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A META-HEURISTIC APPROACH TO A STRATEGIC MIXED INVENTORY-LOCATION MODEL: FORMULATION AND APPLICATION

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In the present day, it is increasingly more important for the companies to have a distribution network that minimize the logistic costs without reducing the level of service to the customer (delivery time, enough inventory, etc.). To reach conciliation within these objectives that may look conflicting requires developing some tools that allow decision-making. Having this in mind, the authors present a strategic inventory-location model, multiproduct and different with demand periods. This is a complex problem of integer mixed programming, that allow to determine the optimum distribution network given the fixed, transportation and inventory costs. The problem is illustrated by applying it to a real case of a steel company in Colombia, to resolve it, exhaustive revision and a genetic algorithm were used. The results obtained reveal the importance of the making joint strategic-tactic decisions, as well as the impact of each of the variables considered in the logistics costs.

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Keywords: *Distribution network; inventory location; distribution centers location; genetic algorithm; exhaustive revision.*

1. Introduction

In a context of a globalized market, companies are forced to develop innovation methods that allow them to differentiate from their competitors. An interesting case is the one from the companies that produce low-density value goods, where the logistics costs have an important impact on the products final price, so it is necessary to optimize

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them without decreasing the level of service. In addition to the cost reduction, to offer a better level of service is crucial to keep and attract customers.

Logistic strategies as in how to broaden the network distribution centers (DC) of the companies are an interesting option because they cover both problems simultaneously: they offer an effective and rapid response to the customers (optimize level service) and on the other hand they allow to consolidate shipment to the DC. Which with the taking advantage of scale economies of scale it can translate into important savings on transportation costs. However, making the decision to create new DC implies a serious amount of investment and it must be supported on an economic evaluation, which requires a detailed analysis.
An optimal design of a distribution network is one of the most difficult problems managers and operation investigators encounter, the decisions that concern this design can be broken down into three levels (Berman, et al., 2011).

- Strategic: how many facilities it's going to have and where to locate them
- Tactical: Where to keep the inventory and how much could it be stored in each facility
- Operational: How to organize the transportation flow between facilities.

The levels explained above result very difficult to clarify by themselves, and by tradition they have been worked separately. On the past years a strong movement for the integration of levels 1 and 2 has existed (strategic and tactical) through the models of inventory location (Daskin & Coullard, 2002).
The great interest in integrating these levels stems from the premise that inventories consolidate multiple facilities in one has been shown to reduce inventory costs (Eppen, 1979).

A general problem of locating facilities includes a series of spatially distributed clients and a set of facilities to supply those customers (Figure 1), from which they must answer the questions of which facility should be used? Which customers will be served by each facility in order to minimize costs? In addition to these basic questions, different constraints and considerations have been added depending on the application (Melo, et al., 2009)

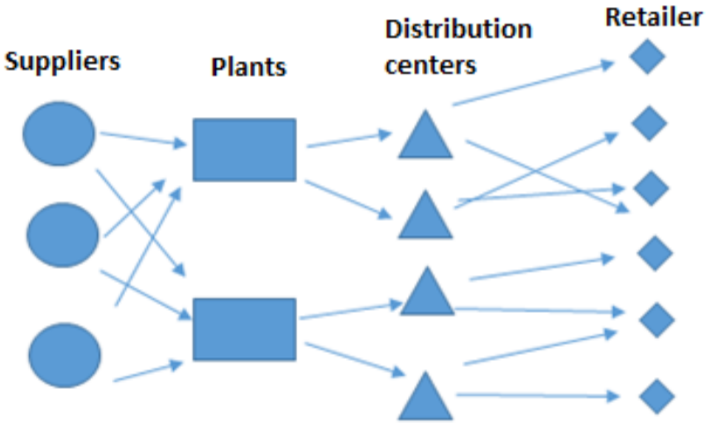

Figure 1. *Generic facility location*
Source: Author

In this paper, a mathematical strategical-tactical model for the optimization of the distribution networks is proposed. For its application there was a gathering of information of a company in the laminated steel sector and as a result it was determined for their case which will be the best configuration for their distribution network , the number of facilities needed, and the client allocation for each facility, this taking into account the costs derived from the cycle inventory and safety stock, as well as the fixed costs of new facilities and of transportation between the different points of the distribution network (plant, facilities, demand zones).
Although the model shows levels of inventory for the installation of the networks, these may not be considered as the

exact levels required in each facility, because being a strategic model rather than a tactical one, the products are added into categories; therefore, the resulting levels of the application of the model can be considered as a magnitude of order or as reference with the purpose of estimating the costs associated with these levels, to define the necessary inventory for each item there must be done a detailed analysis for this exclusive objective.

2. Inventory location models

The administration of the supply chain (ASC) is the process of planning, installing, and controlling in an efficient manner the operations of the chain supply. The ASC includes all the movements since the manipulation of the raw materials, inventories and finished products, from their origin raw state until they get to the costumers that will consume them. Historically investigators have focused only on the optimization of the distribution network, ignoring the areas of production, inventory and routing, which is not adequate because they are not considering the supply chain as a whole (Melo, et al., 2009).

The design of a logistic network is one of the most strategic designs for the chain supply, because to open or close a facility it's very expensive, it takes time and it's irreversible on a short term. Some strategic and tactical decisions are limited to this decision even though the distribution networks are directly related to the location of the facilities (Kaya & Urek, 2015).

Usually strategic decisions are taken by the higher ranks of a company (President, Vice-president), while tactical and operational decisions are taken by lower ranks of a company (managers), which generates incompatibilities and incoherencies on the practice. For instance, the facility location problem (FLP) it's considered strategic, that is when it was defined in an separate manner it restrains tactical and strategic decisions that are related with an optimal facility location. Some examples of these decisions are inventory control politics, the election of the method/capacity of the transportation, design and facility management, routing vehicles, among others (Miranda & Rodrigo, 2004).

It has been proven that increasing the variance or reducing the capacity of the inventory does not imply a relevant increase on built facilities. This is due to a compensatory effect in which the amount of orders will be reduced, allowing the designation of more customers to a facility or customers with a high variance. The increases on costs are due to the reduction of the amount of orders, and it is not much higher than the fixed cost of opening a new facility and the increase on the safety stock. Nevertheless, controlling the amount of orders in this case of strategic models can have a relevant impact on the performance of the system. This effect is not possible with the traditional way of handling this types of problems which with this model it has a great advantage (Miranda & Garrido, 2006).

The literature concerning inventories tends to focus on finding optimal resupply strategies for the inventories on distribution centers, for them they assume that there is already an existing number and places defined for such distribution centers. On the other hand, the facility location theory focuses on developing models that determine the numbers of DC and their location, as well as the designation of customers, these models usually include fixed costs and transportation costs, leaving aside costs associated with inventory and shortage (Daskin & Coullard, 2002). Daskin & Coullard (2002), conclude that for these types of models, when fixed costs of ordering an order reduce in a significant manner the number of DC to build increases.

A great amount of literature has been developed, taking into consideration that there is a serious interest to resolve this challenge. Operational investigators have programmed mathematical models to represent a range of FLP with their respective objectives, unfortunately the resulting models are extremely difficult to solve in an optimal manner (most of them are considered as NP-hard); a great deal of these models require a whole new programming (Daskin & Susan, 1998)

Various authors have studied the impact of including inventory politics on the FLP. Daskin & Coullard (2002) and Shen & Coullard (2003) incorporated inventory controlled politics that designates a safety stock for each facility. For the largely studied FLP without capacity restrictions, on this politic a fixed quantity Q is ordered to the supplier once the levels of inventory get to the point of rearrangement, the annual quantity of orders D/Q was considered a variable of decision. For its resolution it was taken into account the Lagrangiana relaxation (Daskin & Coullard, 2002) while

Shen & Coullard (2003) they resolve it with a different method, with columns, Miranda & Rodrigo (2004) also use Langrangean relaxation to resolve the PLI, this said, there can be findings on the literature of broad variety of integrated localization inventories models with different details and considerations among them, but as said earlier the complexity to resolve too robust models make them unattractive.

The objective of this article is the development of a model that incorporates strategic decisions concerning the PLI taking into account the tactical decisions of inventory controlled policies, the proposed model goes in hand to the actual approaches in this area, where the tendency to replace models of unique products for the demands of multiproduct, this lets us create in a more realistic manner the situations that the companies face nowadays.

The model which was applied to the steel sector company, whose products are on a low density of value (low cost storage), and it was made a sensibility analysis in terms of those costs to observe its impact on the final configuration of the network

These types of models depending on the size of the problem could be solved by different methods, which can be exact or approximate:

Exact methods:

- Relaxed linear programming (Church & Revelle, 1974).

Approximate method (Heurísticas, Meta-heurísticas) (Farahani, et al., 2012):

- Lagrangean heuristics (Miranda & Rodrigo, 2004) (Balas & Carrera, 1996) (Diabat, et al., 2013) (Daskin & Coullard, 2002).
- Genetic algorithm (Soleimani & Kannan, 2015) (Mousavi & Hajipour, 2013)
- Tabu search (Kaya & Urek, 2015).
- Particle swarm. ((Soleimani & Kannan, 2015) (Mousavi, et al., 2014)
- Simulated annealing. (Kaya & Urek, 2015)

On the last couple of years a new focus on the resolution based on the creation of hybrid heuristics have been developed. Kaya & Urek (2015) used three hybrid heuristics among three widely used heuristics like Tabu search, Genetic algorithm and Simulated annealing with Variable neighbor search also known as TBVNS, GAVNS, SAVNS, obtaining the best results with the TVVNS in terms of profitability. Soleimani & Kannan (2015) developed a hybrid algorithm between Particle swarm and Genetic Algorithm obtaining much better results than only using genetic algorithms by itself.

3. Modeling

In the current paper, an integer mixed nonlinear programming model is proposed. The model determines the optimum configuration of a distribution network, involving the DC operational and fixed costs, the transportation costs between the production plant and the DC and between the DC and the retailer and safety and cycle stock costs for each DC. To accomplish this, the model needs to decide where to install new DC having N possible sites to serve M given retailers. Only one DC must attend each retailer, therefore the model must allocate these retailers to a DC.

The model pretends to optimize logistics costs by freight consolidation and the exploitation of scale economy. According to the current needs of the companies and the new tendencies on the literature, the model includes a k variable which allows a multi-product approach and considers different demands periods (low demand, high demand) with the t variable, this generates a better approximation in the calculation of the total costs, giving a result that is closer to reality.

$$
\begin{aligned}
Min \quad & \sum_{i=1}^{N} F_i \cdot X_i + \sum_{i=1}^{N}\sum_{j=1}^{M} Y_{ij} \cdot C_{ij} \\
& + \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{k=1}^{K} r_t \cdot HC_i^k \cdot Z \cdot \sqrt{LT_i^k} \cdot \sqrt{V_i^{kt}} \\
& + \sum_{t=1}^{T}\sum_{i=1}^{N} r_t \cdot \left(\sum_{k=1}^{K} HC_i^k \cdot \frac{Q_i^{kt}}{2} + OC_i \cdot \frac{\left(\sum_{k=1}^{K} D_i^{kt} \right)}{Q_i^{kt}} \right)
\end{aligned}
$$

$$(1) \quad \sum_{i=1}^{N} Y_{ij} = 1 \qquad \forall j = 1,\ldots,M$$

$$(2) \quad Y_{ij} \le X_i \qquad \forall i = 1,..,N,\ j = 1,..,M$$

$$(3) \quad D_i^{kt} = \sum_{j=1}^{M} Y_{ij} \cdot d_i^{kt} \qquad \forall i,t,k$$

$$(4) \quad V_i^{tk} = \sum_{j=1}^{M} Y_{ij} \cdot v_j^{kt} \qquad \forall i,t,k$$

$$(5) \quad X_i, Y_{ij} \in \{0,1\}$$

Where:
F_i: Fixed and operational costs of a DC installed in the site *i*.
X_i: Binary variable that has the value of one if a DC is installed in the site *i* and zero otherwise.
Y_{ij}: Binary variable that has the value of one if the retailer j is attended from the DC *i* and zero otherwise.
Cij: Total transportation cost from DC *i* to retailer *j*.
$C_{ij\,:}$ is given by the following expression:

$$\sum_{i=1}^{M}\sum_{J=1}^{N}((\mathrm{Tc}_{ij} + Pw) \cdot \mathrm{D}_j)Y_{ij}$$

Where Tc_{ij} is the transportation cost per unit from DC *i* to retailer *j*, *Pw* is the transportation cost from the production plant to the DC and *Dj* is the total demand per year of the retailer.

K: Number of product categories.
Z_α: Safety factor according to the level of service desired.
HC_i: Holding cost associated to each product category.
LT_i: Lead time to supply DC *i*.
V_i^{tk}: DC *i* variance of daily demand, for each product *k* and each demand period *t*.
Q_i: Lot size.
OC_i: Cost per order.
D_i^{tk}: Average daily demand of DC I, for each product *k* and each demand period *t*.
R_t: Number of days for each demand period.

From the equation, the first and second term refers to the fixed, operational and transportation costs, the third term refers to the safety stock costs and the last term refers to the costs associated to the cycle inventory.
The lot size is the quantity produced or acquired in a stage of the supply chain.
In case there are several production plants in different locations, the model is rewritten as follows:

$$Min \quad \sum_{i=1}^{N} F_i \cdot X_i + \sum_{i=1}^{N}\sum_{j=1}^{M} Y_{ij} \cdot C_{ij} + \quad C_s\left(P\right) \quad + \quad C_s\left(I_p\right)$$

$$+\sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{k=1}^{K} r_t \cdot HC_i^k \cdot K \cdot \sqrt{LT_i} \cdot \sqrt{V_i^{kt}}$$

$$+\sum_{t=1}^{T}\sum_{i=1}^{N} r_t \cdot \left(\sum_{k=1}^{K} HC_i^k \cdot \frac{Q_i^k}{2} + OC_i \cdot \frac{\left(\sum_{k=1}^{K} D_i^{kt}\right)}{Q_i} \right)$$

$$(1) \quad \sum_{i=1}^{N} Y_{ij} = 1 \qquad \forall j = 1,\dots,M$$

$$(2) \quad Y_{ij} \leq X_i \qquad \forall i = 1,..,N, j = 1,..,M$$

$$(3) \quad D_i^{kt} = \sum_{j=1}^{M} Y_{ij} \cdot d_i^{kt} \qquad \forall i,t,k$$

$$(4) \quad V_i^{tk} = \sum_{j=1}^{M} Y_{ij} \cdot v_j^{kt} \qquad \forall i,t,k$$

$$(5) \quad \left(\sum_{k=1}^{K} Q_i^k\right) + \sum_{k=1}^{K} \left(Z_{1-\alpha} + Z_{1-\beta}\right)\sqrt{LT_i} \cdot \sqrt{V_i^k} \leq ICap \qquad \forall i = 1,\dots,N$$

$$(6) \quad X_i, Y_{ij} \in \{0,1\}$$

Where the new variables are Cs (P) and Cs (Ip), which represent the production costs and the raw material inventory costs.

It should be noted that the proposed model is an extension of the classic facility location model, which is NP-Hard, therefore this model is also NP-Hard, in addition the objective function made is nonlinear, which increase the solving difficulty of this problem especially with big distribution networks, which are common in the reality. This is why heuristics and metaheuristics are the best way to solve this kind of problems. (Miranda & Rodrigo, 2004).

4. Application and solution

The model was applied to a Colombian laminated steel company. In order to solve the problem two methodologies were used, the first one using an exact method (exhaustive revision) and the second was based in a metaheuristic, a genetic algorithm.

The company has retailers distributed in all the states of Colombia, zoning these retailers were grouped in 28 zones. Seven (7) sites were proposed using site demand and geographic position as criteria for the potential DC location. The production plant of the company is located currently in the zone 2 (Z2) and it also works as a DC, so it was prefixed in the solution and from it all the others DC will be served.

Table 1. DC and zones coding

Cod zone	Zone
Z1	ANTIOQUIA
Z2	ATLANTICO
Z3	BOGOTA

Cod DC	DC
C1	Barranquilla
C2	Bogotá
C3	Cali

Z4	BOYACA
Z5	BUCARAMANGA
Z6	CALDAS
Z7	CALI
Z8	CAQUETA
Z9	CASANARE
Z10	CAUCA
Z11	CESAR
Z12	CLIENTE RECOGE
Z13	CORDOBA
Z14	CUNDINAMARCA
Z15	GUAJIRA
Z16	HUILA
Z17	MAGDALENA
Z18	META
Z19	NARIÑO
Z20	NORTE DE BOLÍVAR
Z21	NORTE DE SANTANDER
Z22	QUINDIO
Z23	RISARALDA
Z24	SANTANDER
Z25	SUCRE
Z26	SUR DE BOLÍVAR
Z27	TOLIMA
Z28	VALLE DEL CAUCA

C4	Medellin
C5	Puerto Berrío
C6	Barrancabermeja
C7	Eje cafetero

Source: Author

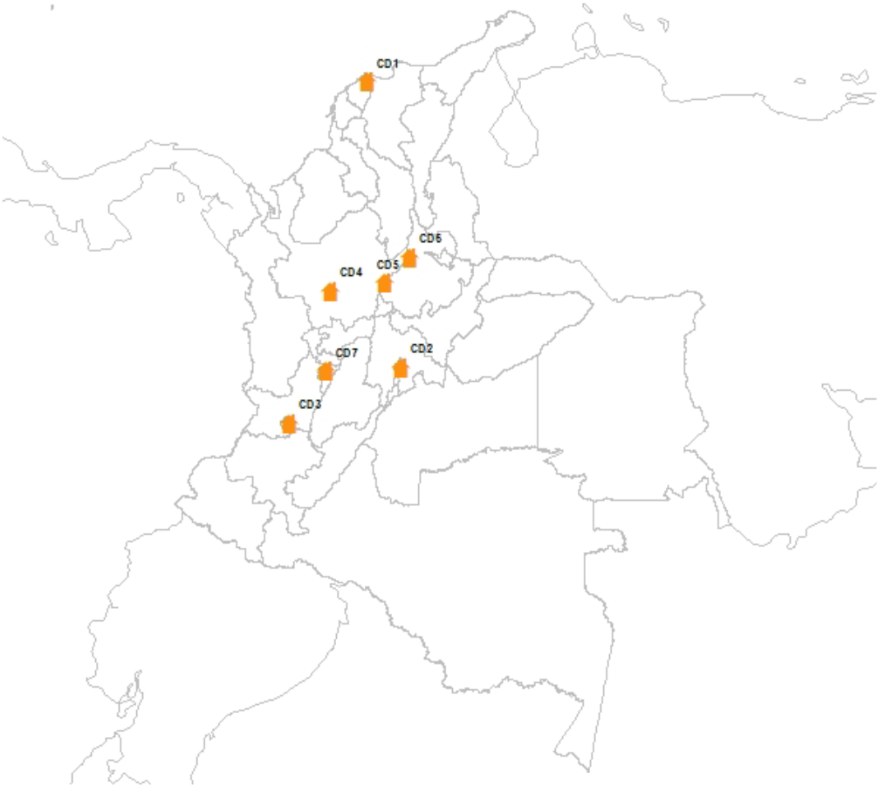

Figure 2 Potencial DC location, transportation routes and zones
Source: Author

As a result, the model will determine which DCs should be installed; zone/retailer allocation to each DC and the fixed, operational, transportation and inventory (both safety and cycle) costs of the optimized distribution network.

As been mentioned before, two methodologies were implemented for the problem resolution, the first was exhaustive revision and the second a genetic algorithm.

Different scenarios were evaluated; some of these contemplate multimodal transport, using Colombia´s fluvial wealth to complement ground transportation, having lower transportation fees by using the rivers and reducing logistics costs, improving Colombian company's competitiveness and promoting the economic development of the country. This analysis justifies the investment to improve rivers navigability in Colombia.

4.1. Exhaustive revision

This method was used to give the model a practical solution approach, it allows to obtain a result with a lower level of complexity and therefore less solution time but it requires a higher level for analyzing the results and database management. Given the dimension of the problem, the solution area was limited by discarding unreasonable solutions to reduce its complexity, also ten scenarios were created.

4.1.1. Results

The costs of each scenario according to the modeling results are shown in Table 3. The scenario with the lower total costs is scenario 9 which implies to install both C1 and C5 distribution centers, which are Barranquilla and Puerto Berrio respectively, this scenario was planned to supply C5 from C1 by river and then supply the retailers by road transportation.

Table 2. Results

Scenario	DC LOCATION	Total costs (Million USD)
Scenario 1	**BAQ-CALI**	$ 13.99
Scenario 2	**BAQ-BAR**	$ 13.37
Scenario 3	**BAQ-BOG**	$ 13.43
Scenario 4	**BAQ-BOG-CALI**	$ 14.30
Scenario 5	**BAQ-BOG-MED**	$ 14.58
Scenario 6	**BAQ-BOG-MED-CALI**	$ 14.94
Scenario 7	**BAQ-PER**	$ 14.77
Scenario 8	**BAQ-MED**	$ 14.68
Scenario 9	**C1-C5**	$ 12.90
Scenario 10	**BAQ-PTOB-BOG**	$ 13.43

Source: Author

For the best scenario (Scenario 9) the distribution network would be as follows:

Table 3. Allocation results best scenario

Cod zone	Zone	BQ	PB
Z1	ANTIOQUIA	0	1
Z2	ATLANTICO	1	0
Z3	BOGOTA	0	1
Z4	BOYACA	0	1
Z5	BUCARAMANGA	0	1
Z6	CALDAS	0	1
Z7	CALI	0	1
Z8	CAQUETA	0	1
Z9	CASANARE	0	1
Z10	CAUCA	0	1
Z11	CESAR	1	0
Z12	CR	1	1
Z13	CORDOBA	1	1
Z14	CUNDINAMARCA	0	1
Z15	GUAJIRA	1	0
Z16	HUILA	0	1
Z17	MAGDALENA	1	0
Z18	META	0	1
Z19	NARIÑO	0	1

Cod zone	Zone	BQ	PB
Z20	NORTE DE BOLÍVAR	0	1
Z21	NORTE DE SANTANDER	0	1
Z22	QUINDIO	0	1
Z23	RISARALDA	0	1
Z24	SANTANDER	0	1
Z25	SUCRE	1	0
Z26	SUR DE BOLÍVAR	1	0
Z27	TOLIMA	0	1
Z28	VALLE DEL CAUCA	0	1

Source: Author

The result shows the importance of multimodal transport, allocating all zones/retailers south of C5 to C5 and all the way to the north of it to C1. This way C1 supplies C5 by river and the retailers are supplied by road.

In order to analyze the influence of the inventory costs in strategic decision-making, a sensitivity analysis was made, modeling the same scenario with products with a holding cost of 50% its value.

The result allocates all zones/retailers to C1, which means only this DC should be installed. This shows that high-holding costs implies higher inventory costs and because it is necessary to have a safety stock for each DC, the impact of the high holding cost in the objective function is higher than the savings from the economics of scale if several DCs were installed, therefore in this case the best option as the model suggest, is to install only one DC.

Table 4. Results comparison with HC variation.

Costs	Best scenario (BQ-PB)		High Holding Cost (BQ)	
Transport costs	$	9.763.157	$	11.621.306
Safety stock costs	$	347.892	$	1.014.665
Cycle inventory costs	$	244.363	$	570.358
Fixed costs	$	2.547.008	$	1.505.884
Total costs	$	12.902.420	$	14.712.215

Source: Author

Table 4 clearly shows the importance of scale economy in transportation, because in the high-holding cost scenario having only one DC, it must supply directly to each retailer unlike the first result where we have two DCs and freight consolidation which results in lower transportation costs. In addition, it is clear why the model suggests installing only one DC if we observe the safety stock costs, this costs would increase potentially for each new DC to be installed.

4.2. Genetic algorithm

The genetic algorithm parameters used were the following:

- Initial population size: 20
- Crossover type: Roulette
- Mutation probability: 5%

A binary coding was used, where each gene represents a distribution center, taking a value of one if the DC should be installed and zero otherwise. In this problem, the DC capacity is infinite so it is not necessary to code the retailers inside each chromosome; instead, an internal algorithm allocates optimally each retailer to the DC with the lower cost.

If $CT(i,j)$ represents the partial total cost associated to the fact that the DC i supplies the retailer j, we have:

$$CT^*(j) = \underset{i}{\text{ArgMin}}\, CT(i,j)\ ;\ \forall\, j$$

This function searches the center with the less partial cost for each retailer and makes the respective allocation. The chromosome *fitness* is given then by the following equation:

$$Fitness = \frac{1}{\sum_{j=1}^{M} CT^*(j)}$$

The fitness is the base to determine the algorithm´s crossovers, which will lead to the final solution. The parameters of the problem to be solved are:

- Two demand periods.
- Seven potential distribution centers.
- Twenty eight zones/retailers.
- Twelve product categories.

The algorithm was applied to three different scenarios in order to make a sensitivity analysis of the model variables. The first scenario is the original problem, considering all the variables and the magnitudes of the real problem, the second scenario omits the costs associated to inventory (safety and cycle) and the third one decreasing the transportation costs by river (in order to stimulate the multimodality) and the holding costs by 50%.

1. For the first scenario the algorithm suggests to open only one DC (C1) and supplying all the retailers from it, the associated costs to this configuration are:.

Table 5. GA results (USD)

Fixed costs	$ 958,849
Inventory costs	$ 347,074
Transport costs	$ 11,423,745
Total costs	$ 12,729,665

Source: Author

2. If inventory costs are not considered, the algorithm suggests to open C1 and C5, the associated costs to this configuration are:

Table 6. Results ignoring inventory costs (USD)

Fixed costs	$1,502,728
Inventory costs	-
Transport costs	$ 10,180,025
Total costs	$ 11,682,755

Source: Author

As shown in Table 8, disregarding the inventory costs makes feasible to open another DC, which exploits the economics of scale decreasing the global transportation costs, nevertheless the fixed costs increased by 63%.

Table 7. Retailer's allocation ignoring inventory costs

Cod zone	Zone	DC allocation
Z1	ANTIOQUIA	C5
Z2	ATLANTICO	C1

Cod zone	Zone	DC allocation
Z3	BOGOTA	C5
Z4	BOYACA	C5
Z5	BUCARAMANGA	C5
Z6	CALDAS	C5
Z7	CALI	C1
Z8	CAQUETA	C5
Z9	CASANARE	C5
Z10	CAUCA	C5
Z11	CESAR	C1
Z12	CR	C1
Z13	CORDOBA	C1
Z14	CUNDINAMARCA	C5
Z15	GUAJIRA	C1
Z16	HUILA	C5
Z17	MAGDALENA	C1
Z18	META	C5
Z19	NARIÑO	C1
Z20	NORTE DE BOLÍVAR	C1
Z21	NORTE DE SANTANDER	C1
Z22	QUINDIO	C5
Z23	RISARALDA	C5
Z24	SANTANDER	C5
Z25	SUCRE	C1
Z26	SUR DE BOLÍVAR	C1
Z27	TOLIMA	C1
Z28	VALLE DEL CAUCA	C5

Source: Author

3. In the third scenario when decreasing the fluvial transportation costs by 70% and the holding costs by 50% the associated costs of this configuration are:

Table 8. Results for third scenario

Fixed costs	$	1,949,150
Inventory costs	$	221,294
Transport costs	$	7,809,948
Total costs	$	9.980,191

Source: Author

As it was expected, in this scenario the algorithm suggests to open more DC than the previous scenarios, being Barranquilla (C1) and two river-supplied sites, which are Puerto Berrio (C5) and Barrancabermeja (C6). The fluvial transportation fees used on this scenario aren´t far from reality, if the navigability of the Magdalena River is improved. Table 10 shows the retailer´s allocation for this scenario.

Table 9. Retailer´s allocation third scenario

Cod zone	Zone	DC allocation
Z1	ANTIOQUIA	C5
Z2	ATLANTICO	C1
Z3	BOGOTA	C5
Z4	BOYACA	C5
Z5	BUCARAMANGA	C6
Z6	CALDAS	C5
Z7	CALI	C5
Z8	CAQUETA	C5
Z9	CASANARE	C5
Z10	CAUCA	C5
Z11	CESAR	C1
Z12	CR	C1
Z13	CORDOBA	C1
Z14	CUNDINAMARCA	C5
Z15	GUAJIRA	C1
Z16	HUILA	C5
Z17	MAGDALENA	C1
Z18	META	C5
Z19	NARIÑO	C5
Z20	NORTE DE BOLÍVAR	C1
Z21	NORTE DE SANTANDER	C6
Z22	QUINDIO	C6
Z23	RISARALDA	C6
Z24	SANTANDER	C6
Z25	SUCRE	C1
Z26	SUR DE BOLÍVAR	C1
Z27	TOLIMA	C5
Z28	VALLE DEL CAUCA	C5

Source: Author

It can be concluded from this results that the holding cost is inversely proportional to the number of DC to be installed, this is due to the safety stock, because each DC needs its own safety stock. Therefore, if the holding costs are low, installing several DC can be attractive.

A graphical analysis of the results is made from the figures 3, 4, 5, and 6.

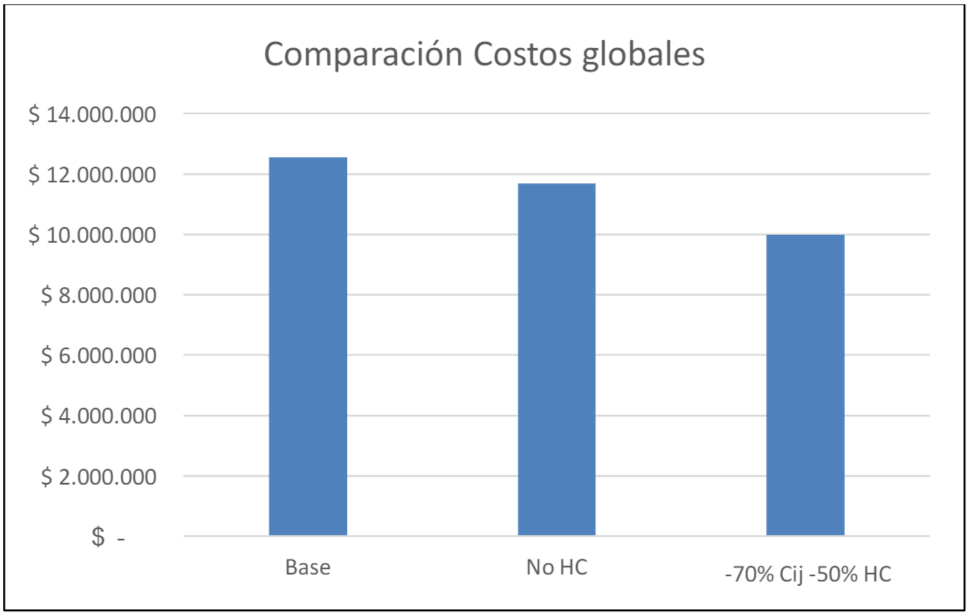

Figure 3. Global costs comparison between scenarios
Source: Author

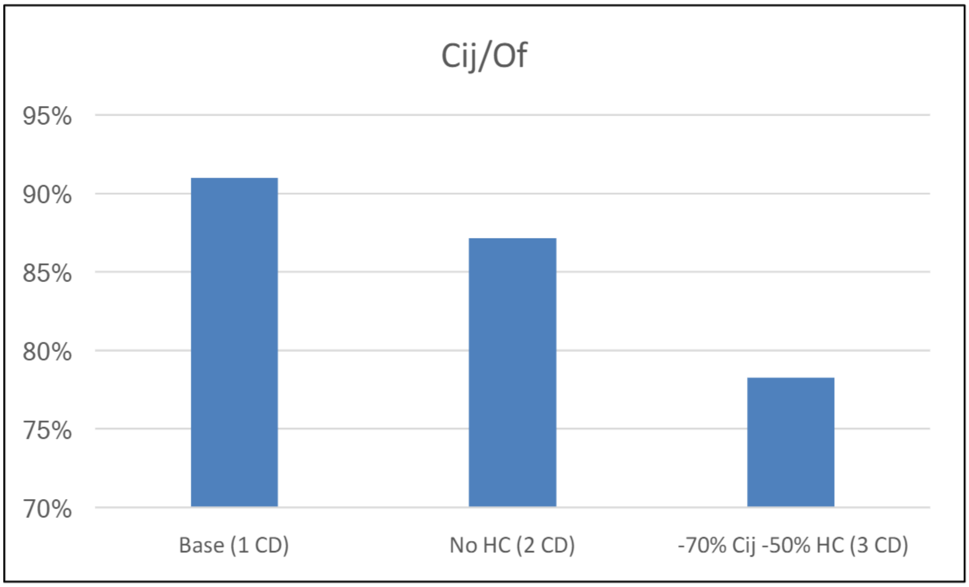

Figure 4. Impact of the transportation cost in the objective function
Source: Author

Figure 4Figure 5 clearly shows the impact of transportation costs in the objective function decrease if the number of DCs is increased; this is due to scale economy and freight consolidation to others DCs, which then realize the distribution to retailers in lower capacity vehicles.

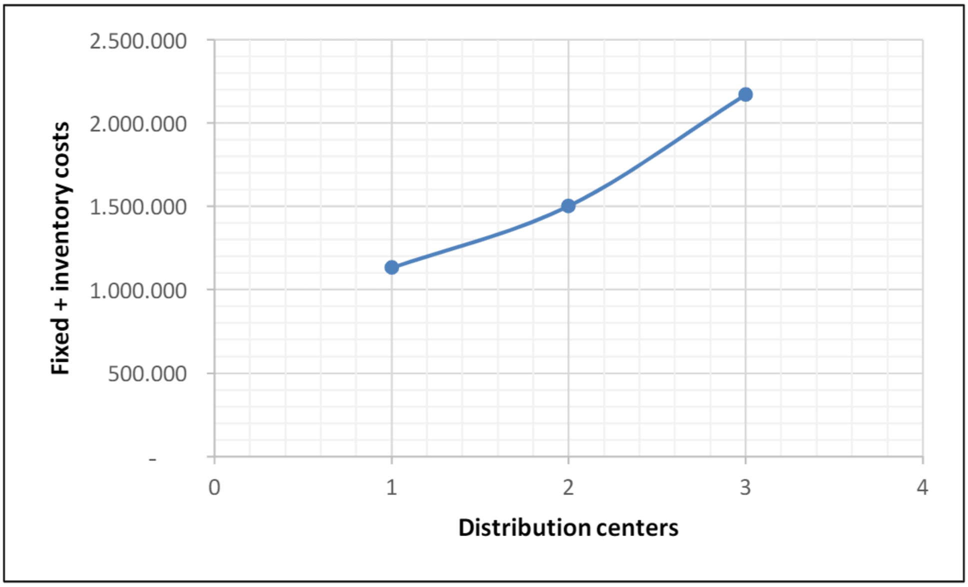

Figure 5. Impact of the number of DCs in the fixed and inventory costs
Source: Author

The Figure 5 shows that for each new DC to be installed the inventory and fixed costs increase by 50%. This conclusion is crucial and should be always consider when making this kind of strategic decisions.

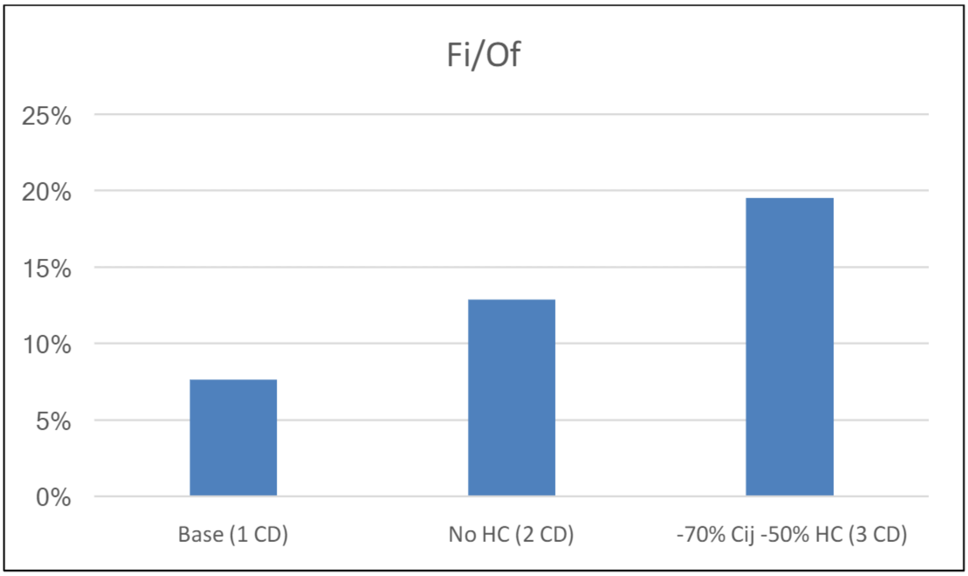

Figure 6. Impact of the fixed costs in the objective function.
Source: Author

As shown in Figure 6, the impact of fixed costs in the objective function increase proportionally to the number of DCs to be installed, in this case this costs increase by 100% for each new DC.

4.3. Results comparison between methodologies

The result of the exhaustive revision methodology suggests installing two DCs (C1-C5) with a global cost of $12.9 million dollars, while the genetic algorithm suggests installing only one DC (C1) with a global cost of $12.7 million dollars for the same problem. This difference could be product of the fact that the first methodology is initially based in prefixed matrixes created by the researcher´s criteria, these substantially reduce the computing resolution time but it lowers the algorithm effectively.

In both cases the results are close to the optimum, therefore the use of one or another depends of the researcher or consultant needs, if the objective is a fast, low programming complexity solution and there exists obvious allocations that allow to enclose the problem, then exhaustive revision should be used. On the other hand, if there are few to none obvious allocations and the programming complexity is not relevant, the genetic algorithm gives a nearly optimum solution without falling into local optimums.

5. Conclusion

The result of the application of the proposed model to a real case of a company of the steel sector in Colombia, allows visualizing the impact on each of the logistic costs that the company falls into, being on this particular case the cost of transportation the most relevant for strategic-tactical decision-making. On the other hand, building new distribution centers will result in large sums of savings when the company consolidates shipment. It must be pointed out this would be so if they have low density value goods, like steel, because the inventory costs depends directly to the value of the product. On the contrary, in the case of high-density value goods, the inventory costs have a larger value, which some may say it is not advisable to build new facilities for distribution centers. It can be noticed that an augmentation in the number of DC tends to reduce the transportation costs, but can increase the inventory costs, in particular the impact on the safety stock. The proposed model allows estimating the quantity of safety stock that each DC must install for each type of product for the quality service to be optimized, which is highly useful for the company because it strategically guarantees that there will be no shortage on none of the level services and a highly trustworthy service.

When the sensibility analysis was made regarding the holding cost Eppen (1979) premise was confirmed, that means consolidating multiple facilities inventories at once only decreases the costs of them. The model for an scenario where there is a high holding costs demonstrates that the best option in this cases is to make the distributions from just one distribution center because it might be possible that the savings made from the transportation costs do not compensate the costs of maintaining an inventory. For low holding cost products, the cost of inventory is not relevant directly but it has an indirect impact because the quantity of the inventory defines the size of the facility, which yields into fixed costs. On this scenario it is better to analyse the inventory costs that generates having several facilities if it compensate with the savings in transportation costs by consolidating shipment, taking into account the increase on the level of service that they offer to the customers when they reduce estimated delivery time. This last concept is hard to quantify so there will be a need to revise each case specifically and that the company establishes a methodology like the PAJ (Saaty,1990) which indicates the importance for the company to make the right decisions.

As mentioned earlier applying a strategic-tactical model it was obtained an integral result in which we can clearly appreciate the importance of making the right decisions as a whole, because as it can be observed in the results of the genetic algorithms, when an strategic decision is taken individually it is ignored the impact of the storage costs and also the inventory costs, so the model indicates that there must be 2 distribution centers for the original problem, in which there is the same data and it is taken into account the impact of the inventory costs, letting us take strategic-tactical decisions as whole, the model indicates to just build one distribution center for the optimization.

Working this paper under the assumption that the variances between destiny zones where independent, it is interesting to analyse in future investigations how would it influence the results regarding the fact that the demand variance in a present zone might not have correlation regarding the zones that are near this zone, which could happen on reality.

Other interesting extensions of this investigation would be including the costs associated with shortage and evaluating the model considering different production points, which might yield into a decentralized problem regarding the solution methodology, using the lagrangean relaxation or other heuristic such as tabu search or ant colony might be considered in upcoming investigations.

6. Referencias

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