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Application of a Capacitated Centered Clustering Problem for Design of Agri-food Supply Chain Network

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Abstract

The supply chain of agricultural products has received a great deal of attention lately due to issues related to public health. Something that has become apparent is that in the near future the design and operation of agricultural supply chains will be subject to more stringent regulations and closer monitoring, in particular those for products destined for human consumption (agri-foods). This work is concerned with the planning of a real agri-food supply chain for chicken meat for the city of Tlemcen in Algéria. The agri-food supply chain network design is a critical planning problem for reducing the cost of the chain. More precisely the problem is to redesign the existing supply chain and to optimize the distribution planning. As mentioned in our paper, the entire problem is decomposed into two problems, and each problem is solved in sequential manner, to get the final solution. LINGO optimization solver (12.0) has been used to get the solution to the problem.

Keywords: *agri-food supply chains network, clustering cluster, optimization, CO2 emissions* .

1. Introduction

The The term agri-food supply chains (ASC) has been coined to describe the activities from production to distribution that bring agricultural or horticultural products from the farm to the table [1]. ASC are formed by the organizations responsible for production (farmers), distribution, processing, and marketing of agricultural products to the final consumers. The supply chain of agri-foods, as any other supply chain, is a network of organizations working together in different processes and activities in order to bring products and services to the market, with the purpose of satisfying customers' demands [2]. These products must therefore be rapidly shipped from the sellers to the customers. More-over the demand of consumers on healthy products in ever increasing and the regulations of the authority require an improvement on current ASC planning. Still integrated approaches for ASC planning are limited, see [3]. Furthermore, literature on real design and distribution planning examples is rare. More precisely, the aim of this work is coordination of decisions for location, allocation and transportation of products to achieve an efficient and green logistic network design and distribution planning. Furthermore, environmental costs of road transportation in terms of CO_2 emissions are taken into account in the computations. The Capacitated Centered Clustering Problem (CCCP) used in this study consists of defining a set of p groups with minimum dissimilarity on a network with n points. Demand values are associated with each point and each group has a demand capacity. The problem is well known to be NP-hard and has many practical applications.

2. State Of The Art

The location problem is to determine the location of one or more sites, so as to optimize a mathematical function that depends on distances between these sites and a set of potential users. The study of location theory began formally in 1909 when Albert Weber considers a problem of locating a warehouse to minimize the total distance between the warehouses and customers. After Weber, Hakimi in 1960 had considered a more general problem that considers the location of one or more sites in a network in order to minimize the total distance between customers and these sites, or to minimize the maximum distance.

[Florence Pirard 2005] gave the basic version of this problem as follows [11]:
Minimize the sum of fixed costs of the locations and variable costs related to transportation.
Constrained: Meet the entire demand from open sites.

A .Problems allocation
The allocation problem is to assign processing or manufacturing to the sites and determine the flow between the various network sites.
This problem is expressed as follows [11]:
Minimize the sum of costs of production and transportation.

Constrained:

- Meeting demand.
- Provision of raw materials.
- Respect the available capacity at the supply
- Respect the available capacity at the production
- Respect the available capacity at the distribution
- Balance the flow.

B. location-allocation Problems

In a location-allocation problem, we distinguish the term localization that refers to the determination of the locations of sites (sites of production or distribution centers), and the term allocation that refers to assigning activities to production sites, distribution centers or customers.

This location-allocation problem is expressed as follows [11]:

Minimize the sum of fixed costs related to facilities and variable costs related to production and transportation.

Constrained:

- Meeting demand
- Provision of raw materials
- Respect the available capacity at the supply
- Respect the available capacity at the production
- Respect the available capacity at the distribution
- Balance the flow
- Ensure that when a site is closed, no product is manufactured in this site and the material flows entering and leaving this site are void.
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Osman ALP et al. (2003) have proposed in their paper [4] a new genetic algorithm for the problem of site locations (facilities). This algorithm is simple and gives good solutions. The purpose of the model is to select the best location of the P sites to serve N points (areas) of application to minimize the distance between these sites and demand points.

M. J. Canos et al. (2001) defined the classic problem of localization of P-median as the location of P facilities to cover the requested command with the minimization of the total transport cost. They assume in their work [5] that these costs are directly proportional to the distance covered and the quantity of products transported.

M.T MELO et al. (2008) presented in their paper [6] a literature review of models of plant location and planning strategy for supply chain. The authors have noted the interest shown by several researchers treating stochastic cases. The authors' note that the tactical and operational decisions (routing and mode of transport) strongly depend on the decision of the location of sites and that integration decisions in Supply Chain Management is less studied.

Omar Ahumada et al. (2009) gave in this paper [3] the main contributions in the field of production and distribution planning for agri-foods. The authors have focused particularly on those models that have been successfully implemented. Then, they have classified this model according to relevant features, such as the optimization approaches used, the type of crops modeled and the scope of the plan.

Antonio Augusto et al. (2010) presented a solution for the CCCP (capacitated centered clustering problem) using the CS (clustering search) algorithm that uses the concept of hybrid metaheuristics, combining metaheuristics with a local search in a clustering process [7].

Lusine Aramyan et al. (2006) provide a literature review on existing performance indicators and models, and discuss their usefulness in agri-food supply chains [8].

3. Problem Description

Our problem is to determine the centroid of the cluster customers, and location / allocation between the slaughterhouses and the cluster customers (set of retailers). A cluster of customers includes customers in the closest distance with a condition that the amount of demands from different customers of this customer clusters is less than the capacity of the truck transport used. We used two types of transport trucks; one capacity of 400 chickens which sum customer orders of this customer clusters is less than 400 chickens and the other 800 chickens. Once the customer clusters are defined with their positions and capabilities, it remains for us to locate the different slaughterhouses and allocate the customer clusters to slaughterhouse, in such a way that capacity of vehicles (truck transport) and slaughterhouses are respected.

3.1 Assumptions

The assumptions made in this model are given as follows:

(1) The demand delivered to customers each day as an average of the order.

(2) The capacity of each customer cluster (sets of retailers) must not exceed vehicles capacity.

(3) The Processing capacity in slaughterhouses is always less than the sum of orders for each customer clusters assigned to this slaughterhouse i.

3.2 Model parameters

i: Index for slaughterhouse, $i \in I$;

j : Index for customer clusters; $j \in J$

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k: Index for customers, $k \in K$;
v:Index for vehicles; $v \in V$
x_i, y_i : Geometric position of the slaughterhouse i;
x'_j , y'_j : Geometric position of the customer cluster j;
x_k , y_k :Geometric position of the customer k;
n_j :Number of customers assigned to cluster j;
Q_j: Capacity of a vehicle that travels to the customer cluster j;
Dc_k: Demand of customer k;
Dcc_j: Demand of customer cluster j;
FC_i: Fixed cost for establishing a slaughterhouse i;
D_{ij}: Distance from slaughterhouse i to the centroid of customer cluster j;
P_l:Unit volume of the products l;
T_l: Operating time per unit.
C_jk^(v;km): Transportation costs per kilometer from site k to site j by vehicle v. These transportation costs involve costs for operating vehicle v, infrastructures costs, fuel consumption when v is empty and tolls;
C_jk^(v;t/km) : Transportation costs per ton/kilometer from site k to site j by vehicle v. These costs are for fuel consumption per ton and environmental costs; these latter are calculated in two steps. First the emission factor per vehicle per ton kilometer is assessed with the quantification method developed by ADEME. Then carbon dioxide emissions due to transportation are priced with the European Trading Scheme of carbon allowances on the European Energy Exchange, see [10].
Qi : Capacity of a slaughterhouse i;

3.3 Decision Variables
Y_{jk}=1,if the customer k is assigned to customer cluster j,= 0, otherwise;
Z_{ij}=1,if the customer cluster j is allocated to slaughterhouse i, =0, otherwise;
X_i = 1, if the slaughterhouse i is open, = 0 otherwise;

3.4 Model formulation

The mathematical model formulated for the minimization of Total Cost (TC) transportation in the city of Tlemcen (Algeria) (see Figure 1) in order to cover the entire order requested. Since the problem is highly complex, it cannot be solved in a single stage.

For this purpose, the entire problem is decomposed into two problems; each problem is solved in a sequential manner, while accounting for dependence between them.

The objective criterion is decomposed into the following sub problems:

(a) Capacitated Centered Clustering Problem (CCCP) [problem 1].

(b) Location- Allocation Problem [problem 2].

a) Capacitated Centered Clustering Problem (CCCP)

The The problem (1) aims at defining the set of customer's clusters by minimizing the total distance between these customers and the centre of the clusters. The mathematical model of CCCP is given as follows:

$$Min\ Z1 = \sum_{i \in I} \sum_{j \in J} \left\| (x_i - x'_j) + (y_i - y'_j) \right\|^2 Y_{ij} \ldots\ldots\ldots (1)$$

Subject to:

$$\sum_{i \in I} Y_{ij} = 1, \forall i \in I \ldots\ldots\ldots (1.1)$$

$$\sum_{i \in I} Y_{ij} = n_j, \forall j \in J \ldots\ldots\ldots (1.2)$$

$$\sum_{i \in I} x_i Y_{ij} \leq n_j x'_j, \forall j \in J \ldots\ldots\ldots (1.3)$$

$$\sum_{i \in I} y_i Y_{ij} \leq n_j y'_j, \forall j \in J \ldots\ldots\ldots (1.4)$$

$$\sum_{j \in I} (Dc_{il} * p_l) Y_{ij} \leq Q_j \quad \forall l \in L \ldots\ldots\ldots (1.5)$$

$$(x_i, y_i), (x'_j, y'_j) \in R^2, n_j \in N, Y_{ij} \in \{0,1\}, \ldots\ldots\ldots (1.6)$$

Constraint (1.1) impose that each customer is allocated to exactly one customer cluster. Constraint (1.2) gives the number of customers in each cluster. Constraints (1.3), (1.4) locate the centroid of customer cluster. Constraint (1.5) imposes that a customer cluster must be less than the capacity of truck transportation and constraint (1.6) defines the decision variables, and the upper limits to the number of individuals per group.

b) Location- Allocation Problem

The objective of the problem (2) is to minimize the cost function composed of fixed and variable costs. The fixed costs are linked to the opening of slaughter- houses and include investment costs for the land, the land tax and the slaughter units. The variable costs include the economic as well as the ecological transportation costs. The mathematical model is given as follows:

$$Min\ Z2 = \sum_{i=1}^{r} FC_i X_i + \beta \sum_{i=1}^{r} \sum_{j=1}^{t} \sum_{j=1}^{t} (C_{jk}^{v;km} + C_{jk}^{v;t/km}) Dcc_j D_{ij} Z_{ij} \ldots\ldots (2)$$

Subject to:

$$\sum_{i \in I} Z_{ij} = 1, \forall j \in J \ldots\ldots\ldots (2.1)$$

$$Z_{ij} \leq X_i, \forall i \in I, \forall j \in J \ldots\ldots\ldots (2.2)$$

$$\sum_{j \in J} \mathrm{Dcc}_j Z_{ij} \leq Q_i X_i, \forall\, i \in I \ldots\ldots\ldots\ldots\ldots (2.3)$$

$$\sum_{j \in J} \mathrm{Dcc}_j * T_i \leq Q_i \ * X_i, \forall \ldots\ldots\ldots\ldots\ldots (2.3)$$

$$Z_{ij} \in \{0,1\};\ X_i \in \{0,1\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

The objective function (2) minimizes total costs, which are the sum of fixed facility costs and total demand weighted distance multiplied by the cost per unit distance per unit demand.
Constraint (2.1) assumes that each customer cluster j (sets of retailers) is assigned to exactly one slaughterhouse i. Constraint (2.2) states that customer cluster j (sets of retailers) can only be assigned to open slaughterhouse. Constraint (2.3) ensures that the sum of demands covered by the slaughterhouse i does not exceed the maximum capacity of this slaughterhouse. Constraints (2.4)) are integrity constraints.

4. Methodology and Results

As mentioned earlier, the entire problem is decomposed into two sub problems; each sub problem is solved in sequential manner, to get the final solution. Optimization Branch & Bound solver has been used to get the solution to the problem. The inputs to the phase 1 or CCCP are the coordinates of locations of customer's k (x k, yk), The input data can be taken from the small sized benchmark problems. For this, we used AutoCAD software to position the different. After solving this phase 1 with the objective of minimization of total cost (Z1), we can get the centroid of each customer clusters with their coordinates (x'j, y'j), total number of customers assigned to each customer cluster (nj). These results (output phase1) are configured in the table 1.

The output of phase 1 along with the coordinates of locations of slaughterhouse (xk, yk), fixed cost for establishing a slaughterhouse k (FCk), capacity of a slaughterhouse i (Qi) and the distance from slaughterhouse k to centroid of each customer clusters j(Dij) will become the input to the Phase 2 and it has been assumed that the number of slaughterhouses is equal to the integer part of total number of customer clusters.
After solving phase 2 with the objective of minimization of total cost (Z2), we can get location of slaughterhouses needed to cover the total demands of customer cluster j and allocated slaughterhouses k to customer cluster j, in such a way that capacity of vehicles and slaughterhouses are respected. These results (output phase2) are presented in the table 2.

TABLE 1. RESULT OF PROBLEM 1

Cluster N°	n_j	Cluster's centre position	Assigned customers number
1	1	(8819.19 ; 5632.02)	5
2	1	(8854.72 ; 5646.22)	7
3	1	(8856.22 ; 5617.00)	6
4	1	(8880.51 ; 5638.30)	8
5	8	(7758.02 ; 6679.99)	3/4/11/17/18/102/103/104
6	12	(9007.11 ; 6033.94)	10/12/13/14/15/16/20/88/89/90/91/105
7	8	(7540.73 ; 6046.07)	1/53/54/56/57/58/59/112
8	0	/	
9	7	5112.69 ; 5767.09)	46/64/66/67/68/69/70
10	8	(7568.44 ; 5825.43)	2/9/19/49/51/52/55/60
11	10	(10043.23 ; 9490.09)	79/80/81/82/83/84/92/93/94/95
12	8	(7478.42 ; 5177.42)	23/26/30/32/33/34/50/111
13	5	(7146.53 ; 5353.10)	21/22/27/47/65
14	10	(7532.64 ; 4847.30)	24/25/28/29/31/35/36/37/38/48
15	0	/	
16	12	(10685.80 ; 9767.27)	71/72/73/74/75/76/77/78/85/86/87/110
17	10	(7726.06 ; 9343.55)	96/97/98/99/100/101/109
18	10	(6974.03 ; 4724.97)	39/40/41/42/43/44/45/61/62/63

TABLE 2. RESULT OF PROBLEM 2

Plants (slaughterhouses)	Location(Xi)	Allocation (Zij)
P1	Open	CC3, CC5, CC7
P2	Open	CC1, CC17
P3	Close	/
P4	Close	CC6, CC8, CC11, CC12, CC13
P5	Open	CC9, CC10, CC14
P6	Open	/
P7	Close	CC2, CC4, CC15, CC16

4. Conclusions

The In recent years, many companies (production or service) are trying to reactivate their logistics networks.

The objective of this work is to reform the distribution network of chicken meat in city of Tlemcen, because of different retailers claim on the market instability of the chicken's meat (prices, lags behind the delivery ...).

For this, we have constructed a mathematical model that consists of two problems. Once the customers have been grouped into clusters, the slaughterhouses to set up, to close or to reopen have been located, and the clusters of retailers have been allocated to them. For solve this model, we decomposed the problem into two sub problems; sub problem is solved sequentially by LINGO optimization solver (Version12.0).

The encouraging results obtained in this work, suggest devoting our further research activities to:

- Introduce the vehicle routing to optimize the transportation problem for each cluster.
- Suggest an expansion of current model, when we may include multi-level and multi product consideration.
- Apply other methodologies such as heuristics and meta-heuristics to solve real life problems were size is important.

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