CVRPTW model applied to the collection of food donations

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Abstract

This paper shows a CVRPTW (Capacited Vehicle Routing Problem with Time Windows) problem applied to collecting donations from a food bank. The main objective is to minimize the costs and operating times that are affected by the fact of being subject to a dynamic variation in the programming of donors to visit. This problem is solved by means of a mixed integer linear programming model that allows defining the best route system, using information extracted from the Google Maps API for calculating the distance matrix. The model plans the sequence of visits that the vehicles must make, which includes the main, donor and secondary nodes, which are common points between the routes through which the vehicle must pass.

Keywords
VRPBTW, CVRPTWV, RPTW, Food bank.

1. Introduction

The Archdiocesan Food Bank of Bogotá (BAAB for its acronym in Spanish) is a non-profit organization (ESAL for its acronym in Spanish) that receives donations of different companies such as food, clothing, furniture, appliances and other items for vulnerable populations. Because it is an ESAL has few resources and as a main activity for its operation must go to donations of different organizations and companies along with the solidarity contribution those beneficiaries must pay. The problem is that the routes are empirical programming and requires minimize the total transport cost.

For that reason, we use a mixed integer linear programming to solve a CVRPTW applied to collecting donations for a food bank. After that, we obtain of Google Maps API input information as distance and travel times. Finally, we use GNU solver which applies “Branch and Cut” and “Branch and Bound” methods for achieve the optimal solution.

The rest of the paper is structured as follows. In Section 2, the literature reviews are gave. Section 3 explains the proposed mathematical model and graphic interface programming. The computational results, including the generation of created CVRPTW data set, are presented in Section 4. As a final point, a summary of the conclusions and future researches is provided in Section 5.

2. Literature Review

The classic Vehicle Routing Problem or VRP was introduced by Dantzig & Ramser [1] and it is a generalization of Traveling Salesman Problem or TSP, which was introduced by Flood [2]. A VRP variant is VRPTW, which consists of delivering goods from a depot to a set of customers for design routes based on vehicles capacity, customer demands, time windows and travel distances. The other VRP variant is VRPBTW and it was introduced by Potvin, Duhamel and Guiertin [3]. Its main characteristic is involving two types of customers: the first are delivery points, known as linehaul customers with a demand of goods to delivery from the depot or distribution center; the second are pickup points, known as backhaul customers and it requires a quantity of goods that must be collected and taken to the depot. When the vehicle does the route, it visits the backhaul customers after to visit all linehaul customers [4].

The most of researches found in the literature use different heuristics and exact approaches to solve the VRP, VRPTW and VRPBTW, these problems are considered NP – hard. Thangiahl, Potvin, & Sun [5] use a greedy insertion heuristic in which the linehaul and backhaul customers that must be visited according to their pre-established priority are inserted one by one to program the initial route. In each iteration, the cost function is evaluated to insert each customer in the route, in such a way as to minimize the weighted sum of detours and delays in the service for the next point to visit. If the new insertion position is not feasible, a new route is created to serve this client, the process is repeated to cover all points. The genetic algorithm (GA) is used to improve de initial solution. They test with 100 customers and resolve instances for 10%, 30% and 50% of re-allocated clients and only take into account the first 25 or 50 of them, for a total of 45 different problems. In the GA were fixed 50 generations to solve problems of 25 and 50 clients, and 100 generations for problems of 100 clients.

The VRPBTW is solved by Thangiahl et al. [5]. They proposed an insertion method to obtain an initial solution then it is improved through a local search (two-phase heuristic - λ exchanges and 2-opt method). The λ exchanges are used to find the nearest neighbors of each route and improve the solution and 2-opt method is adapted for the linehaul and backhaul customers in order to comply with the rule of visiting first all the linehaul and then the backhaul.

Recently, other VRP variant appears denoted as VRP in Reverse Logistics (VRPRL). The main characteristic of VRPRL is collect certain amount of end-of-life products from the customer site and returned to the central depot in order to be processed again [6]. This problem is usually solved by means of exact algorithm as direct tree search, dynamic programming and integer linear programming; classical heuristics as saving algorithms, sequential improvement algorithms, sweep algorithms, petal algorithms, two-phase algorithms, improvement heuristics; and metaheuristics as local search and population search [6].

In the literature review [7] works a VRPB model for hazardous material returns with distribution as one primary authors that mention it. Others authors as [8] y [9] formulates VRPRL models as integer programming. In [8] the authors work a VRPRL model as symmetric CVRP with one depot and a defined maximum tour distance for the transport of end-of-life (EOL) consumer electronic goods for recycling in South Korea. In this case, the objective is maximizing resource utilization and minimizes cost by minimizing the transport distance of vehicles over a fixed period of time taking into account parameters such as depot, number of vehicles available and number of EOL collector. This model is solved by means of a Tabu Search, taking into account the following restrictions: each customer visits only once, the total demand of any route should not exceed the capacity of the vehicle (Q) and the distance of each route (L) must not exceed the previously programmed maximum tour distance.

In [9] it is presents a VRPRL for food waste by solving CVRP comparing tree different scenarios denoted as Fixed CVRP, daily Dynamic CVRP and Currently. First, the collection days are divided into two groups where the first group corresponds to Mondays, Wednesdays and Fridays, and the second group comprises Tuesdays, Thursdays and Saturdays. Later, the Fixed CVRP is based on the average daily weight of each collection area and consists of vehicles that take the same fixed routes every day, regardless of the actual amount of food waste disposed in each collection area. The daily Dynamic CVRP the optimum vehicle routes are determined solving the CVRP by obtaining the real-time weight using RFID technology. And in the Currently the routes are determined according to the experiences of the drivers.

On the other hand, [10] and [11] work a mixed integer programming to solve a Selective Multi-Depot VRP with Pricing in Reverse Logistics (SMDVRPPRL) and Waste Collection VRP, respectively. In [10] the SMDVRPP model is formulated as mixed integer nonlinear programming model and it solves by a Rich Neighborhood Tabu search (TS-RN). This model is a VRP for end-of-life products where all vehicles have the same capacity and each is assigned to a collection center (CC) from which they must leave and return and there is no limit on number of vehicles assigned to a CC. The specific problem is called "Selective MDVRP with pricing" (SMDVRPP) due to the company decides not to send a vehicle to collect the end-of-life products if this action is not profitable.
In this paper the authors propose two formulations of nonlinear mixed programming that are linearized to produce versions of mixed linear programming. The objective of this model is to maximize the profit collected from the value of the products used.

In the waste collection VRP, [11] formulates a linear mixed integer programming model solved by means Neighborhood search. They present a waste recyclable collection model in which the vehicles leave the depot to take the waste to a recycling plant or to the depot. In this model are considered time windows for the depots, collection centers and recycling plants. The formulation takes into account which route is limited by the legal length of the work day and includes multiple origins, multiple destinations, multiple capacities and site dependencies, additionally a directed graph is defined *G(N, A)* where *N = O'* U *O''* U *D* U *P* where *O'* is the set of depots of origin and *O''* is the set of destination depots, *D* is the set of recycling plants, *P* is the set of containers and *A* is the set of arcs. Also takes into account the weight and volume to be collected. The model is solved by a multiple neighborhood search with which an initial feasible solution is obtained and then an iterative improvement procedure is applied.

[12] proposes a PVRP in a certain time horizon to collection of raw materials for the manufacture of autoparts where the goal is to minimize the total transport cost. The scatter search method is performed to solve the problem. This is an evolutionary method and consists of two phases: in the first phase the orders are assigned to the calendars, and in the second phase, routes are built for each day in the planning horizon. The solution by means of calendar assignments is obtained, then the VRP's solution. Two situations are taken into account for the solution of the model: the first is when a change occurs in an order after all the orders have been assigned to the calendar and the second situation is when an order is assigned to the calendar while a solution is being building.

The collection of donations has similar characteristics to the VRPRL because the vehicle capacities must be fully utilized. The vehicles leave empty from the depot, they must follow the route collecting products and returning.

3. Mathematical Model

3.1 Formulation

This problem has different characteristics. First, all donors have different donation quantities and each of them has their own time window. The fleet of vehicles is homogeneous and there is a single depot, the Food Bank, from which all vehicles departure and return after collecting the donations. The above nuances suggest the use of a CVRPTW model in order to solve the problem.

The VRPTW and the CVRPTW have been widely studied. Under a directed graph $G = (V, A)$, where $V = \{v_0, v_1, \ldots, v_n\}$ is the set of nodes and A is the set of arcs. Node v_0 is the depot or the Food Bank in this case, and the other nodes represent the donors. A cost $c_{ij}$and a travel time t_{ij} are defined for each pair of nodes. Every donor has a positive amount of donation d_i, time window $[a_i, b_i]$ and a positive service time st_i. a fleet of U vehicles of capacity C is available for collecting the donations. The problem consists in finding a minimum cost set of routes visiting exactly one each donor subject to the above constraints.

[13] proposes a solution CVRPTW with branch and bound method and we use its formulation for applied to CVRPTW with the collection of food donations. This CVRPTW formulation is described as follows:

$$minimize \sum_{1\le u\le U} \sum_{(v_i,v_j)} c_{ij} x_{iju} \tag{1}$$

Subject to

$$\sum_{1\le u\le U} \sum_{\{v_j \in V | (v_i, v_j) \in A\}} x_{iju} \ge 1 \qquad (v_i \in V \setminus \{v_0\}) \tag{2}$$

$$\sum_{\{v_j \in V | (v_i, v_j) \in A\}} x_{iju} - \sum_{\{v_j \in V | (v_j, v_i) \in A\}} x_{jiu} = 0 \qquad (v_i \in V, 1 \le u \le U) \tag{3}$$

$$\sum_{\{v_i \in V | (v_0, v_i) \in A\}} x_{0iu} \le 1 \qquad (1 \le u \le U) \tag{4}$$

$$\sum_{(v_i,v_j)\in A} x_{jiu} d_i \le Q \qquad (1 \le u \le U) \qquad (5)$$

$$s_{iu} + st_i + c_{ij} - s_{ju} + M x_{iju} \le M \qquad \left((v_i, v_j) \in A, v_j \ne v_0,\ 1 \le u \le U\right) \qquad (6)$$

$$s_{iu} + st_i + c_{i0} - b_0 + M x_{i0u} \le M \qquad \left((v_i, v_0) \in A,\ 1 \le u \le U\right) \qquad (7)$$

$$a_i \le s_{iu} \le b_i \qquad (v_i \in V,\ 1 \le u \le U) \qquad (8)$$

$$x_{iju} \in \{0,1\} \qquad \left((v_i, v_j) \in A,\ 1 \le u \le U\right) \qquad (9)$$

Where x_{iju} and s_{iu} are decision variables, b_0 is the end of the time horizon and M is a large number. Variables x_{iju} indicate whether arc (v_i, v_j) is used by vehicle u or not. s_{iu} is the service starting time of the donor v_i visited by the vehicle u. Constraints (2) impose the visit of every donor and constraints (3-4) define the sequence followed by vehicles. Constraints (5) concern to vehicle capacity and constraints (6-8) are related to the time windows.

3.2 Solution Method

To solve this method, we use a GNU solver. This is a package is intended for solving large-scale linear programming (LP), mixed integer programming (MIP), and other related problems as the one we raised in the present study. The model was fed from the following information: demand (quantity of products) to collect from each point (donor), the time windows at each collection point where not only plays the time (TW) but the day in which the collection must be done. From the information taken from the API Google, which we explain in the following section, the matrix of distances is constructed from which the routes to be followed by the vehicles are generated. Finally, the total route distance is calculated by the model.

3.3 Route presentation software system for the Bogotá Food Bank

The software developed for this research consists of the following components:

- Presentation component (guiCliente). This presents to user the path obtained after the application of the algorithms and optimizations. It is developed in HTML5 and javascript.
- Route Calculation Component (bancodeAlimentos). This component performs route calculation using algorithms and software-based optimizations called GEMS. It is developed in Java.
- Coordinator component (core). This component allows you to manage the requests of users of the system and coordinates the generation of routes from the external component of Google Maps and the route calculation component.
- API Google Maps component (apiGoogle): It is the external component of the system, Google Maps allows to obtain information about the roads of the city and is a complement to the analysis of routes since it is possible to obtain relevant information about the distances between the points and possible routes for vehicles.
- Database component (baseDatos): This component allows you to store the relevant information about the typical collection points.

Design

The design is oriented by components and its configuration is as follows:

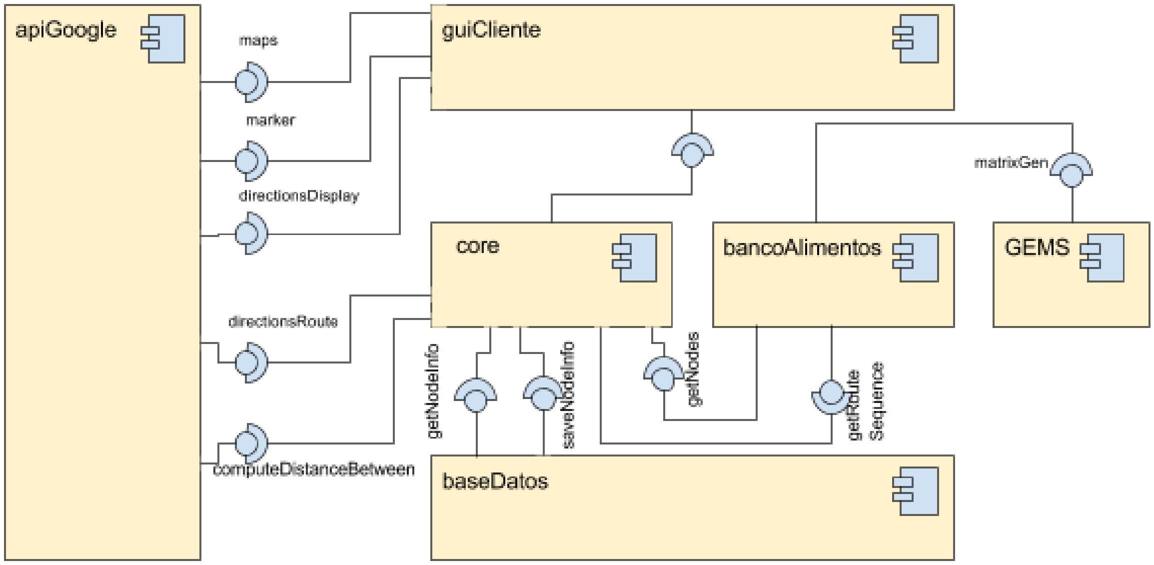

Figure 1. Diagram of components of the developed software

Sequence of execution

The *guiCliente* component communicates with *apiGoogle* component to show the city map in a browser. In this map, the user can select the points corresponding to the collection places, in this moment the *core* component uses the information from Google to create an array of distances which will be sent to *bancodeAlimentos* component, it generates the sequences of points to cross in the city of Bogotá D.C. thanks to routing algorithm model. Next, the sequence of points is sent back to *core* component to arrange and store it in data base and then show it by means of *guiCliente* component. This last step is done with the support of API from Google Maps.

API Google

API Google has a large number of services applicable to projects that have to do with location and routing problems. We have used basically five services from API to develop de system showed:

- Maps presentation service (maps).
- Service of marking of points within maps (marker).
- Distance calculation service (spherical.computeDistanceBetween).
- Service route generator (dirесtionsRoute).
- Route presentation service (directionsDisplay).

All those services from Google Maps are free and applicable to projects based on javascript and HTML5.

Infrastructure used for software

The infrastructure required for the operation of the software is as follows:

Apache Server: In which the *guiCliente* and *core* components will be located for the presentation and capture of information of the users by means of the deployment of a website. This server must have a public IP address.
GlassFish Server: In this is *bancodeAlimentos* component and the processes of calculation of routes and the connection to specialized software are realized.
MySQL database server: Here is the *baseDatos* component that allows the storage of nodes within the city map, each node has information corresponding to the entities in which the food collection process is done.

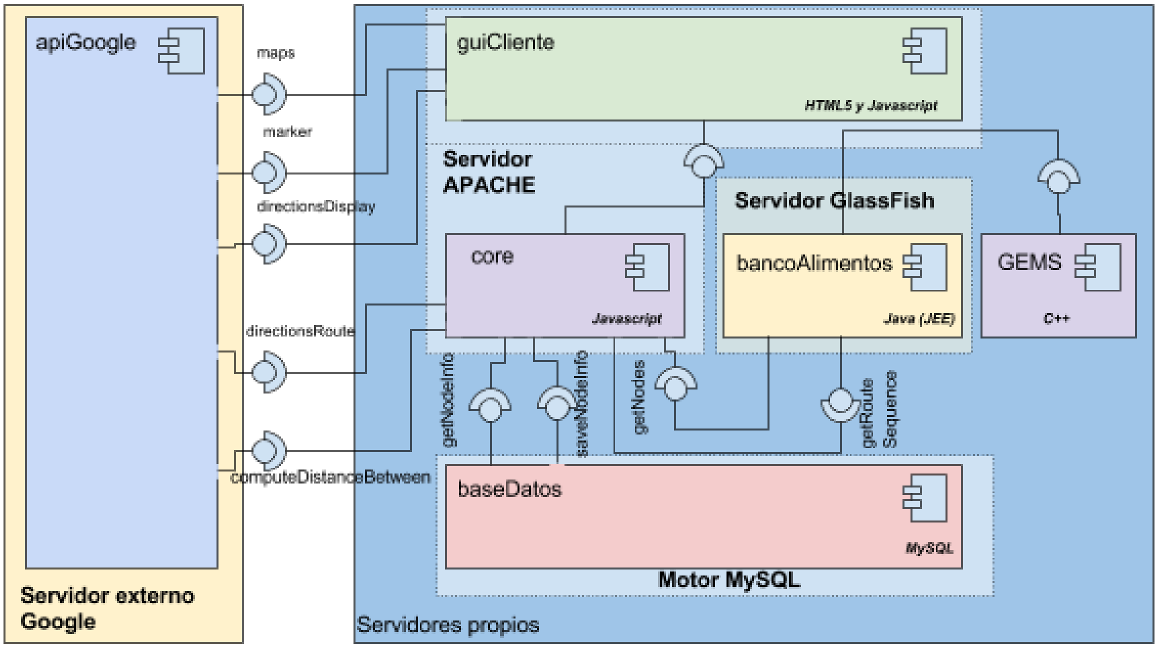

Figure 2. Platform infrastructure required for the developed software

4. Results

We use GNU solver for obtain sequence of routs based on average demand, time service and time windows, which reported in Table 1.

Table 1. Average demand, service time and time windows of donors

NODE	AVERAGE DEMAND (Kg)	SERVICE TIME (Min)	TIME WINDOW	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
2	158	33,57	8 am - 5 pm	X		X		X	
3	107,9	31,53	6 am - 2 pm	X		X		X	
4	152	31,22	8 am - 5 pm	X	X	X	X	X	
5	106,7	34,17	8 am - 5 pm	X		X		X	
6	139,7	27,28	2pm a 4pm	X		X		X	
7	151,4	26,87	8 am - 11 am	X		X		x	
8	26	33,13		X		X		X	
9	385,5	20,00	6 am - 2 pm	X		X		X	
10	520,8	29,10	8am a 4pm	X		X		X	
11	197,7	27,03	8am a 4pm	X		X		X	
12	38	30,28	8 am - 5 pm	X	X	X	X	X	X
13	33,9	26,80	7 am- 12 pm	X		X		X	
14	70	33,22	8 am - 5 pm			X			
15	68	29,58	7 am - 5 pm		X				
16	65	50,00	2pm - 4pm		X				
17	65	30,28	8 am - 5 pm	X	X	X	X	X	X

NODE	AVERAGE DEMAND (Kg)	SERVICE TIME (Min)	TIME WINDOW	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
18	58	56,20	8 am - 5 pm	X	X	X	X	X	X
19	66	31,00	8 am - 5 pm	X	X	X	X	X	X
20	73,1	25,13	10:30 a.m.	X	X	X	X	X	

The actual routes are tree, which reported in table 2 and Table 3 shows the sequence of routes of the first instance results.

Table 2. Average demand, service time and time windows of donors

Route	***Sequence***	***Distance (km)***
1	BAAB-3-5-10-11-6-BAAB	27
2	BAAB-9-13-7-20-BAAB	27
3	BAAB-19-8-17-2-15-14-16-18-12-4-BAAB	63
	Total distance (km)	**117**

Table 3. Sequence and travel total distance of routs

Route	***Sequence***	***Distance (km)***	***Time execution (min)***
1	BAAB-3-10-5-11-6-BAAB	23	0,11
2	BAAB-20-7-9-13-BAAB	19	0,11
3	BAAB-8-18-12-2-16-19-17-15-4-14-BAAB	116	0,47
	Total	**158**	**0,69**

It can be observed in Table 3 that it result 3 routes where the route number 3 is largest than the routs number 1 and 2. This is because there are 20 donors. Although the total distance of route 3 in Table 2 is less than that shown in table 3, the first one fails to comply with the time windows. Finally, the optimal solution is reported in Table 4, which shows sequence, travel total distance of routes and time execution, in which each route starts at 6am.

Table 4. Optimal sequence and travel total distance of routs

Route	***Sequence***	***Distance (km)***
1	BAAB-7-9-19-8-14-17-2-15-18-16-12-4-20- BAAB	25,7
2	BDA-3-10-5-13-11-6- BAAB	70,3
	Total distance (km)	**96**
	Time execution (min)	**8,23**

This study is a pilot test for in the future implemented this model in the all national food banks.

5. Conclusions

This study introduces a VRPRL variant based on characteristics of collecting donation of the "BAAB". The model is formulates as integer linear programming problem and solves by GNU solver. It is a pilot test. This variant could be called CVRP applied to collecting donations (CVRPCD). On the other hand, this study is a part of a larger work that intends to implement this model in all national food banks.

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Biography

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