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Supply Network Design by Using Clustering and Mixed Integer Programming

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Abstract

The Supply Network Design represents one of the high impact strategic decisions in competitiveness for companies. An optimal location of facilities in relation to the capacity of supply and demand, allows a high level service to attend the markets. In this paper, a methodological framework for designing supply networks by joining application of clustering techniques and mathematical programming are presented. The proposed methodology has been tested with real data obtained from a company of non-alcoholic beverages in Colombia. The approach considers three main stages. First, the costumers clustering process is performed by K-means in order to obtain the location for potential Distribution Centers (DC's). In the second stage, the model for supply network design is performed using a Mixed Integer Programming (MIP) by considering different options to assign DC's, and finally the valuation of the proposed methodology on a real case. A distribution scheme, which allows enter to new market areas with an efficient strategy to penetrate products to big cities such as Bogotá in Colombia, was found.

Key words: *Clustering, Mixed Integer Programming, Supply Chain Management, Supply Network Design*

1. INTRODUCTION

The growth of an organization is subject to market conditions and capabilities, which must be managed for the long term. The previous statement is distinguished as a key strategic issue in managing the supply chain. The Supply Network Design (SND) represents the impact of strategic decisions on the competitiveness of an organization, defining the number, location, and capacity of the warehouses and manufacturing plants, or the flow of material along the logistics network. [1]. This article addresses the issue of the Supply Network Design (SND) for industries, by considering the growth and aspiration to enter new markets, and also by changing their distribution strategies and schemes of operation, with the inclusion of new warehouse locations, outlets and a heterogeneous fleet for product delivery. The proposed methodology has been tested on real data obtained of the case of an industry dedicated to the regional production and distribution of Non- Alcoholic Beverages (NAB) in Colombia.

Non- Alcoholic Beverages in Colombia remain at a constant increase due to two primary forces: increased income and poverty reduction. This second element has been one of the principal reasons to generate an increase in Non-Alcoholic Beverages (NAB) consumed in the previous years, despite a considerable decrease between 2010 and 2013 of about 37%. In other words, approximately 1.7 millions of people have become part of the middle class and have converted into active market consumers [2]. As a result of the previous fact, there exists benefits and challenges for the big companies of the sector, but also for the medium-sized industries which are not part of the national distribution in a big scale, but that look for space to sell their products in small and big cities.

This article addresses the problem of designing a distribution network for companies that sell soft drinks (NAB). The problem has been split into three stages: i) generation of clusters through grouping of mathematical techniques to determine the potential customers of distribution centers locations; ii) development of a mathematical model of mixed integer programming for network design; iii) validation of the proposed methodology in a company dedicated to the production and distribution of NAB. The proposed model considers a distribution system - inventory of three links in the supply chain (factories, distribution centers and areas of consumption), in which decisions must be made for expansion or contraction of distribution centers, allowing tactical decisions and strategic logistics network.

The main contribution of the paper is to examine the applicability and effectiveness of a mixed methodology by combining clustering and Mixed Integer Linear Programming in a real case study associated with a supply chain of consumer products NAB. According to the literature reviewed, there are few articles that include methodologies for design distribution networks with clustering techniques to solve real cases.

Section 2 presents relevant literature with supply chain management and clustering technique. The section 3 offers the proposed methodology. Finally, computational results and conclusions are presented in the section 4.

2. LITERATURE REVIEW

Part of the planning process of the Supply Chain Management (SCM), is oriented to find the best possible configuration of the network. The process considers decisions related to the location of facilities, the production and the inventory decisions, as well the distribution systems by considering routing decisions [3].

2.1 Supply network design and management

Many studies related to the supply network design SND problem, or SCND (Supply Chain Network Design) have been published [4–13]. From the conceptualization and scope of the supply network design, these works considerate three levels: strategic, tactical and operational [1], [8], [9] and [10]. In particular, the fulfilment of demand by a set of performed routes, the pricing, the service level, are elements related with the level of operational decisions. The amount to be transported from the network locations, the transport mode, volume, type of inventory, quantities to buy from suppliers, the type of information technology and knowledge management are considered as problems of the tactical level.

Finally, the decision of the number and the location of the echelons in the network, its capability, the quality, the technology type, the number of contracted suppliers, and the reserve capacity of suppliers and decompositions points are decisions of strategy level [10] and [12].

The previously published works present a base of the decision levels in SND environment; however, they can specific decisions between the combination of levels (especially in the tactical and operational level), where the route and fleet definition results are a high impact on the performance of the distribution [14]. The considered problem in this work is related to decision of strategic and tactical level.

2.2 Supply network design by using mathematical programming and clustering techniques

Given the nature of the mathematical models of the supply network design and the impact of their decisions throughout the supply system for a company; the field related to the supply network design is quite extensive. Some specific areas related to the network design are: deterministic models of echelons, deterministic models of multiples echelons and multiple product, design methodology by using exact methods, design methodology by considering simulation design methodology using heuristics and metaheuristics, dynamics network design models, and stochastic models [7]. Many of these areas have been integrated into the study of the problem by experts and academics, achieving important developments in the evolution of the supply network design theory [4–13].

In addition, different objective functions have been considered to address different network design problems [7 – 8]. Works [11] and [15] show a complete classification of modelling approaches used in the network design, including models with one or more objectives, and deterministic and stochastic approaches. In the literature reviewed, it is common to find deterministic applications with linear or nonlinear mixed formulation such as [16–20]. In addition, applications including uncertainty of parameters [4–8] and [21–23]. Generally binary variables are used to determine the opening or closing decisions of the supply network design [23].

In the last decade, different approaches have been proposed to group up installations in the supply networks [24], where the coordination between agents demonstrates synergies that allow improve the performance of the supply system. [25], specifically for emergent markets [26]. In summary, the clustering technique brings benefits from the point of view of SCM as well as from their joint application to the mathematical programing to respond to the SND problem [27–29].

3. METHODOLOGY

The development of the investigation was conducted into three stages: i) determine a possible number of groups of customers to select the potential location of the distribution centers. It is possible to determinate a superior and inferior limit to find the optimal number of clusters of a considered solution area, when the number of groups or clusters is unknown, ii) development of a deterministic mathematical model of mixed integer programming for the network design; and iii) validation of the proposed methodology in the study case for a company.

The case studied company is dedicated to NAB production and distribution in the department of Cundinamarca in Colombia. The growing projection of the company is venturing into new consumption areas.

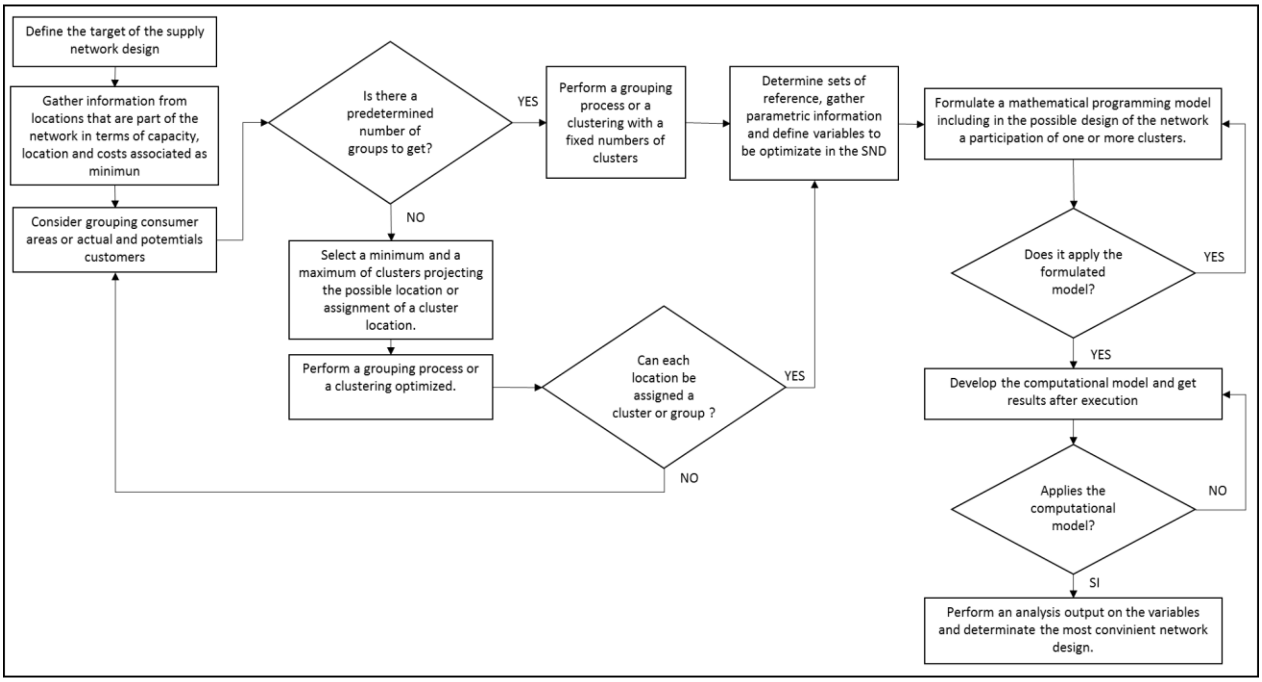


Figure 1. Proposed methodological framework for SND problem
Source: Authors.

3.1 Grouping and Modelling for a supply network design

In this paper, the clustering algorithm k-means has been used, given its simplicity and effectiveness to the problem to generate clusters in similar logistics problems. The general idea of the algorithm is determining the best location of distribution centers that reflect a customer group. The algorithm description is shown below:

3.1.1 *Clustering K-Means algorithm*

Since group of objects is X and an integer is $k\ (\leq\ n)$, the algorithm *K-means* tries to find the participation of X in *k* groups that minimize the sum of errors squared in the groups (WGSS), by its acronym in English *Within groups sum of Scared errors*) [30]. This process is commonly formulated as show below:

$$Min\ P(W,Q) = \sum_{l=1}^{k}\sum_{i=1}^{n} w_{il} d(X_i, Q_l) \tag{1}$$

Subject to

$$\sum_{l=1}^{k} w_{il} = 1 \quad 1 \leq i \leq n \tag{2}$$

$$w_{il}\ \in \{0,1\},\ \ 1 \leq i \leq n; \quad\ \ 1 \leq l \leq k \tag{3}$$

w_{il} is a binary variable represented with the value of 1 if object i is assigned to group l, otherwise the variable is represented with the value of 0. W is a matrix partition$n\ x\ k$, $Q\ =\ \{Q_1, Q_2, \dots, Q_k\}$ is a set of objects in the same domain, and $d(.,.)$is the Euclidian distance between two objects. The restriction (2) assures that one object is assigned to one group; meanwhile the restriction (3) indicates the integrality of the variables.

Once the *K-means* algorithm is applied, the potential location of each distribution center (assuming that one distribution center serves a group of customers) will be equivalent to the geographic coordinates of the center of gravity for each cluster. In the case that the center of gravity corresponds to a prohibited geographic site, the distribution center is then located in the nearest possible site. This way, the potential number and location of the distribution centers (subscript *k* of the mathematical model) to be considered in the mathematical model is described below:

3.1.2 *Mathematical model proposed for the SND problem*

General characteristics and assumptions

The general characteristics and assumptions of the deterministic mathematical model of the supply network design are as follows:

- The entire physical network infrastructure is assumed inside of one unique country, without considering international physical distribution.
- The objective is minimize total logistics costs, emphasizing storage costs, fixed operating costs, opening and closing distribution centers, transportation costs and manipulation products cost.
- The model is designed to make relative consideration for a unique period of planning and

- accepts the consideration of multiple products (beverage)
- The model includes as decision variables, the closure and consolidation of distribution centers and manufacturing and shipping flow of products through the network.
- We considerate a multi-echelon distribution system. One of the echelons is constituted by the center distribution (CD's), which is of sizable magnitude and has a considerate amount of inventory.
- The proposed model starts of an infrastructure of plants and center of distribution, which are already established, and it seeks to review the closure, opening and consolidating the distribution operation in the CD's.
- We consider the capability and storage constraints for each echelon.
- The plants could send the finished product to the CD´s, that is to say that they are not considered direct shipments between plants and customers.
- It is considerate as a unique mode of transportation overland by truck (the proposed model not include the decision of mode of transportation), and to not include decisions on truck types.
- The model does not explicitly take into account financial considerations relative to taxes and tax benefits typical to marketing processes.

Index

i	Beverage type	$(i = 1 \dots m)$
j	Fabric type	$(j = 1 \dots n)$
k	Type of Intermediate CD	$(k = 1 \dots K)$
l	Consume zone type	$(l = 1 \dots . L)$
v	Truck type	$(v = 1 \dots V)$

Parameters

The parameters consider all the information (data) required for the development of the proposed model.

$\boldsymbol{CAlm_k}$ Maximum storage capacity in the intermediate distribution center of type k

$\boldsymbol{CAlmin_k}$ Minimum storage capacity in the intermediate distribution center of type k

$\boldsymbol{NMAX_v}$ Maximum permitted number of trips per month by truck of type v

$\boldsymbol{NCam_v}$ Available number of trucks type v

$\boldsymbol{CCag_v}$ Capacity in units per truck of type v

$\boldsymbol{CF_k}$ Fixed cost of operating store type k

$\boldsymbol{Cm_k}$ Variable cost for operating a unit in the store k

$\boldsymbol{S_v}$ Enlistment cost of one trip in the truck type v

$\boldsymbol{CKM_v}$ Cost per traveled kilometer for the truck type v

$\boldsymbol{CDESC_v}$ Discharge cost for the truck type v when it reaches the target site

$\boldsymbol{absCD_k}$ X coordinate for the intermediate distribution center of type k

$\boldsymbol{OrdCD_k}$ Y coordinate for the intermediate distribution center of type k

$\boldsymbol{absCP_j}$ X coordinate for the plant type j

$\boldsymbol{OrdCP_j}$ Y coordinate for the plant type j

$\boldsymbol{absZC_l}$ X coordinate for the consume zone type l

$\boldsymbol{OrdZC_l}$ Y coordinate for the consume zone type l

$\boldsymbol{Dem_{il}}$ Estimate demand for the beverage type i in the consume zone type l

$\boldsymbol{Cof_{ij}}$ Supply capacity for the beverage type i in the plant type l

$\boldsymbol{CProd_{ijk}}$ Unit cost production of the beverage type i in the plant type j, which is taken to the intermediate distribution center type k

$\boldsymbol{D1_{jk}}$ Distance between the plant of type j and the intermediate distribution center type k.Where:

$$\boldsymbol{D1_{jk}} = \sqrt{\left(absCD_k - absCP_j\right)^2 + \left(OrdCD_k - OrdCP_j\right)^2} \quad (4)$$

$\boldsymbol{D2_{kl}}$ Distance between the Intermediate distribution center of type k and the Consume zone type l Where:

$$\boldsymbol{D2_{kl}} = \sqrt{(absZC_l - absCD_k)^2 + (OrdZC_l - OrdCD_k)^2} \quad (5)$$

$\boldsymbol{CTransA_{jkv}}$ Transport cost from the plant type j to the Intermediate distribution center of type k in the truck type v. Where:

$$\boldsymbol{CTransA_{jkv}} = S_v + \left(D1_{jk} * CKM_v\right) + CDESC_v \quad (6)$$

$\boldsymbol{CTransB_{klv}}$ Transport cost from the Intermediate distribution center of type k to the Consume zone type l in the truck type v. Where:

$$\boldsymbol{CTransB_{klv}} = S_v + (D2_{kl} * CKM_v) + CDESC_v \quad (7)$$

Scalar

p Indicates the number of intermediate stores CD to wish to open

Variables

$\boldsymbol{X_{ijk}}$ Variable that determines the beverage count type i made in fabric type j and sent to the distribution center type k.

$\boldsymbol{Y_{ilk}}$ Variable that determines the beverage count type i from the distribution center type k to the consumer zone type l

$\boldsymbol{BIN1_k}$ Binary variable that determines the assignation of a fixed cost to open the distribution center type k.

$\boldsymbol{BIN2_{kl}}$ Binary variable that determines the opening (value=1) or closing (value=0) to the distribution center type k serving the consume zone type l

$\boldsymbol{NVA_{jkv}}$ Number of trips between plant type j and intermediate distribution center type k in the truck type v

$\boldsymbol{NVB_{klv}}$ Number of trips between the intermediate distribution center type k and the consume zone type l in the truck type v.

Objective Function

The main function of the problem considered here is to minimize the total cost of the distribution network (CT), which includes fixed costs of opening or closing distribution centers, fixed operating costs of distribution centers, production costs, and transporting costs of the finished product.

$$Min\ CT = \sum_{k}^{K} BIN1_k * CF_k + \sum_{i}^{m}\sum_{l}^{L} Dem_{il} * \frac{BIN2_{kl}}{p} + \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} CProd_{ijk} * X_{ijk} + \sum_{j}^{n}\sum_{k}^{K}\sum_{v}^{V} CTransA_{jkv} * NVA_{kjv} + \sum_{k}^{K}\sum_{l}^{L}\sum_{v}^{V} CTransB_{klv} * NVB_{klv} \quad (8)$$

Restrictions

Constraints that determine the amount of flows of product must be less than the capacity of each factory.

$$X_{ijk} \leq Cof_{ijk} * BIN1_k \quad \forall i, \forall j, \forall k \quad (9)$$

Constraints ensuring the compliance of the demand of the beverage type i in the consumer zone l, which must be served by the intermediate distribution center type k.

$$\sum_{k}^{K} Y_{ikl} = \sum_{k}^{K} Dem_{il} * \frac{BIN2_{kl}}{p} \quad \forall i, \forall l \quad (10)$$

Constraints that determine the number of open centers of distribution type k.

$$\sum_{k}^{K} BIN2_{kl} = p \ \forall l \quad (11)$$

Constraints that determine the maximum storage capacity for each CD type k.

$$\sum_{i}^{m}\sum_{l}^{L} Dem_{il} * \frac{BIN2_{kl}}{p} \leq CAlm_k * BIN1_k \ \forall k \quad (12)$$

Constraints that determine the minimum storage capacity for each CD type k.

$$\sum_{i}^{m}\sum_{l}^{L} Dem_{il} * \frac{BIN2_{kl}}{p} \geq CAlmin_k * BIN1_k \ \forall k \quad (13)$$

Constraints that determine the allocation of fixed costs to the buffer that is in operation.

$$\sum_{k}^{K} BIN1_k = p \qquad \forall k \quad (14)$$

Constraints that determine the number of scheduled trips by truck type v to not exceed your monthly limit

$$\sum_{j}^{n}\sum_{k}^{K} NVA_{jkv} + \sum_{k}^{K}\sum_{l}^{L} NVB_{klv} \leq NMAX_v NCam_v \ \forall v (15)$$

Constraints ensuring that the load limit that could carry on the path 1 (factory - CD) is less than the maximum transport capacity

$$\sum_{i}^{m} X_{ijk} \leq CCag_v * NVA_{jkv} \quad \forall j, \forall k, \forall v \quad (16)$$

Constraints ensuring that the load limit that carries on the path 2 (CD- consume zone) is less than the maximum transport capacity

$$\sum_{i}^{m} Y_{ikl} \leq CCag_v * NVB_{klv} \quad \forall k, \forall l, \forall v \quad (17)$$

Constraints ensure maximum utilization of truck capacity in a scheduled trip.

$$\sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} X_{ijk} \leq \sum_{v}^{V} CCag_v * NMAX_v * NCam_v \quad (18)$$

Constraints of balance between fabrics and distribution centers.

$$\sum_{j}^{n} X_{ijk} = \sum_{l}^{L} Y_{ikl} \quad \forall i, \forall k \quad (19)$$

4. CASE STUDY

The company case of study has a long trajectory in the regional market in the departments of Cundinamarca and Tolima, Colombia, and could be incorporated into a wider market such as the city of Bogota D.C. In particular, the company wants to address this need as an opportunity to design a supply network that allows creating a competitive advantage and expanding its market, serving with the product manufactured and distributed in the right amounts, to the exact destinations and at the right time. The company case of study was performed obtaining its supply through different providers; the supply is unloaded and taken to the different areas of production. Depending on the product, the raw material is worked in its corresponding line, for example the production of plastic containers (PET) in the machine, meanwhile, inputs such as syrups, dyes and chemicals in their respective measurement areas. The most common consumption zones in Colombia, where the product is distributed are: Girardot, Melgar, La Mesa, Mesitas, Fusagasugá, Carmen de Apicalá, Nariño, Agua de Dios and Flandes (Figure 2). The main products marketed are sodas, juices and water in presentations of 335ml, 600ml, 1 liter and 2 liters, for sodas and juices; water is produced and packed by PET bottle 600ml, 5.5 liter bags, 340ml, 600ml bag; 30ml and refreshments.

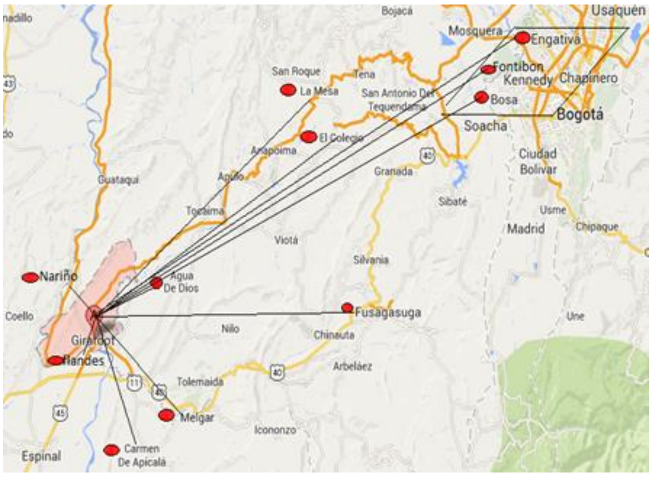


Figure 2. Scheme geo- referencing of the locations of current production and consumption Source: Authors.

4.1. **Results and Discussion**

As shown in Fig.2 there are three possible areas of consumption in the city of Bogotá D.C., which is a decision generated after an economic study conducted previously.

The new zones: Bosa, Fontibón and Engativá, are part of a plan to include product to the Colombian capital. Following the methodology proposed, the results of clustering and optimization are shown below.

4.1.1 *K -means clustering*

After identifying the consume centers X , it is necessary to identify a reference point in each zone, this way there can be a *k* number of groups depending on their distances *d(·,·)* so that later on it is possible to identify possible collection centers for product distribution, the software available for this use is *Orange Canvas* which has a free version available at (http://orange.biolab.si/) and runs on a computer with processor Corei5 to 1.8HGz and 6GB RAM . The number of *clusters* is 3 and it is a known priori in this case study.

Figure 3 and 4 show how the clusters are formed, thus providing three groupings: *cluster* one is conformed by the consume zone of Fusagasugá, La Mesa and Bosa; *cluster* two conformed of Agua de Dios Girardot, Carmen de Apicalá, Melgar, Flanders and Nariño; Finally, *cluster* three is formed with the remaining consume zones, such as, Mesitas, Engativá and Fontibón.

4.1.2 *Identification of distribution centers*

Once the clusters were obtained, the possible areas for new distribution centers to be located are identified, this way there is a benefit when the consume zones that are part of the group are highly populated. Figure 5 shows the available areas where the new locations could be located, which in summary are: for the first cluster, Granada (a), for second cluster Ricaurte (b) and for the last cluster (c) Mosquera. It is noteworthy that in the case of the third cluster, Mosquera was chosen as a potential location since it has an industrial potential and its proximity to the consume zones in that group.

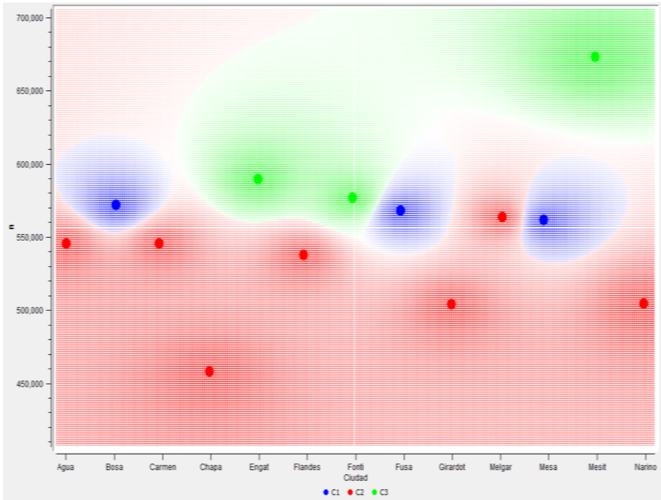


Figure 3. Cluster diagram for NAB supply network Source: Authors

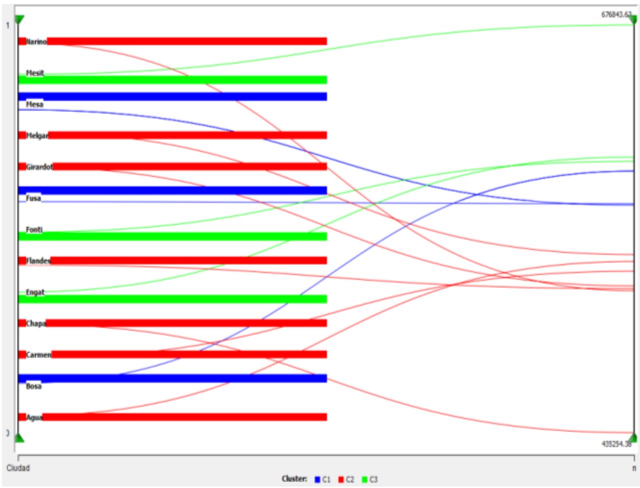
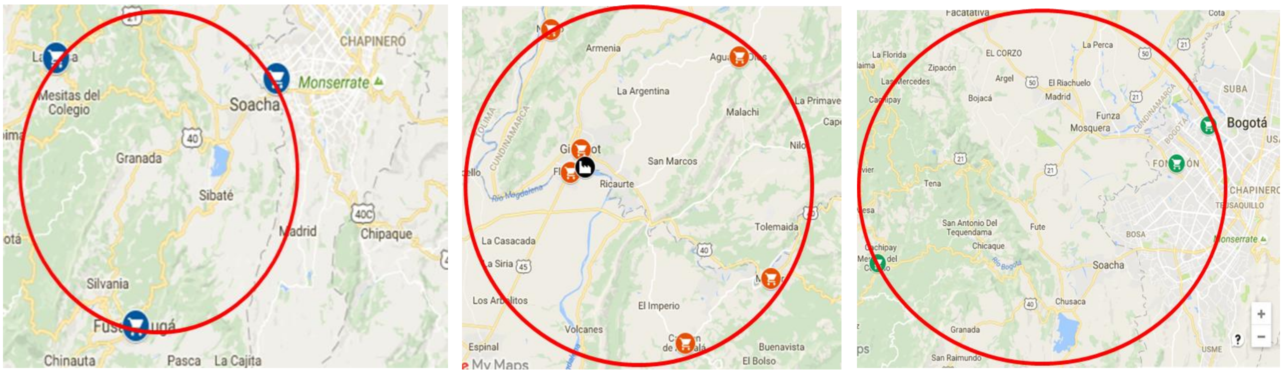


Figure 4. Parallel coordinates diagram for Cluster Source: Authors



(a). (b). (c).

Figure 5. Georeferencing scheme for possible locations of new Distribution centers in (a) cluster one, (b) cluster two and (c) cluster three. Source: Authors

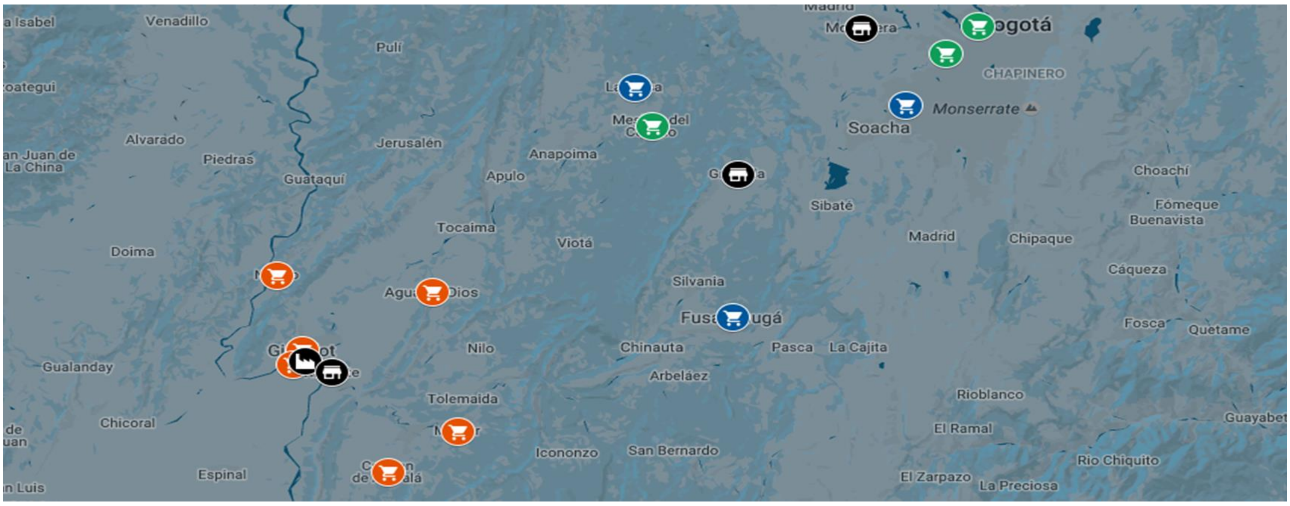


Figure 6. Geographical location for each facility. Source: Authors

Continuing the proposed methodology with the previous results, we have different possibilities of designs for the distribution network with the computational results shown below (see Table. 1). These results were obtained with the GAMS software (*General Algebraic Modelling System*, which is available in http://www.gams.com/download/) for use on a computer with the same characteristics mentioned in the previous section. It identifies that the given characteristics of a binary variable $BIN2_{kl}$ is assignable to each CD k opened, one consume area l to attend, generating for each unit increase a value p, a decrease in the variable cost of the total network. In other words, the sum of the associated cost to produce, storied and carried out, given by X_{ijk}, Cm_k y $CTransA_{jkv}$, $CTransB_{klv}$, decrease primarily by reducing distances to travel by transport. On the contrary, given the unit increase of p, the total fixed cost $\sum_k^K CF_k$ increases (See. Table 2).

The final design recommended for the case study is given by the factory, the distribution center CD2 and CD5 Ricaurte and Bosa. Since it denotes lower logistics costs and better use of resources, as evidenced by Figure 7.

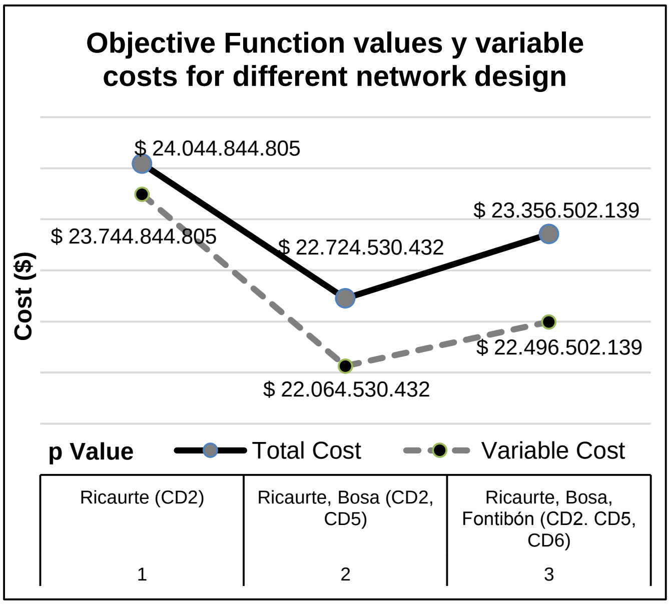


Figure *7.* Values for the objective function and variable cost to different network designs Source: Authors

Table 1. Computational results for possible network designs. Source: Authors

Valor de p	Y(i,k,l)	Mesitas	La Mesa	Carmen	Flandes	Melgar	Nariño	Agua de D	Fusa	Engativa	Fontibon	Bosa	Costo Variable
Diseño con p=1	Ref1.CD2	3215	3898	2750	2029	2521	3900	3127	3503	3383	6574	5277	23744844805,35
	Ref2.CD2	4853	4790	1257	4674	4353	4332	1841	2331	5731	3956	3884	
	Ref3.CD2	2044	2113	2445	2942	1633	2426	1835	1464	4950	2938	2950	
	Ref4.CD2	959	1187	504	976	536	851	1043	1259	1968	2299	3836	
	Ref5.CD2	3544	4559	4247	3675	4356	4649	3059	3183	5531	6483	4031	
	Ref6.CD2	1853	2568	2635	1494	2200	2530	2606	2421	3646	3667	3480	
	Ref7.CD2	1262	1765	1363	1593	1735	1296	1377	1207	2334	2725	2465	
	Ref8.CD2	4101	4285	6247	5050	7134	2648	5788	7443	1665	2061	2094	
	Ref9.CD2	3315	3606	4654	2143	3343	6025	4358	2051	3240	3057	3247	
	Ref10.CD2	7605	6602	3561	6434	5903	5275	4621	4713	2293	2385	1568	
	Ref11.CD2	7536	7659	7733	7485	6606	6865	7435	7462	845	1433	1700	
	Ref12.CD2	4572	5170	3722	5108	4725	3842	3834	5450	3208	2221	3344	
Diseño con p=2	Ref1.CD2				2029		3900		3503	3383	6574	5277	22064530431,81
	Ref1.CD5	3215	3898	2750		2521		3127					
	Ref2.CD2				4674		4332		2331	5731	3956	3884	
	Ref2.CD5	4853	4790	1257		4353		1841					
	Ref3.CD2				2942		2426		1464	4950	2938	2950	
	Ref3.CD5	2044	2113	2445		1633		1835					
	Ref4.CD2				976		851		1259	1968	2299	3836	
	Ref4.CD5	959	1187	504		536		1043					
	Ref5.CD2				3675		4649		3183	5531	6483	4031	
	Ref5.CD5	3544	4559	4247		4356		3059					
	Ref6.CD2				1494		2530		2421	3646	3667	3480	
	Ref6.CD5	1853	2568	2635		2200		2606					
	Ref7.CD2				1593		1296		1207	2334	2725	2465	
	Ref7.CD5	1262	1765	1363		1735		1377					
	Ref8.CD2				5050		6025		7443	1665	2061	2094	
	Ref8.CD5	4101	4285	6247		7134		5788					
	Ref9.CD2				2143		2648		2051	3240	3057	3247	
	Ref9.CD5	3315	3606	4654		3343		4358					
	Ref10.CD2				6434		5275		4713	2293	2385	1568	
	Ref10.CD5	7605	6602	3561		5903		4621					
	Ref11.CD2				7485		6865		7462	845	1433	1700	
	Ref11.CD5	7536	7659	7733		6606		7435					
	Ref12.CD2				5108		3842		5450	3208	2221	3344	
	Ref12.CD5	4572	5170	3722		4725		3834					
Diseño con p=3	Ref1.CD2				2029		3900		3503	3383	6574	5277	22496502138,56
	Ref1.CD5		3898	2750		2521		3127					
	Ref1.CD6	3215											
	Ref2.CD2				4674		4332		2331	5731	3956	3884	
	Ref2.CD5		4790	1257		4353		1841					
	Ref2.CD6	4853											
	Ref3.CD2				2942		2426		1464	4950	2938	2950	
	Ref3.CD5		2113	2445		1633		1835					
	Ref3.CD6	2044											
	Ref4.CD2				976		851		1259	1968	2299	3836	
	Ref4.CD5		1187	504		536		1043					
	Ref4.CD6	959											
	Ref5.CD2				3675		4649		3183	5531	6483	4031	
	Ref5.CD5		4559	4247		4356		3059					
	Ref5.CD6	3544											
	Ref6.CD2				1494		2530		2421	3646	3667	3480	
	Ref6.CD5		2568	2635		2200		2606					
	Ref6.CD6	1853											
	Ref7.CD2				1593		1296		1207	2334	2725	2465	
	Ref7.CD5		1765	1363		1735		1377					
	Ref7.CD6	1262											
	Ref8.CD2				5050		6025		7443	1665	2061	2094	
	Ref8.CD5		4285	6247		7134		5788					
	Ref8.CD6	4101											
	Ref9.CD2				2143		2648		2051	3240	3057	3247	
	Ref9.CD5		3606	4654		3343		4358					
	Ref9.CD6	3315											
	Ref10.CD2				6434		5275		4713	2293	2385	1568	
	Ref10.CD5		6602	3561		5903		4621					
	Ref10.CD6	7605											
	Ref11.CD2				7485		6865		7462	845	1433	1700	
	Ref11.CD5		7659	7733		6606		7435					
	Ref11.CD6	7536											
	Ref12.CD2				5108		3842		5450	3208	2221	3344	
	Ref12.CD5		5170	3722		4725		3834					
	Ref12.CD6	4572											

Table 2. Comparation of total costs in the network to values of p between 1 and 3. Source: Authors

Number of clusters	Distribution Centers opened	Total Cost (Objective Function) ($/t)	CF	CV
			Fixed Cost of each Distribution C.	Variable Cost Total
1	Ricaurte (CD2)	24.044.844.805	300,000,000	23.744.844.805
2	Ricaurte, Bosa (CD2, CD5)	22.724.530.432	660,000,000	22.064.530.432
3	Ricaurte, Bosa, Fontibón (CD2, CD5, CD6)	23.356.502.139	860,000,000	22.496.502.139

5. CONCLUDING REMARKS

The development and implementation of the proposed methodology provide significant results to conclude that in the case study, different options for network designs are obtained and that after the computer runs with p = 1, p = 2 and p = 3. The obtained results are better when comparing network costs for the three distribution centers available.

In addition to determining the overall use of clustering to group consumption centers and mathematical programming, it turns out to be an option to organize the scheme layout and design of the network to different scenarios. Thus, the subsequent modeling process provides results that are close to the operational reality of the system and serves as support for the process of decision-making at a strategic and tactical scenario. Consequently, the strategy of entering new markets for the organization of the case study, dedicated to the production and regional distribution of NAB, is supported by the coverage of the paradigm of managing the supply chain SCM and important phase of the process planning supply network, known as network Design supply SND or SCND.

It is important to mention that in adopting the mathematical model together with K-means clustering, may propose additional changes in the conformation of groups using other clustering algorithm, which would entail changes to the distribution scheme found at the optimum network design.

Finally after reviewing the results, network designs with *p=1* and *p=3* are discarded due to its high logistics costs and due to dynamic distribution that could arise, for example in the case of *p=1*, if only the CD 2 (Ricaurte) is opened, it would be required to bring the product to the town of Ricaurte, store it and then distribute it to the surrounding municipalities of the original manufacturing site of NTBs; in this case the variable cost of operating in the network would be 7.62% higher than that of *p=2*. Similarly, in the case of *p=3*, if only CD2 (Ricaurte), CD5 (Bosa) and CD6 (Fontibón) are opened, the same situation would be presented, showing a variable cost of operating the network of 1.96% above the option *p=2*.

For future research, it is recommended that a process of experimentation with different clustering algorithms and the inclusion of alternative routes and sequencing of vehicles to make the modeling process more complete in its approach to the operational reality of companies looking to design their network and serve new consumption areas which are characterized by a demand of high level of service

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Dizajn distributivne mreže primenom klastera i mešovitog programiranja celih brojeva

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Apstrakt

Dizajn distributivne mreže predstavlja jednu od strateških odluka u konkurenciji za kompanije visokog uticaja. Optimalna lokacija objekata u odnosu na kapacitet ponude i potražnje omogućuje visokom nivou usluga prisustvo na tržištu. U ovom radu predstavljen je metodološki okvir za projektovanje distributivnih mreža kombinovanjem primene tehnika klastera i matematičkog programiranja. Predložena metodologija je testirana sa realnim podacima dobijenim od kompanije bezalkoholnih pića u Kolumbiji. Pristup razmatra tri glavne faze. U prvoj fazi, proces klasteriranja kupaca vrši se pomoću K-sredstava kako bi se dobila lokacija za potencijalne distributivne centre (DC). U drugoj fazi, model za dizajn distributivne mreže se vrši pomoću mešovitog programiranja celih brojeva (MPCB) razmatrajući različite opcije za dodeljivanje DC-ma. U finalnoj fazi vrši se procena predložene metodologije u realnom slučaju. Kao rezultat, definisana je distributivna šema koja omogućava ulaz u nova tržišna područja sa efikasnom strategijom za prodiranje proizvoda u velike gradove kao što je Bogota u Kolumbiji.

Ključne reči: *Klasteriranje, mešovito programiranje celih brojeva, upravljanje lancima snabdevanja, dizajn distributivne mreže*