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TRANSPORTATION ISSUES FOR DECIDING WHEN TO DIPLOID A NEW DISTRIBUTION CENTER

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ABSTRACT

This work analyses the problem of defining when to diploid a new distribution center. The decision model considers the usual logistic cost drivers such as shipping, inventory, infrastructure and administration, focusing in the first one. The shipping cost driver is determined by the client coverage of the centers, which is calculated using a first order condition heuristic that takes into account the facilies' internal congestion. The model is applied to a company that operating in Santiago de Chile which faces a highly seasonal demand. We show that by defining the coverage in a dynamic fashion that depends on the demand, it is possible to postpone the deployment of a new center so the company can save an estimate of 2 percent of the delivery cost.

Keywords: Distribution center, coverage, transportation, Chile
JEL Classification: L91, L81, R41.

RESUMEN

Este trabajo analiza el problema de decidir cuándo habilitar un nuevo centro de distribución. El modelo de decisión considera los costos logísticos usuales tales como transporte, inventario, infraestructura y administración, concentrándose en el primero de ellos. El costo de transporte está determinado por la cobertura de los clientes desde los centros, la que es calculada usando una heurística basada en una condición de primer orden que toma en cuenta la congestión interna de las instalaciones de la empresa. El modelo es aplicado a una compañía que opera en Santiago de Chile y que enfrenta una demanda altamente estacional. El trabajo muestra que, gracias a que se definen en forma dinámica la cobertura, es posible posponer la habilitación del nuevo centro, con lo que la compañía ahorra aproximadamente un 2 por ciento de sus costos de entrega.

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There has been a significant amount of research devoted to the optimal design of the supply chain both by academia and industry. As reviewed by Geoffrion and Powers (1995) and Vidal and Goetschalckx (1997), several models have been developed, varying on both the nature of the problem to be solved and the level of complexity they involve. These models and their algorithms have been applied to the specific setting of many companies, as shown by Martin *et al*. (1993), Robinson *et al*. (1993), Shapiro *et al*. (1993), Pooley (1994) and Arntzen *et al*. (1995). They have proved that an integrated definition of the distribution system increases the effectiveness of the company by allowing a prompt service to the client, as well as improves its efficiency by reducing operation costs.

According to Vidal and Goetschalckx (1997), one of the main issues in the design of a supply chain is defining the number, location and capacity of the distribution centers to use, as well as their client coverage. The papers that have addressed these issues can be classified according to their geometry of location space and distance metrics, objective function and time dependency, number of echelons and capacity constraints of the facilities, optimization algorithms, and other criteria.

Avella *et al*. (1998) classify the geometry of location space into three different types: Continuous, discrete and network based. Brimberg and Love (1995) show that the distance metrics is closely related to the geometry of location space. Both the continuous and the discrete space usually works with evaluation formulas that depend on the coordinates (x,y) of each point. In the network space the distance measure is defined by the shortest path between nodes. The models can be classified depending on whether their distance metrics hold the property of non-negativity, definiteness, symmetry and triangular inequality.

The type of objective function that a facility location problem may have is surveyed by Current *et al*. (1990). They identify as the most common objectives in the literature the cost minimization, demand orientation, profit maximization and environmental concern, with the first one being the most frequent. The time dependency of a model is related to the static or dynamic nature of the problem, where a location decision may be taken once and then remain unchanged, or it could depend on the period being analyzed.

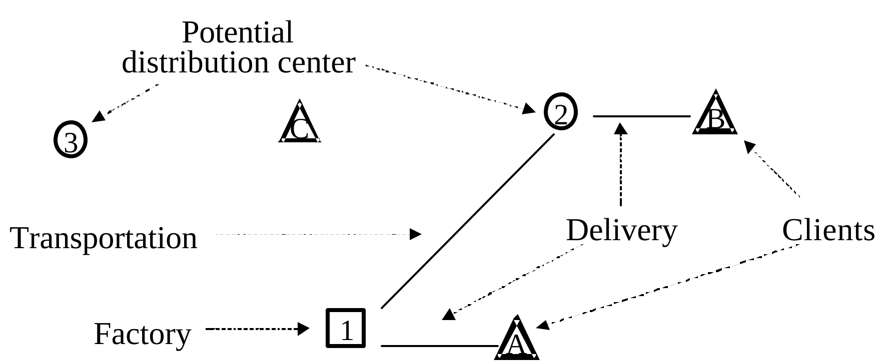
The number of echelons corresponds to how many facilities the product must visit from the factory to the final customer. A distribution system may have one echelon so all the products are dispatched from the factory to the clients, two echelons in which the products are sent from the factory to one warehouse and later dispatched to the customers, and so on, as shown by Diks *et al.* (1996). Tragantalerngsak *et al.* (1997) explains a number of capacity constraints that may apply both to the facilities and customers.

This paper presents a technique for defining when to deploy a new distribution center for a product distribution company. It is assumed that the location of the potential facility is known in advance, as well as the distance metrics to the customers and their demand. The objective function is cost minimization over many periods. The number of echelons can be either one or two, with capacity restrictions both on the factory and the distribution centers. Section 1 states the problem to be solved, which is formalized and solved in Section 2 using a heuristic for defining the client coverage that is explained in Section 3. In Section 5 this model is applied to a distribution company in Santiago de Chile with more than 30,000 clients that range from small convenience stores up to large supermarkets. The results and conclusions are presented in Section 5.

I. DESCRIPTION OF THE PROBLEM

Consider the distribution system in Figure 1 that consists on a factory, depicted by node 1, from where products can be shipped to a customer represented by node A, through a process called *delivery*, which is usually performed during the day. The system includes distribution centers, depicted by node 2 and node 3, from where the delivery can be performed as suggested by the line between node 2 and node B, which corresponds to

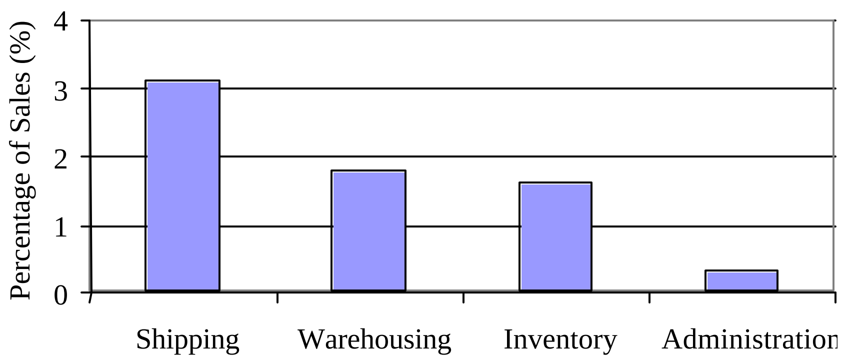
FIGURE 1
SCHEME OF THE DISTRIBUTION SYSTEM



another customer. If so, products should be moved from the factory to distribution centers as shown by the line from node 1 to node 2, in a process called *transportation*, which can be performed overnight in order to avoid traffic congestion.

The main logistic cost drivers considered in this analysis are adapted from the work by Higginson (1993), and are classified as shipping, warehousing, inventory and administration. Figure 2 shows their relevance as a percentage of sales for several U.S. companies, according to Herbert W. Davis and Company (2000).

FIGURE 2
LOGISTIC COSTS AS A PERCENTAGE OF SALES FOR SEVERAL U.S. COMPANIES



The cost drivers involved in each category are the following.

- Shipping

- Transportation to centers: Cost paid for transporting the products from the factory to the distribution centers, which grows as more products are delivered from the centers.
- Delivery fleet fixed cost: Fixed cost of the fleet that delivers the products from either the factory or the distribution centers. It depends on

the total number of trucks, which decreases as the number of work centers increases, because of the lower congestion of each plant and the shorter traveling times to the customers.

- Delivery variable cost: Variable cost due to the delivery of the products, which includes fuel, tires, and other supplies. It decreases as the number of centers increases since each center is closer to its customers

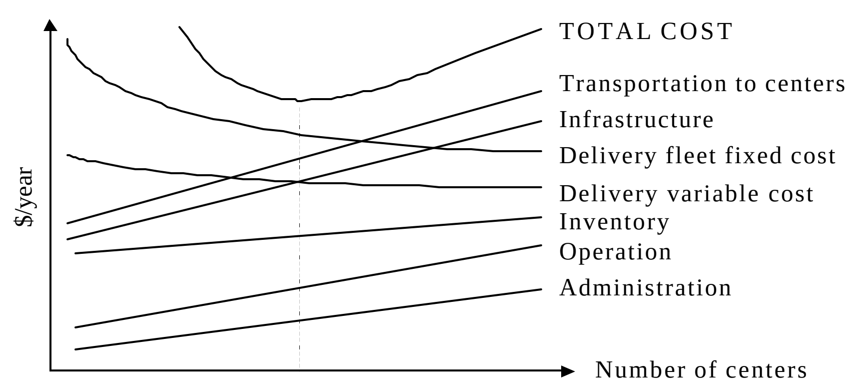
- Warehousing
- Infrastructure: Land and building cost of the centers.
- Operation: Human labor to be hired to operate each of the centers. Even though by externalizing the operation to the new facilities there will be a reduction of personal in the factory, in many cases there will be a duplication of functions that will increase the total operation cost.

- Inventory: A less consolidated warehouse system has more uncertainty due to the provision of the centers, as well as the variability in the demand of the area covered by each center. Therefore, safety stocks must increase.

- Administration: Supervisors running and monitoring the different facilities, which cost will increase with more facilities.

The summary of the relationship between the different cost drivers and the number of facilities being operated is shown by Figure 3. For the

FIGURE 3
LOGISTIC COST DRIVERS AS A FUNCTION OF THE NUMBER OF CENTERS



purposes of this paper we will assume that the warehousing, inventory and administration costs can be obtained, so the trade-off between the transportation to centers and the delivery costs must be calculated.

Suppose that a given company is facing changes in the structure of the logistic cost drivers in such a way that the optimal number of centers may increase by one. For instance, the congestion of the loading dock in the factory may be causing an important cost to the company's delivery fleet, which is measured by Donoso *et al.* (1998). Assume that the potential location of the new distribution center is known due to the scarcity of land portions in the city that can be used for these purposes. If so, the company must decide two interrelated matters: Whether to deploy or not the new center, issue that is addressed by Section 2, and from which facility the products should be delivered to each customer, a concern that is analyzed in Section 3.

II. CALCULATION OF THE LOGISTIC COST DUE TO THE NEW FACILITY

Formalizing the decision problem stated above, we must evaluate whether the deployment of a new center has a lower logistic cost, which is equivalent to asses if the savings in the delivery cost overcome the additional expenditure in transportation to centers, warehousing, inventory and administration. To do so we consider the following parameters, where the brackets "[ ]" indicate the units in which they are measured:

- Load[u]: Number of units that each truck can carry, measured in pallets.
- Working Time [h]: Number of hours worked by a truck in one day shift.

We define the following decision variables:

- $Demand_j$ [u]: Number of units to be delivered from the center $j \in J$, where J is the set of facilities. The demand is measured in pallets, and it is defined using the Client Coverage Heuristic introduced in Section 3. This decision influences all the variables defined below.
- $Number\ of\ Trucks_j$: Size of the fleet doing the delivery from the center j to the customers.
- $Reloading\ Factor_j$: Number of times that a truck assigned to center j

makes a full distribution circuit in one day.

The company is expected to be capable of reacting to its client's demand variability in order to comply with a committed service level. Such a commitment is due to the nature of the products which purchases are cancelled if they are not delivered within 24 hours after the order has been placed. This constraint is used to define that the number of trucks assigned to each facility is equal to the daily demand to be delivered, divided into the daily capacity per truck:

$$Number\ of\ Trucks_j = \frac{Demand_j}{\text{Load} \times Reloading\ Factor_j}. \tag{1}$$

The $Reloading\ Factor_j$ depends on the following variables:

- $Time\ on\ Route_j$ [h]: Number of hours that a truck assigned to center j takes to complete a distribution round trip.
- $Time\ at\ Center_j$ [h]: Number of hours that a truck assigned to center j stays at the distribution center in every trip, which is calculated in Section 3.

The $Reloading\ factor$ is given by:

$$Reloading\ Factor_j = \frac{\text{Working Time}}{Time\ on\ Route_j + Time\ at\ Center_j}. \tag{2}$$

By replacing (2) in (1) the $Number\ of\ Trucks_j$ is obtained as a function of the $Time\ at\ Center_j$, among other variables, which will be crucial for the assignment algorithm:

$$Number\ of\ Trucks_j = \frac{Demand_j}{\text{Load} \times \left(\dfrac{\text{Working Time}}{Time\ on\ Route_j + Time\ at\ Center_j} \right)}. \tag{3}$$

With these relationships, the following algorithm is proposed for estimating the cost due to the deployment of a new center, which should be compared to the current logistic cost:

a) Suppose that the new distribution center is allocated in its predefined place.
b) Allocate customers to the different facilities using the Client Coverage Heuristic of Section 3.
c) Given the number of customers and their demand allocated to each center, define the size of the new facility, and therefore the infrastructure cost.
d) Given the demand allocated to each center, calculate the cost due to transportation from the factory to the distribution centers.
e) Calculate the number of trucks needed for delivery in every facility using expression (3). The fleet cost is such number multiplied by the cost per truck [M$/year].
f) Calculate the delivery, operation, administration and inventory costs from the configuration obtained in (a) through (e)

III. CLIENT COVERAGE HEURISTIC

In this section we introduce a heuristic for defining the client coverage of each facility, which is equivalent to define $Demand_j$ since the demand of each client is supposed to be known. The heuristic defines an index that relates the transportation cost, the delivery cost and the congestion in the facilities, which discriminates whether it is worthwhile to deliver from a distribution center rather than from the factory. The clients are sorted according to such index and then assigned to the different facilities.

For simplicity, we first present the formulas considering two facilities, being facility 1 the factory and facility 2 a distribution center. Later in this section we generalize them for many facilities. We define the following parameters:

- c_h [$/u h]: Delivery cost per unit per hour, calculated as the fixed cost of a truck per year, divided by the working days per year, the hours worked per day, and the capacity of the truck.

- a_i [u]: Demand of customer $i \in I$, where I is the set of customers, measured in pallets.
- h_{ij} [h]: Chronological distance of customer i to facility j, measured in hours that takes to travel from one place to the other.
- t_j [$/u]: Cost of transportation per pallet, from factory to distribution center j.

The reason for measuring distances in hours rather than in kilometers is because the fleet fixed cost such as salaries and depreciation is much greater than the variable cost due to the fuel and tires when the traveling speed is low. That is the case of the of the application presented in Section 4, where the congestion in the city produces that short distances are covered in long times, so the variable cost are insignificant. In less congested cities or in rural areas this distance should probably be combined with a geographical metric.

We also define the following decision variables:

- P_j: Set of customers i assigned to center j, which defines the coverage of the center. The expression $\sum_{i \in P_j} a_i = Demand_j$ is the demand assigned to center j, measured in pallets. The term $\left(\left(\sum_{i \in P_j} a_i\right) / Load\right)$ is equal to the number of trips dispatched by center j. For instance, if a center has 3,000 [u] to deliver in one day and the capacity of each truck is 10 [u], then the number of trips is (3,000 / 10) = 300.

- H_j [h] = $Time\ at\ Center_j$ [h]: Time spent by a truck each time it visits facility j. It depends on the number of pallets [u] that are dispatched from the facility, so the expression $H_2\left(\sum_{i \in P_2} a_i\right)$ corresponds to the number of hours that each truck spends in distribution center 2.

- $G(P_1,P_2)$: Congestion function measured in pallets hours [u h] that expresses how much time are the pallets waiting in the facilities. It depends on the assignment of clients to be served:

$$G(P_1, P_2) = \text{Load}\left[\frac{\sum_{i\in P_1} a_i}{\text{Load}} \times H_1\left(\sum_{i\in P_1} a_i\right) + \frac{\sum_{i\in P_2} a_i}{\text{Load}} \times H_2\left(\sum_{i\in P_2} a_i\right)\right]$$

$$= \left(\sum_{i\in P_1} a_i\right) \times H_1\left(\sum_{i\in P_1} a_i\right) + \left(\sum_{i\in P_2} a_i\right) \times H_2\left(\sum_{i\in P_2} a_i\right) \qquad (4)$$

The shipping cost SC for two facilities is defined as follows, where the customer $i*$ that is currently served by facility 1 has been separated from the first summation for reasons that will be clarified later on this paper:

$$SC = c_h\left[a_{i*}h_{i*1} + \sum_{i\in P_1-\{i*\}} a_i h_{i1} + \sum_{i\in P_2} a_i h_{i2}\right] + t_2 \sum_{i\in P_2} a_i + c_h G(P_1, P_2) \qquad (5)$$

The first term is the fleet cost due to the delivery to each customer i. The term $t_2 \sum_{i\in P_2} a_i$ is the transportation cost from the factory to the distribution center. The third term is the fleet cost that is caused by the congestion on both facilities.

The optimal coverage of each facility can be obtained from an integer program where the shipping cost SC in expression (5) is the objective function to be minimized. The variables are defined as $x_{ij} = 1$ if customer i is served by facility j and $x_{ij} = 0$ otherwise.

$$min = c_h\left[\sum_i \sum_j a_i h_{ij} x_{ij}\right] + \sum_{j\ge 1}\left(t_j \sum_i a_i x_{ij}\right) + c_h \sum_j \left(\left(\sum_i a_i x_{ij}\right) \times H_j\left(\sum_i a_i x_{ij}\right)\right)$$

subject to: $\sum_j x_{ij} = 1 \quad \forall i \in I$

$$x_{ij} \in \{0,1\} \quad \forall i \in I, j \in J$$

Notice that the objective function considers the delivery and transportation costs, plus the congestion cost that can be viewed as a dualization of a capacity constraint for each facility. Suppose that facility j can only serve a demand of A_j, that is, $\left(\sum_{i\in Pj} a_i\right) \leq A_j$. If the demands grows above A_j then a cost of $l\left[\left(\sum_{i\in Pj} a_i\right) - A_j\right]$ is paid, where λ is the lagrangean multiplier equal to:

$$c_h\left[H_j\left(\sum_i a_i x_{ij}\right) - H_j\left(A_j\right)\right] \tag{6}$$

The above mathematical program may be extremely difficult to solve with tenths of thousands of customers. As an alternative, we propose the following heuristic that is based on a continuous space location. Given that the facilities have been already selected and placed on the map, define an *indifference frontier* as the set of points where the cost of serving a customer is the same from one facility or from the other. Once this frontier has been defined, assign the customers to each side of the frontier to their corresponding facility. The definition of the frontier comes from a *first order condition* for the shipping cost of expression (5). To do so we "take the derivative" of SC with respect to P_1 by moving customer i* from P_1 to P_2. It must be noted that the partial derivatives notation used is only for illustrative purposes and not literal, since the function analyzed is not differentiable.

$$\frac{\partial SC}{\partial P_1} = c_h a_{i*}\left(h_{i*2} - h_{i*1}\right) + t_2 a_{i*} - c_h G'\left(P_1, P_2\right) = 0 \tag{7}$$

Here the expression $G'(P_1,P_2) = \partial G(P_1,P_2)/\partial P_1$ can be interpreted as the [pallets hours] gained by the shift of customer i* from facility 1 to facility 2 due to a decrease of the congestion in the most crowded facility. The exact expression for $G'(P_1,P_2)$ is:

$$G'(P_1, P_2) = \left(a_{i*} H_1\left(\sum_{i\in P_1} a_i\right) + \left(\sum_{i\in P_1} a_i\right) \frac{\partial H_1(x)}{\partial x}\bigg|_{\sum_{i\in P_1} a_i} \right) \tag{8}$$

$$- \left(a_{i*} H_2\left(\sum_{i\in P_2} a_i\right) + \left(\sum_{i\in P_2} a_i\right) \frac{\partial H_2(x)}{\partial x}\bigg|_{\sum_{i\in P_2} a_i} \right)$$

We define $G^*(P_1,P_2)$ as the factorization of $G'(P_1,P_2)$, where $w_{ij} = a_i \big/ \sum_{k\in Pj} a_k$ is the proportion between the demand of customer i and the total demand of facility j from where customer i is served.

$$G^*(P_1, P_2) = \frac{G'(P_1, P_2)}{a_{i*}} \tag{9}$$

$$= \left(H_1\left(\sum_{i\in P_1} a_i\right) + w_{i*1}^{-1} \frac{\partial H_1(x)}{\partial x}\bigg|_{\sum_{i\in P_1} a_i} \right) - \left(H_2\left(\sum_{i\in P_2} a_i\right) + w_{i*2}^{-1} \frac{\partial H_2(x)}{\partial x}\bigg|_{\sum_{i\in P_2} a_i} \right)$$

With this expression the first order condition can be restated as follows:

$$\frac{\partial SC}{\partial P_1} = c_h a_{i*}\left(h_{i*2} - h_{i*1}\right) + t_2 a_{i*} - c_h a_{i*} G^*\left(P_1, P_2\right) = 0 \tag{10}$$

Therefore, any customer for whom it is indifferent to dispatch the products from facility 1 or facility 2 must comply with the relation:

$$\left(h_{i*2} - h_{i*1}\right) = G^*\left(P_1, P_2\right) - \frac{t_2}{c_h} \tag{11}$$

The assignment algorithm for two facilities is the following, recalling that I is the set of all the customers:

a) Let $P_1 = I$ and $P_2 = \{\}$.
b) Sort in an increasing order all the customers i according to the index $(h_{i2} - h_{i1})$.
c) Assign customer i to P_2, i.e., facility 2, as long as:

$$\left(h_{i*2} - h_{i*1}\right) < G*\left(P_1, P_2\right) - \frac{t_2}{c_h}$$

The generalization of the assignment algorithm for n facilities is the following, recalling that J is the set of all the facilities:

a) Let $P_1 = I$ and $P_j = \{\}$ for j in $J - \{1\}$.
b) Assign tentatively customers i to facility j for which the index $(h_{ij} - h_{i1}) + t_j/c_h$ is minimum.
c) Sort in an increasing order all the customers i according to the index $(h_{ij} - h_{i1}) + t_j/c_h$.
d) Assign customer i to P_j as long as $\left(h_{i*j} - h_{i*1}\right) < G*\left(P_1, P_j\right) - \frac{t_2}{c_h}$

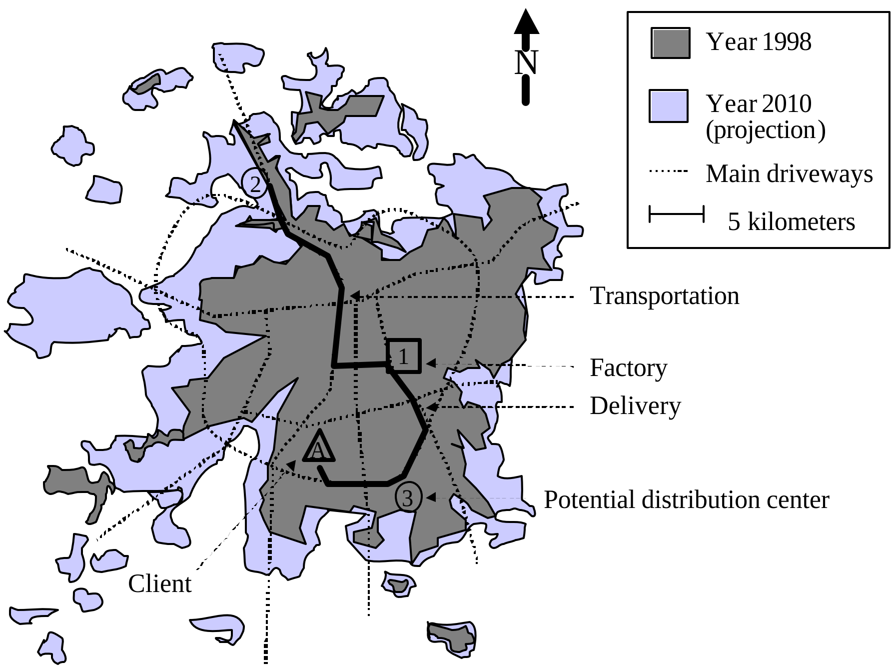
where $G*(P_1,P_j)$ is as in expression (9), replacing the subindex 2 for j.

IV. AN APPLICATION OF THE MODEL IN SANTIAGO DE CHILE

The company where this model has been applied distributes 786.744 pallets a year [u/year] of products in Santiago de Chile, a city with an overall population of 4.5 million people and an area of approximately 324 square kilometers. The demand is highly seasonal with more than 30,000 clients that range from small convenience stores up to large supermarkets. At the moment there are two facilities: The factory from where 80 percent of the sales are delivered and a distribution center from where the remaining 20 percent of the sales are delivered. Figure 4 represents the factory by node 1 and the distribution center by node 2. Depending on the demand, each customer is visited by a truck between one and six times per week.

The company manages a delivery fleet of approximately 230 trucks, while the fleet doing the transportation is subcontracted.

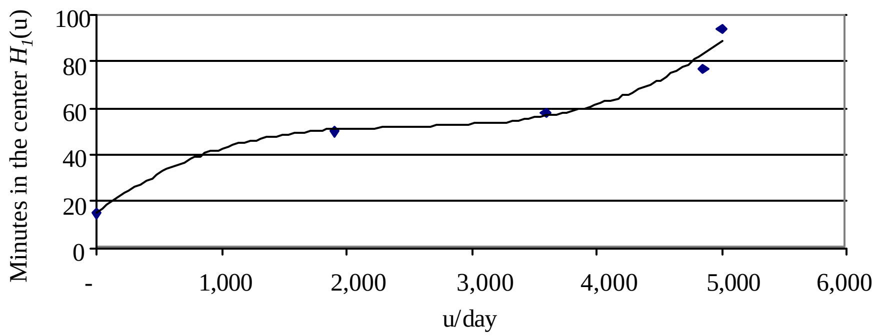
FIGURE 4
DISTRIBUTION SYSTEM IN SANTIAGO YEAR 1998 AND 2010



In order to decrease the operation costs, the company must decide whether to allocate a new distribution center and define its corresponding coverage. Because of commercial considerations, such center should be placed in the southern part of Santiago close to node 3 in Figure 4. We apply the algorithm presented in Section 3, so all the logistic cost drivers mentioned such as transportation, infrastructure, fleet, delivery, operation, administration and inventory are calculated. The function $H_j(u)$ of waiting time in each facility j is obtained as a cubic regression of real data that was measured in peak days in the plant. For instance, the formula for the factory is $H_1(u) = 4.22 \times 10^{-11} \times u^3 - 2.99 \times 10^{-7} \times u^2 + 7.34 \times 10^{-4} \times u + 0.25$, depicted by Figure 5, that shows a collapsing behavior above 4,000 [u/day].

FIGURE 5

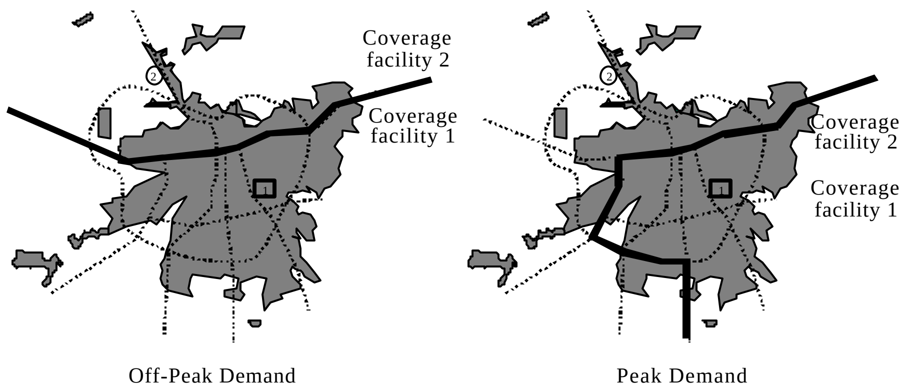
FUNCTION $H_1\left(\sum_{i\in P_1} a_i\right)$ OF WAITING TIME IN CENTER 1 (FACTORY)



Given that the company has the policy of being able to deliver even when the demand is in its peak of 5,000 [u/day] or more, it becomes apparent that the new center must be deployed. If so $G^*(P_1,P_3)$ is close to zero since both the factory and center 3 are relaxed so moving demand from one facility to the other does not decrease the congestion function. In such situation customer i is assigned to center 3 as long as $(h_{i1} - h_{i3}) > t_3/c_h = 1/3$. However, the peak demand occurs only a few days a year, while the rest of them the current two facilities have enough capacity.

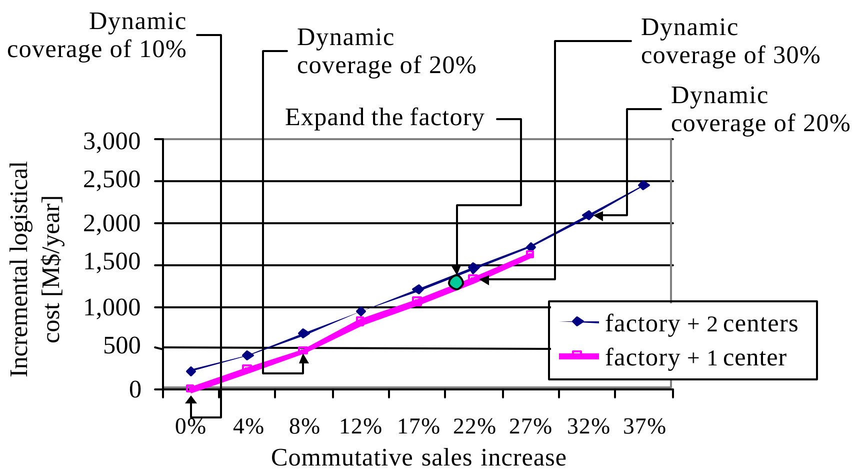
In order to avoid the cost related to allocating a new center, we use the client coverage heuristic in a dynamic manner depending on the demand level. In other words, $G^*(P_1,P_2)$ in expression (11) is first obtained using an off-peak and then an on-peak client demand a_i. The result is a very different chronological distance relation to assign trucks to centers. In the first case it must hold that $(h_{i*2} - h_{i*1}) < 1/3$ to assign a customer to center 2. In the last case the difference in chronological distance $(h_{i*2} - h_{i*1})$ can be up to 1.43 hours. Therefore, if delivering to a given customer from the factory takes 2 hours, and doing it from the distribution center takes 3.42 hours, it is still convenient to serve it from the center due to the decrease of congestion in the factory. This somehow counterintuitive fact is depicted by the Map of Santiago in Figure 6 that shows that the off-peak geographical coverage of the distribution center in node 2 is dramatically increased on peak days. However, in terms of pallets the allocation from the factory to center 2 is only 10 percent, so the portion delivered by the factory falls to 70 percent while the share of the distribution center grows to 30 percent. Such a configuration lasts for about 4 weeks a year.

FIGURE 6
COVERAGE OF THE BASE CASE DEPENDING ON THE DEMAND



The result of this dynamic coverage technique is that the deployment of a new center can be postponed until the sales increase by 27 percent, which could be many years from now. Figure 7 shows the incremental costs for 2 and 3 centers as a function of the sales increase of the company. Since the congestion in the factory grows, the dynamic coverage shifted from the factory to center 2 grows from the current 10 percent to 20 percent when the sales are 108 percent of what they are now. When they reach 22 percent it is necessary to expand the factory, and when they attain an increase of 27 percent a new center must be built due to environmental considerations. With three facilities operating it is convenient to perform a dynamic coverage of 20 percent from the factory to the other centers. The result of the postponement is an estimated saving of 250,000 US dollars that tends to shrink as the demand grows, which represents close to 2 percent of the delivery cost of the company.

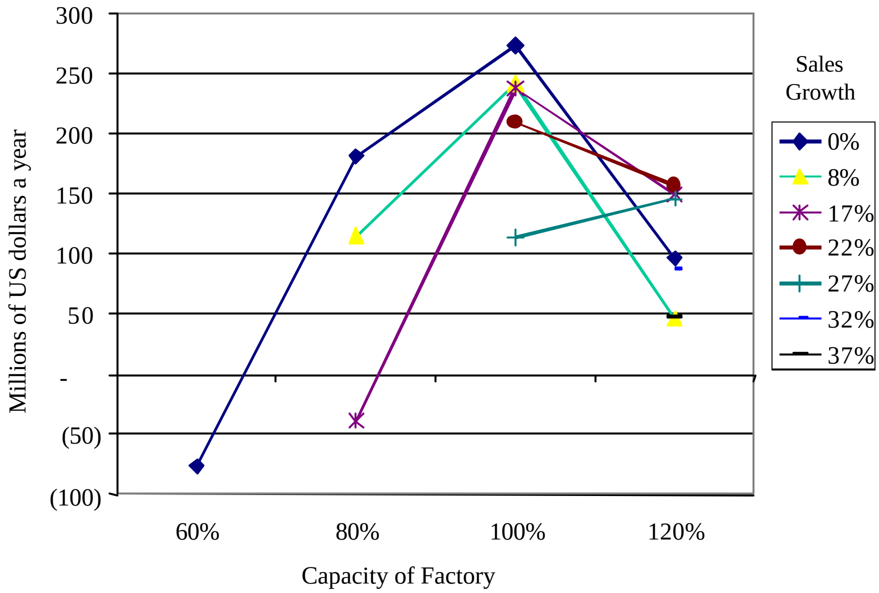
FIGURE 7
INCREMENTAL COSTS FOR 2 AND 3 CENTERS AS A FUNCTION OF SALES INCREASE



The sensitivity analysis can be performed with respect to several parameters, such as congestion and distances growth, transportation and delivery cost, one of them being the capacity of the factory in terms of the waiting time H_1(u) of each truck depicted by Figure 5. In such figure, if the capacity falls to 50 percent then the increase in waiting time starts from 2,000 [u/day] instead of the current 4,000 [u/day] level. Figure 8 shows the differential logistic cost per year of two centers versus the base case, with different capacities for the factory. A second distribution center becomes comparatively less expensive as the capacity of the factory decreases, as well as if it increases too much, since infrastructure investment is more expensive in a factory that already has a lack of space.

Managers may decide to implement a new distribution center when the cost of doing so falls below a given threshold. For instance, if such threshold is 150,000 US dollars and the factory keeps its capacity, they will build the new center when sales grow up to 27 percent. However, if the factory loses capacity to an 80 percent level, then a new center will become feasible when sales grow to 8 percent.

FIGURE 8
DIFFERENTIAL LOGISTIC COST FOR DIFFERENT PLANT CAPACITIES



V. CONCLUSIONS

The importance of the problem of defining the number and coverage of distribution centers has attracted a great deal of attention from the academic literature. This has resulted in a number of models that vary in their geometric considerations, distance metrics, objective function, etc. From an applied research point of view, the task is to select from such a diversity of perspectives the features that best describe the problem being addressed, and then to find decision rules that will derive the best possible results for the company. In this paper we propose a technique for deciding whether to diploid or not a new distribution center, which considers fleet, infrastructure, transportation, delivery, and other logistic costs. Such technique is based on defining the client coverage of the centers in order to minimize the shipping cost. To do so, we propose a new heuristic based on a first order condition that, taking into account the congestion of the facilities, identifies an indifference frontier of clients that can be covered by any distribution center.

The model was applied to a company that delivers 786,744 pallets a year of products to more than 30,000 clients in Santiago de Chile. We show that by using a dynamic coverage policy, which defines the client coverage of each distribution center according to the demand level, it is better to postpone any investment until the demand has grown to a given level, saving close to 2 percent of the delivery cost. This technique is more beneficial when the congestion in the city is high, and it is rather expensive to increase the capacity of the distribution centers. Such may be two features of the logistic business running in the overcrowded cities of Latin America, where the infrastructure tends to be modest compared to developed countries. This distinctive reality suggests the need for elaborating decision techniques that are specific for developing countries, which can carry important savings to the companies that are willing to carefully analyze their strategic logistic decisions.

REFERENCES

Arntzen, B., Brown, G., Harrison, T.P. y Trafton, L.L., (1995), "Global Supply Chain Management at Digital Equipment Corporation," *Interfaces* 25, 69-93

Avella, P., Benati, S., Cánovas Martínez, L., Dalby, K., Di Girolamo, D., Dimitrijevic, B., Ghiani, G., Giannikos, I., Guttmann, N., Hultberg, T.H., Fliege, J., Marin, A., Muñoz Márquez, M., Ndiaye, M. M., Nickel, S., Peeters, P., Pérez Brito, D., Policastro, S., Saldanha de Gama, F.A. and Zidda P. (1998), "Some Personal Views on the Current State and the Future of Locational Analysis," *European Journal of Operational Research* 104, 269-287

Brimberg, J. and Love, R. (1995), "Estimating Distances" in "Facility Location: A Survey of Applications and Methods," Drezner, Z. editor, *Springer-Verlag*, New York

Current, J., Min, H., and Schilling, D. (1990), "Multiobjective Analysis of Facility Location Decisions," *European Journal of Operational Research* 49, 295-307

Diks, E.B., de Kok A.G. and Lagodimos, A.G. (1996), "Multi-Echelon Systems: A Service Measure Perspective," *European Journal of Operational Research* 95, 241-263

Donoso, P. Singer, M. & Scheller-Wolf, A. (1999), "A Performance Agreement to Align the Operation of a Loading Dock and a Fleet," *Abante* 2; 167-188

Drezner, Z., (1995), "Dynamic Facility Location: The Progressive *p*-Median Problem," *Location Science* 3, 1-7

Geoffrion, A.M., and Powers, R.F. (1995), "Twenty Years of Strategic Distribution System Design: an Evolutionary Perspective. (Implementation in OR/MS: An Evolutionary View)," *Interfaces* 25, 105-128

Herbert W. Davis and Company (2000), "Benchmarking Data at the Component Cost Level" http://www.hwdco.com.

Higginson, J.K. (1993), "Modeling Shipper Costs in Physical Distribution Analysis", *Transportation Research -A*, Vol. 27A/2, 113-124

Martin, C.H., Dent, D.C., and Eckhart, J.C. (1993), "Integrated Production, Distribution, and Inventory Planning at Libbey-Owens-Ford," *Interfaces* 23/3, 68-78

Pooley, J. (1994), "Integrated Production and Distribution Facility Planning at Ault Foods," *Interfaces* 24/4, 113-121

Robinson, Jr., E.P., Gao, L.L., and Muggenborg, S.D. (1993), "Designing an Integrated Distribution System at DowBrands, Inc.," *Interfaces* 23/3, 107-117

Shapiro, J.F., Singhal, V.M., and Wagner, S.N. (1993), "Optimizing the Value Chain," *Interfaces* 23/2, 102-117

Tragantalerngsak, S., Holt, J. and Ronnqvist, M. (1997), "Lagrangean Heuristic for the Two-Echelon, Single-Source, Capacitataed Facility Location Problem," *European Journal of Operational Research* 102, 610-625

Vidal, C. J. and Goetschalckx M. (1997), "Strategic Production-Distribution Models: A Critical Review with Emphasis on Global Supply Chain Models," *European Journal of Operational Research* 98, 1-18