as the demand for each raw material required by the customer.
g) Restrictions on the minimum order that the supplier requires to cover the needs of the customer.

h) Restriction on the capacity of the warehouse in the country of destination, in relation to the infrastructure of the establishment.

Finally, with these concepts the mathematical model is described as follows:

a) Variables

a_i = % of the product *i* that goes from location A to plant P
b_i = % of the product *i* that goes from location B to plant P
$(1-a_i)$ = % of the product *i* that goes from location A to warehouse E
$(1-b_i)$ = % of the product *i* that goes from location B to warehouse E
p_i = Total quantity of product *i* (in kilograms) ordered by the plant P
D_i = Total demand of product *i* (in kilograms)

b) Costs

CAP = Transportation cost from location A to plant P
CAE = Transportation cost from location A to warehouse E
CBE = Transportation cost from location B to warehouse E
CBP = Transportation cost from location B to plant P
CEP = Transportation cost from warehouse E to plant P

c) Cost Flows: illustrative equations considering that products *i =1* and *2* are produced by the supplier at A, and products *i = 3* and *4* are produced by the supplier at B

Costs from A to P

$$C1 = CAP(a_1p_1 + a_2p_2)$$

Costs from A to E

$$C2 = CAE[(1-a_1)\,p_1 + (1-a_2)\,p_2]$$

Costs from B to P

$$C3 = CBP(b_3p_3 + b_4p_4)$$

Costs from B to E

$$C4 = CBE[(1-b_3)\,p_3 + (1-b_4)\,p_4]$$

Costs from E to P

$$C5 = CEP[(1-a_1)\,p_1 + (1-a_2)\,p_2 + (1-b_3)p_3 + (1-b_4)\,p_4]$$

d) Objective Function:

Minimize (*C1 + C2 + C3 + C4 + C5)*

e) Restrictions

Demands

$p_1 = D_1$
$p_2 = D_2$
$p_3 = D_3$
$p_4 = D_4$

Minimum purchase for direct delivery at plant P

$$a_1p_1 + a_2p_2 \leq 50{,}000$$
$$b_3p_3 + b_4p_4 \leq 50{,}000$$

Capacity of warehouse E

$$[(1 - a_1)\, p_1 + (1 - a_2)\, p_2 + (1 + b_3)p_3 + (1 - b_4)\, p_4] \leq 600{,}000$$

In order to test the usefulness of the model, we represent some cases considering the above assumptions.

4 RESULTS

CASE 1

Table 1 includes the demand and cost data involved for each product listed. This information was processed in Excel and assistance of the tool SOLVER was considered to optimize the mathematical model.

Tab. 1 *Source Data for Case 1*

PRODUCT	DEMAND (KG)	LOGISTICS COSTS FROM SUPPLIER TO WAREHOUSE (USD)	LOGISTICS COSTS DIRECT TO PLANT (USD)	LOGISTICS COST FROM WAREHOUSE TO PLANT (USD)
1 Paper	50,000	\$15.00	\$34.00	\$11.00
2 Wood	200,000	\$15.00	\$34.00	\$11.00
3 Corrugated cardboard	45,000	\$19.00	\$31.00	\$11.00
4 Polystyrene	148,000	\$19.00	\$31.00	\$11.00

From Table 1 we can observe the values assigned to each product: quantity demanded in kilograms, costs involved for each supplier location A and B to the warehouse E and directly to plant P, and finally from the warehouse E to the plant. Note that all products in the warehouse are consolidated for final delivery at the plant P. Table 2 summarizes the results that define the percentage for each product that will be distributed to different points.

Table 2 *Results for Case 1*

PRODUCT	PERCENTAGE AT EACH LOCATION
a_1	0%
$1-a_1$	100%
a_2	25%
$1-a_2$	75%
b_3	100%
$1-b_3$	0%
b_4	3%
$1-b_4$	97%

In Table 2 we can observe that for the first product (i = 1) it will be necessary to take 100% of the products to the fiscal warehouse E ($1-a_1$ = 100%) and consolidate there for delivery to the plant P. For the second product (i = 2) 25% of all demand will be taken directly to plant P (a_2 = 25%) while 75% will be delivered to the fiscal warehouse E ($1\text{-}a_2$ = 75%) for eventual delivery to plant P. In the case of the third product (i = 3) it is clear that 100% must be delivered directly to plant P (b_3 = 100%). Finally, for the fourth product (i = 4) we have a minimum amount delivered directly to plant P (b_4 = 3%) while most of the product ($1\text{-}b_4$ = 97%) will be delivered to the fiscal warehouse E.

With the above results, the objective function in relation to the costs involved for product distribution is minimized. In this case, and in relation to the objective of minimizing the cost function, a minimized total annual cost of approximately $ 12 million USD was obtained with the distribution presented in Table 2.

CASE 2

Table 3 presents the demand and cost data for each product listed for the second case. Table 4 presents the results obtained with the SOLVER tool.

***Table 3**: Source Data for Case 2*

PRODUCT	DEMAND (PC)	LOGISTICS COSTS FROM SUPPLIER TO WAREHOUSE (USD)	LOGISTICS COSTS DIRECT TO PLANT (USD)	LOGISTICS COSTS FROM WAREHOUSE TO PLANT (USD)
1 Pens	1,000,000	$0.80	$2.00	$1.30
2 Pencils	8,500,000	$0.80	$2.00	$1.30
3 Erasers	200,000	$0.20	$2.40	$1.30
4 Correctors	200,000	$0.20	$2.40	$1.30

***Table 4**: Results for Case 2*

PRODUCT	PERCENTAGE AT EACH LOCATION
a_1	100%
$1\text{-}a_1$	0%
a_2	100%
$1\text{-}a_2$	0%
b_3	90%
$1\text{-}b_3$	10%
b_4	80%
$1\text{-}b_4$	20%

As presented in Table 4, for this second case we can observe that for the first two products (i = 1, Pens, and i = 2, Pencils) it is more convenient the direct delivery to plant P. It is important to mention that we have the highest demands on these products, almost 96%. Therefore, we can conclude that the volume of the demand is a very strong determinant to define the path to take.

For products 3 and 4 (i = 3, Erasers, and i = 4, Correctors) which represent a volume of 4%, we need to carry most of these materials directly to the plant P while small portions must be carried to the fiscal warehouse E. This solution achieves a minimized cost of approximately $ 20 million USD with the distribution presented in Table 4.

5 CONCLUSIONS

After analyzing the above cases, it is concluded that the proposed model can be a tool adaptable to different situations. It is only necessary to conduct thorough reviews of the costs involved for the distribution from one point to another, to verify the demanded volumes of each product, and finally to review the existence of restrictions such as minimum purchase and capacity (as established in the considered cases).

Also, this model can be adapted to situations or cases where one or more suppliers are considered. Thus, fast comparison of scenarios with alternative distribution routes without intermediaries can be explored: direct delivery to the plant, or conversely, an alternative to implement a warehouse to protect the goods to use them in the country of destination. In any case the goal is the minimization of the costs involved in the distribution of raw materials.

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