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IMPROVEMENT OF PICK-UP ROUTES FOR AN INTERNATIONAL SHIPPING ENTERPRISE BY USING A HEURISTIC METHOD

MEJORA DE RUTAS DE RECOLECCIÓN PARA UNA EMPRESA INTERNACIONAL DE MENSAJERÍA Y PAQUETERÍA UTILIZANDO UN MÉTODO HEURÍSTICO

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RESUMEN: El diseño de rutas es un factor importante en la administración de operaciones logísticas de distribución y de suministro para procesos de producción. En el presente trabajo se llevó a cabo el rediseño de rutas de recolección de una empresa de mensajería de clase mundial. Esto con el objetivo de mejorar la utilización de los vehículos de recolección y reducir el tiempo de transporte. Para el rediseño de rutas se utilizó un método heurístico aleatorio. Como resultado se obtuvo que con un número pequeño de vehículos se puede realizar la recolección en todos los puntos cliente de la empresa. De igual manera, la utilización de estos vehículos se puede maximizar a más del 90.00% con una reducción en el tiempo total de transporte. Al tener más tiempo sobrante se puede extender el número de clientes a visitar, aumentando así la presencia de la empresa en el mercado. De igual manera se pueden reducir costos operacionales al reducir el tiempo de transporte.

Palabras-clave: Métodos heurísticos. Problema de ruteo vehicular capacitado. Utilización.

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ABSTRACT: Route design is an important factor for the management of supply and logistics operations required by production processes. In this work the re-design of pick-up/delivery routes for an international shipping enterprise was performed to improve vehicle utilization for pick-up/delivery operations and reduce transportation time. The re-design of the routes was accomplished by using a random heuristic method. As a result, it was obtained that pick-up/delivery for all clients can be performed with a small number of vehicles. Also, vehicle utilization can be maximized over 90.00% with a significant reduction in total transportation time which leads to decrease operational cost. The additional available time then can be used to cover a higher number of clients, increasing the presence of the enterprise in the market.

Keywords: Heuristic methods. Capacitated vehicle routing problem. Utilization.

1 INTRODUCTION

The present work was developed from an analysis focused on improving the pick-up/delivery processes of an international shipping enterprise. This enterprise is continuously exploring opportunities to provide the best service with the available resources and minimum costs/time. Within this context, the enterprise wants to minimize the extra time caused by the drivers of the pick-up/delivery vehicles. This extra time is generally caused by the following factors:

- Extensive pick-up/deliver routes: routes for extensive territories with few clients.
- Quantity of transported packages per route: vehicles with low utilization of capacity.
- Visit time: clients are visited out of working hours (for pick-up and delivery processes).

These factors have also caused an excess of controllable expenses, loss of time to perform tracking and operational re-work. This has affected resource allocation which has a direct impact on the main element of its supply chain: the client.

The interest to develop this work is based on one of the main goals of the enterprise which consists of resource savings. In this case it is expected to accomplish the objective of controllable expenses through route optimization. The Vehicle Routing Problem (VRP) model is considered to address this case given its combinatorial optimization and integer programming features which are closely related to the operational characteristics of the shipping enterprise.

1.1 Problem Description

The enterprise under study works on the logistics for international shipping of packages. Its operational cycle starts at the pick-up stage where packages are collected from clients. Then these packages (services) are taken to its main distribution center (DC) where each package is assigned to specific transfer centers (i.e., cross-docking centers) in-route to its end destination. The transfer centers are located in strategic points through Mexico, which by land and air transportation, facilitate connection with the end customers. The operational cycle finishes with the delivery of the services.

The problems that mostly affect a delivery start from the beginning of the process at the pick-up stage. The pick-up process is an aggregate value which is offered to the clients. Under this scheme, clients do not have to take their packages to the DC for shipping. Instead, the vehicle of the enterprise visits the clients at their locations, picks up their packages, and then takes them to the DC for shipping. The logistics of this process must be efficient in order to accomplish the enterprise's operational goals. Nevertheless, currently the enterprise does not have a model to facilitate a better allocation of the available resources (human, economic and operational) to achieve more efficient processes.

One of the main problems within the pick-up stage is present during the allocation of vehicles to each of the established routes: sometimes small-capacity vehicles are allocated to cover routes for territories with few clients and large demands. This causes multiple visits (up to three) to a single client, an increase in extra time and unnecessary transportation costs. Another problem is present when there are many clients within a large territory. Even though the capacity of the vehicle may allow loading of all the packages for pick-up/delivery, the driver faces a distance-time situation which implies delays to reach all clients on-time. Finally, there is a problem regarding small territories with low-demand clients covered by large-capacity vehicles (more than three times the volume of the actual demand). In this case, the maximum capacity of the vehicle is not exploited. Because of these problems the present work is focused on providing a suitable solution to improve the current situation.

2 DEVELOPMENT

The objective of this study is focused on improving resource allocation to support the operational activities of the shipping enterprise. This is, to maximize the utilization of material and human resources to accomplish more efficient pick-up/delivery processes. This research is descriptive and aims to be experimental, as currently only results will be presented and discussed on the basis of their feasibility to solve the problems of the enterprise. This research also has an exploratory and correlational approach.

The data collected for modelling and analysis were operational historical data of the last six months. This period was considered appropriate to obtain robust estimates of demands.

The territory covered by the enterprise consists of 191 points (190 clients + 1 DC). For each client its average demand over the last six months was obtained. These demands were measured by averaging weight (kilograms, kg) and volume/size (cubic meters, m^3) through all the packages that were picked-up/delivered on each service. Finally, with support of the Google Maps tool, times and distances between each client-point and the DC were estimated for subsequent modelling and optimization. In the following sections information regarding the techniques and data used for the analysis and improvement of the pick-up/delivery routes is presented and discussed.

2.1 Vehicle Routing Problem (VRP)

Transportation Planning (TP) is defined as the process of making decisions concerning resource requirements of transportation considering their importance in achieving strategic goals in the short and long term. In general, TP is involved in the assessment, design and scheduling of transportation facilities and it is based on specific planning models for each context.

Most models used in TP are called Travel Demand Models (TDM) and evaluate the transportation demands in terms of numbers of travelers or transportation services. This is in order to predict traffic volumes and associated effects. As shown in Fig.1 the VRP, which is an important subject within the TDMs, consists of a set of paths that start and end in a specific point (e.g., a DC or warehouse). These paths must serve or visit a set of points (e.g., clients) only once and satisfy their demands. Each route or path is served by only one vehicle in order to minimize the overall transportation cost of meeting all the clients' demands. Hence, the elements of the VRP are the following: paths between all clients, location of clients and the DC, and the number of vehicles.

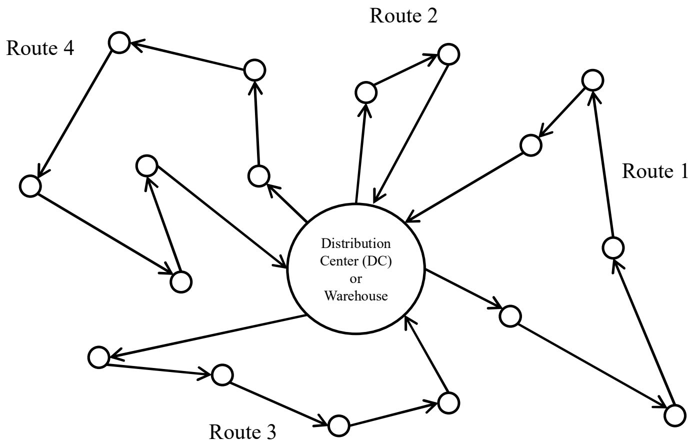

Fig. 1. Distribution network modelled by the VRP (own work).

The VRP has several applications in the real-world such as accumulation of solid waste, street cleaning, school bus routing and routing of vendors and service units. According to Farahani et al. (2011) the pioneers of the VRP model were Datzing and Ramser. In 1959 they proposed the first formulation of mathematical programming and algorithmic solving approach for the VRP in a real application. Years later, Clark and Wright improved the approach of Datzing and Ramser by proposing a solving heuristic (Savings Method, or C&W). Currently many researchers are developing algorithms and models for different contexts of the VRP. Among these models the following can be mentioned: Capacitated VRP (CVRP), VRP with Time Windows (TWVRP), Pickup and Delivery VRP (PDVRP), VRP with Multiple Depots (MDVRP) and Periodic VRP (PVRP).

For our case study the CVRP was considered. To adapt this model to the pick-up and delivery requirements of the clients (considering that this is done in the same visit), the demand of each client was determined as the maximum amount between the quantity that is delivered and the quantity that is picked-up. The integer-linear programming formulation of the CVRP proposed by Toth and Vigo (2002) is described as follows:

a) Considerations:

- Demands are deterministic and cannot be divided or separated.
- Homogeneous fleet: all vehicles are identical.
- There is only one central repository or DC.
- Capacity constraints for vehicles are fixed. All vehicles have the same capacity.

This case study also considers the VRP to be asymmetric: the distance (or transportation time) from client i to client j may be different from client j to client i.

b) Nomenclature:

- $G = (V, A)$: a complete graph (network).
- $V = \{0, \dots, n\}$: a set of vertices where 0 is the node (point) that represents the DC and n is the total number of clients.
- A: set of arcs between all clients and the DC.
- d_j: demand of each client j (d_0=0).
- c_{ij}: non-negative transportation cost associated to the arc from the vertex (client) i to the vertex (client) j. This cost may represent distance or time.
- $S \subseteq V$: set of clients.
- $d(S)=\sum d_i$: total demand of the sets of clients.
- K: number of identical vehicles.
- C_k: capacity of each vehicle k.
- $r(S)$: minimum number of vehicles required to service all clients.
- x_{ij}=1 if the arc $(i, j) \in A$ belongs to the optimal route and 0 otherwise.

c) Objective Function

$$min \ \sum_{i \in V} \sum_{j \in V} c_{ij} \, x_{ij} \tag{1}$$

d) Restrictions

$$\sum_{i \in V} x_{ij} = 1, \ \forall \ j \in V \setminus \{0\} \tag{2}$$

$$\sum_{j \in V} x_{ij} = 1, \ \forall \ i \in V \setminus \{0\} \tag{3}$$

$$\sum_{i \in V} x_{i0} = K \tag{4}$$

$$\sum_{j \in V} x_{0j} = K \tag{5}$$

$$\sum_{i \notin S} \sum_{j \in S} x_{ij} \geq r(S), \ \forall \ S \subseteq V \setminus \{0\}, \ S \neq \phi \tag{6}$$

$$x_{ij} \in \{0,1\}, \ \forall \ i, j \in V \tag{7}$$

Equations (2) and (3) represent the restrictions that define that only one arc (path) must enter and leave each vertex or node (client). Equations (4) y (5) define that the number of arcs that enter/leave the vertex 0 (DC) must be equal to the number of vehicles. Finally, (6) defines the capacity requirements of the vehicles while ensuring the correct connectivity of arcs and vertices.

2.2 Solving Algorithm

The VRP is continuously studied for its relevance, its practicality and its difficulty. Lenstra and Kan (1981) analyzed the complexity of the VRP concluding that virtually all variations of the VRP are non-deterministic and polynomial. In addition, the VRP is considered an NP-hard problem, hence finding global optimal solutions is difficult if the number of vertices (clients) is large (MÖLLER, 2014; OLIVERA, 2004; TOTH and VIGO, 2002). Because of this, a heuristic algorithm was used to obtain a (non-global optimal) feasible solution for the enterprise's network which consists of 191 locations. In Fig. 2 the stages of the heuristic algorithm are presented. In the first stage the algorithm takes as basis the solution of the Traveling Salesman Problem (TSP) which consists on finding a single path of minimal cost to visit all clients starting and ending in a single node. This route is also known as a Hamiltonian Cycle. At this stage the capacity of the vehicles and clients' demands are not considered.

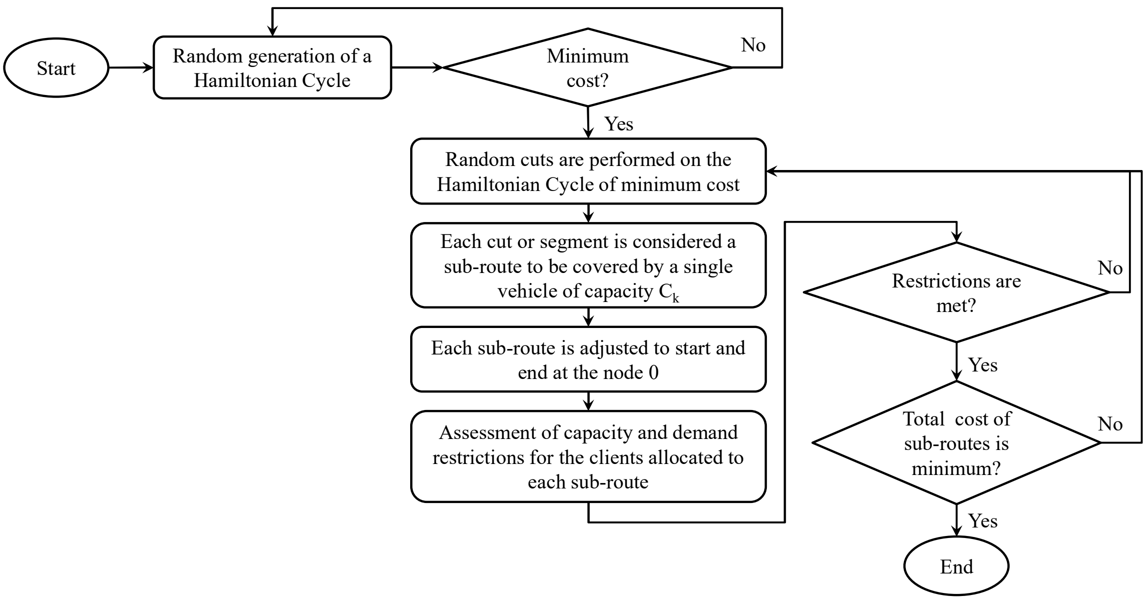

Fig 2. General structure of the heuristic algorithm used to provide a suitable solution for the VRP (own work)

In the second stage a random partition of the Hamiltonian Cycle is performed to obtain sub-routes that could be covered by different vehicles. At this stage the capacities of the vehicles and the demands of the clients assigned to each sub-route and vehicle are considered.

If the sub-routes do not meet the capacity constraints then another partition is performed, otherwise the allocation of sub-routes is saved and its total cost is assessed for minimal cost. If this solution, compared to the previously found feasible solution, is of minimum cost, then the solution is saved. If not, then a new random partition is performed. This random search process was iterated for 2000 cycles. With this algorithm a feasible solution with a minimum number of vehicles was obtained for the enterprise.

3 ANALYSIS OF RESULTS

To propose a solution to the VRP of the courier enterprise the following was assumed:

a) The demand of each client is the maximum amount between the quantity (kg) that is delivered and the quantity (kg) that is picked-up. The pick-up/delivery process is performed on the same visit.

b) The distance was determined in kilometers and minutes for each path between the 191 points to visit without exceeding the maximum work time of 10 hours (600 minutes).

c) The type of vehicle selected for our analysis was the one with the largest capacity. This is a MT45 truck with a capacity of 4 tons (4000 kg).

Table 1 presents the results of the heuristic and it is observed that only 7 units are required to visit all 190 points that represent each of the selected clients. For 6 vehicles their capacity utilization is greater than 90%. The total length of all the 7 routes is 720.38 km (per day) which generates a maximum workday per route of 7 hours 58 minutes. When comparing these results with the current situation savings up to $ 267,753.00 per month are obtained. More details are presented in Table 2.

Table 1. Results of the Heuristic Used for the VRP (own work)

Route	Kilometers Traveled	Minutes	Capacity in Kilograms
R1	129.13km	478 min	3999Kg
R2	151.61km	364 min	4000kg
R3	159.55km	285 min	3999kg
R4	98.33km	241 min	3997kg
R5	118.96km	303 min	3989kg
R6	35.80km	62 min	3963kg
R7	27.00km	53 min	1866kg

Table 2. Comparison of Results: C= Current, P=Proposed (own work)

Routes	C	22
	P	7
Kilometers Traveled	C	7,491.16 km
	P	720.38 km
Minutes Worked (per day)	C	15,840 min
	P	3,572 min
Maximum Capacity in Kilograms	C	45,225 kg
	P	28,000 kg
Total Operational Cost	C	$ 393,910.2
	P	$ 126,157.2

According to the results produced by the heuristic we have the following remarks:

a) The number of existing routes was reduced by 68.18%. Instead of having 22 routes 7 MT45-type vehicles can operate effectively 7 routes.

b) Regarding the kilometers traveled a decrease of approximately 90% was obtained. This decrease is significant and explainable due to vehicles now traveling greater distances with higher capacity utilization. These distances are traveled within the time restriction of 10 hours.

c) Currently, the enterprise has vehicles to carry a total load up to 45.225 kg. However, by considering the proposed solution with the 7 MT45-type vehicles with a capacity of 4,000 kg a total load of 28,000 kg can be carried. This load capacity is valid while the demands of the clients do not exceed the maximum between their loads that are picked-up and their loads that are delivered.

d) The cost of operating the enterprise currently is on average $393,910.23 with 22 operators (i.e., drivers), 2 assistants and the costs of operating each vehicle (salary, overtime, unit wear, fuel, maintenance, etc.). With the proposed scheme, the total operating cost was reduced to $ 126,157.23. Note that this cost was estimated under the assumption that only 7 vehicles (with 7 operators and 7 assistants to support pick-up/delivery processes) are considered.

e) Finally, the operating times were reduced to 77.45% by taking 1 to 8 hours to complete each route per vehicle per day.

4 CONCLUSIONS AND FUTURE WORK

The analysis of results led to a very feasible solution with a decrease in the operating cost of 67.9%. Nevertheless, with this route scheme, the work schedule is reduced to more than half the official working hours per day. Even with the cost and time savings, this scheme may not be suitable under the current work contracts and labor conditions. Thus, opportunities must be explored to take advantage of the additional available time and resources under the proposed routing scheme, and determine activities to cover the whole working hours per day. The following proposals are considered:

a) Additional shipping / courier projects can be developed for local businesses with branch offices /retailers. This can increase the number of clients and shipping routes. Because these projects can present operational difficulties, operators and assistants can support essential activities such as loading and unloading vehicles, organizing cargo warehouses and even transportation to the retailers' locations around the city.
b) Management of resources for cases where shipments cannot be delivered in a timely manner. This management can be performed by calling the addressee or the sender in order to coordinate a new visit and expedite the required delivery/pick-up service. For these activities the available operators and/or assistants can provide support. Hence, the additional available resources can be assigned to cover affected services due to theft or accident. With the available time gap other vehicles can be coordinated to provide a favorable response to the clients.

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