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REDESIGN OF THE SUPPLY CHAIN OF A RESTAURANT FRANCHISE IN THE FOOD INDUSTRY

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ABSTRACT

This research analyzes the problem of facility location and vehicle routing for an efficient logistics system in a practical case study application. It is intended to redesign the logistics network of a franchise company in the food industry in the city of Puebla, Puebla (Mexico). First, facility location is analyzed and two scenarios are presented, installing one new distribution center, and installing two new distribution centers, by the means of the P-median model. Subsequently, a new distribution route between the depots (distribution centers) and demand points (restaurant franchises) will be proposed by means of a Capacitated Vehicle Routing Problem, to satisfy demand and operational constraints of the customer. The objective of this study is to minimize costs through a reduction in delivery times and distances. Exact facility locations are presented along with a vehicle route scheduling, followed by a cost analysis to help in the ultimate decision of the logistics network redesign.

JEL: C6

KEYWORDS: Facility Location, P-median, Capacitated Vehicle Routing Problem, Logistics, Distribution

INTRODUCTION

Given that logistics activities have always been vital to companies and organizations, the fields of logistics and supply chain management represent a synthesis of various concepts, principles, and methods, from the traditional areas of marketing, production, accounting, warehousing, and purchasing, to the disciplines of applied mathematics, organizational behavior, and economics. Logistics revolves around creating value, principally for the customers, as well as for suppliers and shareholders of the company. The value created by logistics activities is expressed fundamentally in terms of time and place; an efficient logistics administration visualizes each activity throughout the supply chain as a continuous contribution to the process of added value (Ballou, 2004). The vulnerability of the supply chain increases with the rise in uncertainty (Svensson, 2000), and the vulnerability increases even more if the companies, through outsourcing or external contracting, have become dependent upon other organizations. The greatest uncertainties in supply and demand, increased globalization of the market, product life cycles, faster technology, increased use of manufacturing, distribution and logistics partners resulting in complex international relations of supply networks have led to an increase in exposure to risks throughout the supply chain. Many problems of economic decision concern the selection and/or placement of determined facilities to serve the given demand in an efficient manner (Vygen, 2005), as well as the coordination and control of adequate routes for the optimal provision from the suppliers to the point of consumption. Seeing as transportation and distribution processes tend to represent from 10% to 20% of the final cost of goods, having an efficient logistics system can produce substantial savings for the company.

The objective of this article is the practical application and proposal of adequate locations for new distribution centers and the redesign of the corresponding distribution routes between the restaurant franchises and the distribution centers that complies with the capacity and schedule restrictions for a supplier in the food industry by means of mathematical models, resulting in efficiency and cost savings. In the following section, a literature review is introduced presenting related articles on the topics in question and real-life applications. Next, data for the case study is provided, followed by methodologies of the tools to be implemented. The *P-median* model will be utilized to provide two new distribution center scenarios, and then the *Capacitated Vehicle Routing Problem* (CVRP) will be utilized to propose logistics vehicle routes for the selected distribution centers. Results for the proposals of a new facility location and vehicle routing are discussed, including a cost analysis table to demonstrate the feasibility of the proposal. Closing are the conclusions and future work to be applied to this case study.

LITERATURE REVIEW

Facility location and logistics network planning are well-known, yet critical problems in the efficiency of the supply chain of a company. When these logistics systems are not optimized, additional costs can be incurred as well as interruptions to the flow of materials throughout the supply chain. By optimizing logistics concepts, a competitive advantage can be obtained for all agents involved in the supply chain. Mathematical approaches have been extensively researched for facility location and vehicle routing problems, having proposed many heuristic methods and algorithms for solving these optimizations. Because of the extensive variants of the CVRP, depending upon the operational constraints of each particular situation, this subject is one of great interest for researching and industrial purposes.

Problems addressing facility location tend to deal with the decision making of new facilities or installations that need to be optimally positioned to serve supply and demand. Mladenović, Brimberg, Hansen, and Pérez (2007) describe that "location models may be divided into three groups: *continuous* ($X \subseteq R^q$), *discrete* (X is finite) and *network* models (X is a finite union of linear and continuous sets)". Mladenović et. al (2007) also mention that location models may be deterministic or stochastic, linear or nonlinear, single or multi criteria, etc. Rolland, Schilling, and Current (1997) present a new heuristic solution for the P-median problem through an efficient Tabu search procedure, while Resende and Werneck (2004) use a hybrid heuristic approach combining elements of traditional metaheuristics to find near-optimal solutions to facility location problems. Dantzig and Ramser (1959) first proposed the Vehicle Routing Problem (VRP) in 1959, introducing it as the truck dispatching problem. This real-world application dealt with the delivery of gasoline to gas stations, proposing a mathematical programming formulation and algorithm to optimally resolve the problem (Toth & Vigo, 2014). Following this seminal paper, Clarke and Wright (1964) proposed an effective greedy heuristic to approximately resolve VRP applications. These two publications gave way to numerous investigations and publications on a variety of VRP applications in the field of operations research. Daza, Montoya, and Narducci (2009) studied the CVRP with a homogenous fleet.

The authors proposed a two-phase metaheuristic algorithm including route design and fleet scheduling. The objective of their work was to minimize the fixed cost of using installed capacity. The proposed methodology for the route design included a greedy heuristic, an Or-opt algorithm, and a Tabu search. The second phase involving the fleet scheduling used an algorithm addressing a sequencing problem on identical parallel machines. The resources used were available vehicles, required jobs, and the routes to be assigned between each vehicle and job. Kim, Kim, and Sahoo (2005) present a real life waste collection Vehicle Routing Problem with Time Windows (VRPTW) considering multiple disposal trips and drivers' lunch breaks, using Solomon's insertion algorithm (Solomon, 1987). The objective function of this work is minimizing the number of vehicles and total traveling time, while improving route compactness and workload balancing. In order to optimize these processes, a capacitated clustering-based waste collection VRPTW was developed. Baldacci, Mingozzi, and Roberti (2012) studied exact algorithms proposed for the CVRP and VRPTW, and state that many formulations have been proposed, but the most successful exact methods are based on the *two-index flow formulation*, the *two-commodity flow formulation* proposed by Baldacci et al. (2012), and the *set partitioning formulation* proposed by Balinski and Quandt (1964). Branch-and-cut algorithms and exact algorithms are further discussed and reported as a computational comparison on six well-known classes of CVRP instances. These *compact formulations* are (mixed) integer programming models with a polynomial number of variables (Toth & Vigo, 2014). The two-index flow formulation, as will be discussed as part of the methodology of the CVRP, has an exponential number of constraints. Laporte, Mercure, and Nobert (1986) introduced a directed CVRP model with integer decision variables indicating how often a vehicle travels between nodes *i* and *j* (hence the two indices). Reviewing these publications on the P-median problem and the VRP and its variants has provided expertise insight into algorithms for exact and approximate applications to solving these operational research problems.

DATA AND METHODOLOGY

Case Study

The present case study considers the analysis and design of the logistics system of Antigua Taquería S.A. de C.V., a company in the food industry located in the city of Puebla, Puebla (Mexico) that initiated its operations 77 years ago with three restaurant franchises. Over time, Antigua Taquería has expanded its operations considerably, currently managing 27 restaurant franchises in the state of Puebla. However, Antigua Taquería has not made sufficient modifications to its logistics strategy, and being solely dependent on one meat supplier has created much vulnerability in its supply chain. Its greatest problem has been identified as the distribution of meat, this product being the most critical and demanded of Antigua Taquería. Presently, Antigua Taquería intends to open its 27 restaurant franchises at 12:00pm, the principal problem being that the supplier does not distribute the meat in a timely manner, delaying the opening of the stores. The meat supplier currently receives all the meat demand for the 27 restaurant franchises at its only distribution center located on Avenida Valsequillo, in the city of Puebla. Currently, the meat supplier has three distribution trucks at its disposition to distribute the meat to the 27 restaurant franchises. Each distribution truck has a maximum capacity of 500 kilograms; the average daily meat demand for the restaurant franchises is 50 kilograms. Nonetheless, the meat supplier begins daily deliveries at 8:00am, not providing sufficient time to adequately distribute the meat demand to each restaurant franchise according to the time restriction set in place.

Models

The selected mathematical model for this case study that will be utilized for the proposal of facility location for new distribution centers is the *P-median*. The objective of this model is to find the location of a fixed quantity of facilities that are found within the network of nodes that satisfy the demand of the customer, always minimizing distances travelled and associated costs (Daskin, 1995). P-median can be used to find the optimal location of only one facility or various facilities. The P-median model is considered a *discrete* method since the facility locations are being selected from a list of possible alternatives that have been identified in accordance with specific criteria (Ballou, 2004). Discrete facility location methods are more frequently used especially when looking to install multiple facilities. The mathematical model formulated by Daskin (1995) can be defined as follows:

Minimize:

$$\sum_i \sum_j h_i d_{ij} Y_{ij} \quad (1.1)$$

Subject to:

$$\sum_j Y_{ij} = 1 \; \forall \, i \tag{1.2}$$
$$\sum_i X_j = P \tag{1.3}$$
$$Y_{ij} - X_j \leq 0 \; \forall \, i, j \tag{1.4}$$
$$X_j = 0{,}1 \; \forall \, j \tag{1.5}$$
$$Y_{ij} = 0{,}1 \; \forall \, i, j \tag{1.6}$$

Where:

h_i: demand in node i.
d_{ij}: distance between the demand in node i and the potential facility j.
P: number of facilities to locate.

X_j: $\begin{Bmatrix} 1 \text{ if facility is installed at candidate node } j \\ 0 \text{ otherwise} \end{Bmatrix}$

Y_{ij}: $\begin{Bmatrix} 1\ if\ the\ demand\ in\ node\ i\ is\ served\ by\ the\ facility\ located\ in\ node\ j \\ 0\ otherwise \end{Bmatrix}$

The objective function minimizes the distance between each demand node and the closest installed facility. The restriction (1.2) indicates that each demand node i is assigned to only one facility j. The restriction (1.3) makes sure that exactly p facilities are located. The restriction (1.4) makes reference to the fact that demand nodes are only assigned to a facility when such has been selected to be installed by the decision variable x_j. The restrictions (1.5) and (1.6) indicate the binary variables. It is important to make note that this mathematical model assumes that all of the facilities are located within a network of existing nodes (Daskin, 1995). CVRP are optimization methods that are being increasingly utilized for the effective management of the provision of goods and services in logistics systems. According to Toth and Vigo (2014), the solution to a CVRP calls for the determination of a set of routes, each performed by a single vehicle that starts and ends at its own depot, such that all the requirements of the customers are fulfilled, all the operational constraints are satisfied, and the global transportation cost is minimized. In particular, for this case study, a CVRP is utilized to propose new distribution routes for the selected distribution centers. In a CVRP, demands are deterministic and may not be split, such that capacity restrictions are imposed upon the vehicles. The CVRP is known to be *NP-hard* (in the strong sense) calling for the determination of a minimum-cost simple circuit visiting all the vertices of G and arising when $C \geq d(V)$ and $K = 1$ (Toth & Vigo, 2014). The following integer linear programming formulation is proposed by Toth and Vigo (2014) indicating if a vehicle traverses an arc in the optimal solution. This model is a *two-index vehicle flow formulation*.

Minimize:

$$\sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij} \tag{2.1}$$

Subject to:

$$\sum_{i \in V} x_{ij} = 1 \quad \forall \, j \in V \; \{0\} \tag{2.2}$$
$$\sum_{j \in V} x_{ij} = 1 \quad \forall \, i \in V \{0\} \tag{2.3}$$
$$\sum_{i \in V} x_{i0} = K \tag{2.4}$$
$$\sum_{j \in V} x_{0j} = K \tag{2.5}$$
$$\sum_{i \in S} \sum_{j \in S} x_{ij} \geq r(S) \quad \forall \, S \in V \; \{0\}, S \neq 0 \tag{2.6}$$
$$x_{ij} \in \{0,1\} \quad \forall \, i, j \in V \tag{2.7}$$

Where:

$$x_{ij}: \quad \begin{Bmatrix} 1 \; if \; arc \; (i,j) \in A \; belongs \; to \; the \; optimal \; solution \\ 0 \; otherwise \end{Bmatrix}$$

Restrictions (2.2) and (2.3) are the impositions that one arc enters and leaves each vertex associated with a demand point. The restriction (2.4) references degree requirements for the depot vertex. The restriction (2.6) is the capacity constraint that imposes connectivity of the solution and vehicle capacity requirements.

RESULTS AND DISCUSSION

The P-median model was utilized to propose and compare two location scenarios for new distribution centers for the supplier: (1) the proposal of one new distribution center, and (2) the proposal of two new distribution centers. A cost analysis was realized to compare and discuss the efficiency and gains of installing new distribution centers based on existing assets and inversion. Using the previous mathematical model proposed by Daskin (1995) for P-median as a basis, the provided data and latitude and longitude coordinates for each restaurant franchise (demand point) were programmed in the software Lingo 10. In Table 1, the coordinate results produced by the P-median model for the proposals of locations to install new distribution centers are presented. The present distribution center on Avenida Valsequillo is first referenced with its respective latitude and longitude coordinates, subsequently followed by the proposed distribution center locations for proposal 1, installing one new distribution center, and proposal 2, installing two new distribution centers.

Table 1: Latitude/Longitude Coordinates For New Distribution Center Locations

Proposal	Street	Coordinates
Proposal 0 (Current Location)	Avenida Valsequillo	(19.009, -98.208)
Proposal 1	Avenida 31 Poniente	(19.045, -98.230)
Proposal 2	Avenida 31 Poniente	(19.045, -98.230)
	Camino Real	(19.051, -98.278)

Table 1 shows the latitude and longitude coordinates for the current distribution center and subsequently, the two proposed locations of new distribution centers. The column labeled STREET indicates the name of the street of the location in the city of Puebla, Puebla (Mexico) The column labeled COORDINATES shows the latitude, longitude of each point.

The principal elements and associated costs that were identified and analyzed in this facility location and distribution logistics proposal were the customers (restaurant franchises), distribution centers (existing and new), transportation, and delivery. The proposals for installing one and two new distribution centers were based on existing assets and the need to avoid installing too many new distribution centers because inventory costs and variability would increase. Since the meat supplier already had three distribution trucks, as well as necessary industrial freezers that could be transferred to new installations, for this reason one and two new distribution centers were proposed. Considering the facility location proposal 2 of installing two new distribution centers, the first located on Avenida 31 Poniente and the second located on Camino Real, plus the existing distribution center on Avenida Valsequillo, the 27 restaurant franchises (demand points) were a priori partitioned among the distribution centers. The existing distribution center on Avenida Valsequillo was partitioned few demand points because they are the most distant nodes, being located in the outskirts of the city of Puebla. Table 2 presents the restaurant franchises that were assigned to the distribution centers and their respective distances in kilometers from the depots. The restaurant franchises are numbered from 1 to 27 and are not listed in a particular order other than corresponding to the assigned distribution center.

Table 2: Allocation of Franchises to Distribution Centers

Distribution Center	Restaurant Franchise	Distance (Km)
Avenida 31 Poniente	1. Humboldt	7.65
	2. Boulevard Norte	1.47
	3. Avenida 25 Poniente	7.24
	4. Centro	4.98
	5. Avenida 31 Poniente	1.50
	6. Plaza Sur	4.02
	7. Plaza Dorada	0.59
	8. Plaza Centro Sur	2.15
	9. Plaza Loreto	1.52
	10. Angelópolis	2.76
	11. Avenida Juárez	1.96
	12. Avenida 4 Poniente	4.23
	TOTAL DISTANCE	40.07
Camino Real	13. Plaza San Diego	2.03
	14. Plaza Express	3.90
	15. Plaza América	4.13
	16. Camino Real	1.97
	17. Cuautlancingo	3.78
	18. Recta Cholula	2.44
	19. Plaza Cruz del Sur	4.36
	20. Plaza Mazarik	5.58
	21. Plaza CAPU	2.82
	22. Cholula	8.70
	23. Mayorazgo	4.21
	24. Zavaleta	4.56
	TOTAL DISTANCE	48.48
Current Distribution Center (Valsequillo)	25. Valsequillo	0.54
	26. Atlixco Centro	25.32
	27. Gran Plaza	1.28
	TOTAL DISTANCE	27.14

Table 2 presents the 27 restaurant franchises a priori partitioned between the two proposed distribution centers and the existing distribution center on Avenida Valsequillo. In the column RESTAURANT FRANCHISE, the points are numbered 1 to 27 corresponding to the assigned distribution center. In the column DISTANCE (KM), distances between the restaurant franchise and the corresponding distribution center are reported and measured in kilometers.

Theoretically having three installed distribution centers to draw a new logistics system, a CVRP was modeled and programmed in the software Lingo 10 to find the most optimal solution in the vehicle scheduling between the distribution centers and the allocated restaurant franchises, minimizing distances and associated costs. Capacity requirements were taken into account considering the determined demand at each restaurant franchise. Table 3 presents the designed distribution routes between each distribution center and its respective demand points. The number to the left of the name of the restaurant franchise refers to its assigned number in Table 2; how they appear listed in Table 3 is the designed route the vehicle will take to deliver the demanded meat to each restaurant franchise. The first point listed is the depot from where the truck will begin and end its distribution route. To verify if incrementing two additional distribution centers is beneficial to both Antigua Taquería and the meat supplier, a cost analysis is required where current costs incurred by the supplier are compared with the costs that would originate when installing two additional distribution centers on Avenida 31 Poniente and Camino Real. Fixed and variable costs of installations are considered. At the moment the supplier has sufficient personnel, equipment, and infrastructure to supply the capacity of three industrial freezers, so that when increasing two more distribution centers, the current resources were divided between three. An important cost to consider for the supplier is the price of fuel, as the original routes of the distribution trucks were not assigned on the basis of any optimization technique or mathematical model.

Table 3: CVRP Allocated Distribution Routes to Each Distribution Center

Avenida 31 Poniente Distribution Center	Camino Real Distribution Center	Current Distribution Center (Avenida Valsequillo)
5. Avenida 31 Poniente	16. Camino Real	25. Valsequillo
11. Avenida Juárez	19. Plaza Cruz del Sur	
10. Angelópolis	22. Cholula	
1. Humboldt	23. Mayorazgo	
3. Avenida 25 Poniente	13. Plaza San Diego	27. Gran Plaza
2. Boulevard Norte	21. Plaza CAPU	
9. Plaza Loreto	20. Plaza Mazarik	
4. Centro	14. Plaza Express	
12. Avenida 4 Poniente	24. Zavaleta	26. Atlixco Centro
6. Plaza Sur	15. Plaza América	
8. Plaza Centro Sur	17. Cuautlancingo	
7. Plaza Dorada	18. Recta Cholula	

Table 3 shows the allocated distribution routes for each proposed distribution center using mathematical programming of the CVRP. Each column represents one of the three distribution centers: the two proposed distribution centers, Avenida 31 Poniente and Camino Real, and the existing distribution center, Avenida Valsequillo. The restaurant franchises are numbered 1 to 27 corresponding to the respective distribution center.

With the proposed CVRP routes, it is guaranteed the minimization of distances and therefore a reduction in the cost of consumed fuel. On the other hand, a penalization cost could be incurred if the demanded product is not delivered on time to the restaurant franchises. This penalization would be at the cost of Antigua Taquería because opening hours would be delayed causing a loss in sales. Antigua Taquería has calculated this penalty cost at $2,000MXN per hour of delaying restaurant opening. In Table 4, actual costs for the current and proposed situations are presented to realize a cost analysis. The cost of fuel being utilized is $13.40MXN per liter of gasoline. In the penalty costs of the current situation, an average cost is determined of what the meat supplier incurs with its current delivery delays.

Table 4: Actual Costs for Current and Proposal Situations in Mexican Peso (MXN)

Situation	Current Situation	New + Existing Distribution Centers		
Locations	Current distribution center (avenida valsequillo)	Current distribution center (avenida valsequillo)	Distribution center avenida 31 poniente	Distribution center camino real
Electricity	$18,000	$6,000	$6,000	$6,000
Rent	$28,000	$13,000	$16,000	$18,000
Freezers	$42,000	$14,000	$14,000	$14,000
Equipment	$9,000	$3,000	$3,000	$3,000
Inputs	$18,000	$6,000	$6,000	$6,000
Administrative Personnel	$24,000	$8,000	$8,000	$8,000
Cutting Boards	$30,000	$10,000	$10,000	$10,000
Drivers	$36,000	$12,000	$12,000	$12,000
Penalties	$30,000	-	-	-
Gasoline	$36,000	$2,296	$2,414	$3,998
TOTAL	$271,000		$232,708	
SAVINGS	$38,292			

Table 4 shows a cost analysis comparison for the current situation with one distribution center located on Avenida Valsequillo and the proposed situation with two additional distribution centers to make a total of three working distribution centers for the logistics system of the meat supplier of Antigua Taquería.

A savings difference can be inferred from the cost analysis shown in Table 4. A savings of $38,292MXN is presented which represents a 14% savings between the current one distribution center scenario and the proposed three distribution centers scenario. In addition to cost savings for the meat distributor, the customer is receiving a more efficient, on-time service, therefore not having to charge penalty fees. Ultimately, value from these logistics activities is being created on both ends, for the supplier and the customer, in terms of timely deliveries and more efficient placing of distribution centers, diminishing vulnerability in the supply chain, minimizing costs and reducing routing distances.

CONCLUDING COMMENTS

In this article, a real-life application of optimizing facility location and distribution routes of a logistics system by the means of mathematical modeling has been analyzed and discussed. A P-median model was presented to propose locations of installing new distribution centers, subsequently followed by the application of a CVRP to determine the optimal distribution routes between the initial depot and corresponding demand points. An optimized vehicle routing was developed considering the proposal of opening two additional distribution centers. Having a total of three distribution centers available for service cuts down on inventory and costs, especially gasoline as routes have been optimized and there should not be any more late penalties incurred. A savings of $38,292MXN has been determined through the realization of a cost analysis for the current situation and the proposed situation. These solutions and cost analysis of this proposal have been presented to the management of Antigua Taquería to rethink their current logistics system and make necessary changes for higher efficiency and cost savings. Future work for this case study could be the determination of an adequate inventory system for each distribution system, based on the demand of the corresponding franchises, to ensure appropriate inventory levels and minimize associated costs. Also, the expansion of new restaurant franchises in optimally located coordinates not currently covered could be considered.

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