A Comparative Analysis of Heuristics Applied to Collecting Used Lubricant Oils Generated in the City of Pereira, Colombia

Diana Fajardo, Sebastián Ortiz, Oscar Herrera, Angélica Santis

Abstract**—**Currently, in Colombia is arising a problem related to collecting used lubricant oils which are generated by the increment of the vehicle fleet. This situation does not allow a proper disposal of this type of waste, which in turn results in a negative impact on the environment. Therefore, through the comparative analysis of various heuristics, the best solution to the VRP (Vehicle Routing Problem) was selected by comparing costs and times for the collection of used lubricant oils in the city of Pereira, Colombia; since there is no presence of management companies engaged in the direct administration of the collection of this pollutant. To achieve this aim, six proposals of through methods of solution of two phases were discussed. First, the assignment of the group of generator points of the residue was made (previously identified). Proposals one and four of through methods are based on the closeness of points. The proposals two and five are using the scanning method and the proposals three and six are considering the restriction of the capacity of collection vehicle. Subsequently, the routes were developed - in the first three proposals by the Clarke and Wright's savings algorithm and in the following proposals by the Traveling Salesman optimization mathematical model. After applying techniques, a comparative analysis of the results was performed and it was determined which of the proposals presented the most optimal values in terms of the distance, cost and travel time.

Keywords**—**Heuristics, optimization model, savings algorithm used vehicular oil, VRP.

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I. Introduction

MANUFACTURING companies have begun to consider the importance of making a proper collection, storage, and disposal of products that have completed their lifecycle, in order to reintegrate them into the production chain with other functions or mitigate or reverse the environmental damage caused by their improper disposition. In respect to the collection, it is essential to have a proper design of their transport systems. This allows for minimizing the time and costs in the delivery and collection of these products, and also effectively manages the activities of the supply chains. The logistics network design allows you to carry out the process with the least economic impact for companies [1]. Taking into account the above, in Colombia different studies have been developed that are based on the use of techniques and methods to find a feasible solution to the problem of routing. Among these studies, one can be highlighted, such as that proposed in [2], where a model of optimization of transport routes was designed in a transport company. The company operates in the urban area of the city of Cali and its neighboring municipalities. This company is responsible for 45 routes, for this study only seven routes was selected (from the route 2 to 5 and from the route 7 to 9). The routes are located in the town center zone of Cali and are group the largest number of customers and represent the greater difficulties. The problem was the absence of a quantitative criterion for the allocation of routes. To solve the problem VRP Solver 1.3 software was used. This software implements the Clarke and Wright's savings algorithm method, in order to reduce the distances that used vehicles must travel and to minimize the required number of them to serve the customers. The most significant results were evident on Route 2 and Route 8 where the distance was reduced by 8% (from 11.93 km to 10.98 km) and 19% (from 17.56 km to 14.34 km), respectively.

The study [3] proposed a heuristic algorithm for establishing the scholar routes of the Secretariat of Education of Bogota for the locality of Kennedy. Due to the availability of the information from a total of 64 routes (that relate to the 20 schools in the locality), 48 routes were chosen. The algorithm used was adapted to the COVRP (capacitated open vehicle routing problem), on the basis of the CVRP (VRP with restriction of capacity) general algorithm. As a result of the algorithm application, the distance traveled decreased by approximately 225 km from the total distance, and for the routes that are using more than one bus, the decrease was 25%. On the other hand, [4] has generated and applied a mathematical model which takes as a reference theoretical central the VRP, whose aim was to improve the supply routes of each storage center in the collection process of milk at the Sugamuxi Province. For this, eight collection centers located in the municipalities of Firavitoba, Iza, Sogamoso and Tibabosa (who concentrated 597 producers) were studied. The times and levels of production were defined, also the provisioning costs, the means of transport used and their capacity. The study population was represented by 102 producers, eight collection centers, and two processors,

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for a total of 112. A model CVRP was developed and the total cost of distribution per kilometer traveled was determined. This with the aim of decrease the total cost transport of the milk supply chain. The savings to the supply chain was $ 55,015.22 pesos per day and the main result was in the milk collection center Sogamoso with a decrease of 46 kilometers with a savings of $ 31,535.88 pesos per day.

Finally, in [5] the method of savings to design a reverse logistics network to collect the used lubricant oils in the city of Pereira was implemented. For the study, 96 points that produce used lubricant oils in that city were located. This was modeled as a CVRP that is solved by means of the heuristic known as routing first and assign later. The first phase of the problem is resolved by applying the savings algorithm and the second, with the clustering algorithm, which is programmed in MATLAB. It was also important to note, that this model was evaluated twice: with the Faw truck and Dongfeng truck. Reverse logistics network is composed of a collection center, four trucks, four routes and 96 generator points and was determined that the network has a capacity of oil collection of 13.316 gallons.

Considering the above, this study focused on the analysis and comparison of different heuristics that are exposed in six proposals, in order to determine which offers the best results in terms of optimization of time and costs for the collection of used lubricant oils in the city of Pereira. These proposals were addressed in two phases: the first, the groups were formed by the method of the closeness of points, the scanning method and from capacity collection vehicle restriction. The second, the routes were designed by the savings algorithm and mathematical optimization model.

It should be noted that for the development of the present study, was taken as a reference the research [5]; some data was used as operating costs, location of the generator points of the used lubricant oils, the distance and amount of residue at these points; all this with the proper authorization of the authors. Also, the data correspond to the year 2014, highlighting that the essence of this study lies in the application and comparison of solving techniques for the VRP.

II. Literature Review

A. VRP

The VRP model has its beginnings in 1956, with the traveling salesman problem that consisted of a salesperson who should visit a certain number of clients in a single trip, starting and ending the tour in a city or point of origin established, so that the distance traveled was minimal [6], [7]. The VRP aims to design a route for a distributor vehicle supplies the demand required for a group of customers who are spatially dispersed, reducing the cost of transportation. It is composed of an initial node known as the deposit, where the vehicle fleet starts the assigned route; and a group of nodes that represent customers [8]-[10]. It may be noted that this study presents a collection problem and no distribution. The collection problem can have restrictions of various types such as the number of vehicles, vehicle capacity, the number of customers, customer location, demand, etc. [6].

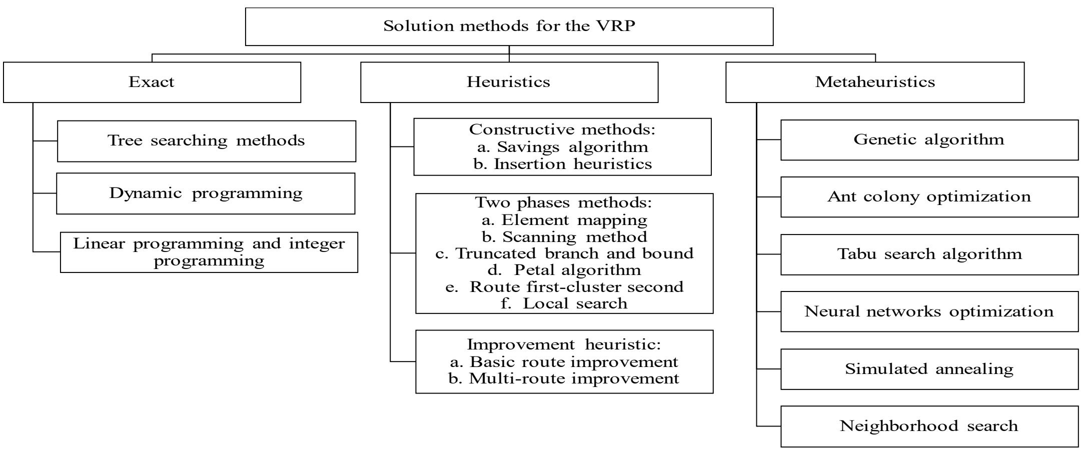

Fig. 1 Solution methods for VRP

B. Solution Methods

Solution methods for the VRP are divided into three groups: exact, heuristics and metaheuristics [6]. Each contains models for its development, as shown in Fig. 1.

C. Heuristic

Heuristics are techniques that generate feasible solutions through a limited exploration of the search space in moderate time periods for its executed action [11]-[13]. These methods are characterized as being applicable to particular problems since they are built according to the structure of the problem.

Table I describes the technical heuristics of solution of most common VRP, based on the arguments presented by [11]. In this research, the heuristics for VRPs are described.

III. Methodology

For the execution of the analysis, a series of activities that allowed the development of each of the proposals that compose and design of the collection network were established. First, the search and background analysis was conducted. After this, the study aim was established and the system was characterized, thus, it was possible to apply the heuristics. Finally, the results obtained were analyzed and the proposal most convenient routing plan was determined. Fig. 2 summarizes the stages of the study.

TABLE I
HEURISTIC TECHNIQUES

	Heuristics	Description
	Clarke and Wright's savings algorithm [14]	If there are two different routes, they can be combined to form a new route, in order to generate savings (in distance), which is given by: $$S_{ij} = C_{i0} + C_{0j} - C_{ij}$$ In this algorithm starts from an initial solution and the connectors that give greater savings are made, without violating the constraints of the problem. The savings algorithm has two versions: parallel and sequential. The first one is described: Initialization: for each customer i build the route $(0, i, 0)$ **1.** Calculation of savings: Calculate S_{ij} for each pair of customers i and j **2.** Better connection: Be $S_{i^* j^*} = max\ S_{ij}$ where the maximum is taken between savings which have not been considered yet. Be r_{i^*} and r_{j^*} the routes that contain to the customers i^* andj^*. If $i^*$is the last customer of r_{i^*} and j^* is the first customer of r_{j^*} and the combination of r_{i^*} and r_{j^*} It is feasible, to combine. Delete $S_{i^* j^*}$ in future considerations **3.** If there are savings to be examined, apply the item 3, otherwise, end up In some cases, the original savings equation can generate circular routes, what is negative. To this end, it has been proposed the following equation: $$S_{ij} = C_{i0} + C_{0j} - \lambda C_{ij}$$ λ It is a parameter that restricts the connection of routes with distant customers
	Sequential insertion heuristic by Mole & Jameson [15]	This heuristic involves inserting customers in a partial solution, for each customer is selected the best position in the current route based only on the distances and without modifying the nodes that already are on route. There is a route $(V_0, V_1, \dots, V_t, V_{t+1})$ where $V_0 = V_{t+1} = 0$. The cost of inserting an unvisited customer W, between V_i and V_{i+1}, where $(0 \le i \le t)$, It is: $$C_1(V_i, W) = \begin{cases} C_{V_i,W} + C_{W,V_{i+1}} - \lambda C_{V_i,V_{i+1}} \ \ if\ (V_0, \dots V_i, W, V_{i+1}, \dots, V_{t+1}) \\ \qquad is\ feasible \\ \infty \qquad If\ not \end{cases}$$ The position to insert W on the route, is given by: $$i(W) = \arg \min_{i=0,\dots,t} C_1(V_1, W)$$ To insert remote customers to the deposit is defined $C_2(V_1, W) = \mu C_{0W} - C_1(V_1, W)$ for each customer W. When no insertion is feasible, and there are customers for visiting, you must select a customer to start a new route *Algorithm:* **1.** Route planning: If all clients belong to a route, end. If not, select a customer unvisited W , and creates route $r = (0, W, 0)$ **2.** Insertion: Be $r = (V_0, V_1, \dots, V_t, V_{t+1})$ where $V_0 = V_{t+1} = 0$. For each customer unvisited$W$, calculate $i(W) = \arg min_{i=0,\dots,t} C_1(V_i, W)$. If no feasible insertions, go to Step 1. Calculate $W^* = argmax_W C_2(V_{i(W)}, W)$. Insert W^* after $V_{i(W^*)}$ in r **3.** Optimization: Apply algorithm 3-opt on r. Go to step 2 The algorithm uses two selection parameters: λ andμ. To make grow λ it promotes the insertion between distant nodes, and To make grow μ it promotes the insertion of remote customers to the deposit.
Cluster first- route second	Scanning heuristic or Sweep algorithm	In this technique, the groups are formed by turning a ray with origin in the deposit, gathering all the customers until the restriction of capacity is met. Each customer i is given by its polar coordinates (ρ_i, θ_i) where the origin of the system is the deposit. Algorithm **1.** Start: Sort customers according to increasing θ. If there are two customers with equal θ it registers the first which has the smallest value ρ. Select a W customer to start and do $K \coloneqq 1\ and\ C_K = \{W\}$ **2.** Selection: If all clients belong to a group, go to step 3. Otherwise, select the next customer W_i. If W_i., you can add without violating capacity restrictions, do $C_K \coloneqq C_K \cup \{W_i\}$. If not, do K:=K+1 and create a new group $C_K = \{W_i\}$. Then, go to step 2 **3.** Optimization
Cluster first- route second	Generalized Assignment heuristic of Fisher and Jaikumar [16]	This technique aims to generate groups solving a problem of generalized assignment (GAP) about customers. First, it must set Kseed customers s_K with $K = 1, \dots, K$ about which groups will be built. Then, is assigned customers to each group so that not be exceed the capacity of the vehicle El GAP is defined as follows: $$\min \sum_{K=1}^{K} \sum_{i \in V \setminus \{0\}} d_{iK} X_{iK}$$ Subject to: $$\sum_{K=1}^{K} X_{iK} = 1 \quad \forall\ i \in V \setminus \{0\}$$ $$\sum_{i \in V \setminus \{0\}} q_{iK} X_{iK} \ \le Q \quad \forall\ K = 1, \dots, K$$ $$X_{iK} \in \{0,1\} \quad \forall\ i \in V \setminus \{0\}, \forall\ K = 1, \dots, K$$

<table>
<tr><th>Heuristics</th><th>Description</th></tr>
<tr><td></td><td>

$$X_{iK}: customers\ i\ is\ assigned\ to\ group\ K$$

The aim is to minimize the cost of the assignment. The first restriction indicates that each customer should be assigned exclusively to a group. The second constraint indicates that customers of each group may not exceed the capacity of the vehicle.
The cost of inserting a client in a group K it is defined as:

$$d_{iK} = \min\{C_{0i} + C_{i,s_K} + C_{s_K},0, C_{0,s_K} + C_{s_K},i + C_{0i}\} - (C_{0,s_K} + C_{s_K},0)$$

If those costs are symmetric, $d_{iK} = C_{0i} + C_{i,s_K} - C_{0,s_K}$
Algorithm:
1. Start: from K groups, each one with a customer s_K $(K = 1, \dots, K)$
2. Assignment: Solving the GAP
3. Routing</td></tr>
<tr><td>Route first-cluster second method</td><td>This method is also of two phases. In the first, it develops a TSP (Traveling Salesman Problem), where a route to visit all customers is calculated, not necessarily the problem constraints are respected. Second, they are divided into several routes, where each is feasible.
$r = (0, V_1, \dots, V_n, 0)$. Is a solution of TSP in the first phase, the best division of the route so respect the vehicle capacity is determined. This problem can be formulated as finding the shortest path in a directed and acyclic graph.
A graph $G = (X, Y, Z)$ is constructed, where$X = \{0, V_i, \dots, V_n\}$. The graph arcs connecting all pairs of customers V_i and V_j with $i < j$ and of such mode that the demand of the customers $V_{i+1}, \dots, V_j$ do not exceed the vehicle capacity:$Y = \{(V_i, V_j) | i < j, \sum_{K=i+1}^{j} d_{VK} \leq Q\}$. Each arc (V_i, V_j) is weighted with the cost of the route $r = (0, V_{i+1}, \dots, V_j, 0)$, as follows:

$$W(V_i, V_j) = C_{0,V_{i+1}} + C_{V_j,0} + \sum_{K=i+1}^{j-1} C_{V_K,V_{K+1}}$$

The least-cost path between $0\ and\ V_n$ represents the partition of the minimum cost of the original route in routes in where to meet the restriction of capacity.</td></tr>
<tr><td>Petal algorithm</td><td>Is an algorithm derived from Sweep algorithm, there is a set of routes R in where each route $r \in R$ and it's feasible, but some customers are visited by several routes. To select a subset of R that visits only once every customer should be formulated a Set Partitioning Problem (SPP):

$$\min \sum_{K \in R} C_K X_K$$

Subject to:

$$\sum_{K \in R} a_{iK} X_K = 1 \quad \forall\, i \in V \setminus \{0\}$$

$$X_K \in \{0,1\}\ \forall\, K \in S$$

a_{iK} takes the value of 1 if customer i is visited by the r_K route and the otherwise takes the value 0.
C_K is the cost of the r_K route
X_K indicates whether the route r_K is selected or not in the final solution</td></tr>
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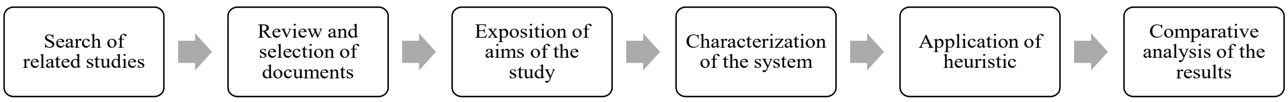

Fig. 2 Stages of the study

It is important to mention that the characterization of system was performed by first identifying the variables that are directly involved in the analysis of the scheme for the collection of the used lubricant oils (ULO) generated in the city of Pereira Second, the location of ULO generators points and the establishment of their monthly demand was made. Subsequently, it classified the generating points according to the volume ULO generated through the diagram of Pareto. Likewise, the zoning of the points in relation to the two main roads of the city of Pereira was made. Finally, the operating costs structure that was taken into account for the study was defined.

IV. Assumptions and Limitations

For the development of this study the following aspects were considered:

- The variables involved in this comparative analysis are the generation of ULO, distances between points, time and cost.
- The number of generators points of used lubricant oils decreased from 96 to 67, since some points were geographically very close, i.e., several points on the same street. It is important to mention that, no point information was removed, since by grouping their demands and distances were concentrated at a central point so that in this way the comparative analysis does not lose validity
- The distances between the generators ULO points are asymmetric, i.e., the distance to the point i to$j$, is different to the distance of going the point j to i ($d_{ij} \neq d_{ji}$) [17].
- The time variable is the sum of the travel time, reception

and dispatch time and vehicle load time

- To calculate the time of the routes between collection center and points, and among these, a speed average of 20 km / h in the center area and 35 km / h in other areas was estimated. A time factor of 30 seconds (0.5 minutes) for ignition and vehicle preparation was added. It is worth mentioning that the level of traffic or possible route closures in the city of Pereira was not considered.
- For receipt and dispatch time, it took an average of 2 minutes, which corresponds to the presentation by the operator of the vehicle, review and signature of the form of follow-up by the responsible for the generator point.
- The relationship of time stipulated in [18] was used to determine the time of load of the vehicle in those generators points of used lubricant oils with a volume equal to or greater than 60 gallons and for points with lower volume, the dumping it makes manually by means of a 5 gallon container, took an average time of 18,112 seconds (302 minutes or approximately 5 hours).

• The capacity of the collector vehicle used in this study is of 3329 gallons.
• The restrictions private as timetables or conditions variable in the handling of material (time windows) from generating points was not included.
• The cost variable per km is $633, 28
• For the study of the costs two possible scenarios are raised:

- In the first stage were added the variable costs, the cost of renting the vehicle service and the salary auxiliary of loading and unloading - to calculate the time of the routes between collection center and points, and among these

• In the second stage, the possibility of the purchase of a new load vehicle was raised. Here, were added to the variable cost, the value corresponding to the depreciation of the vehicle, the driver's salary and the salary of the auxiliary of loading and unloading.

V. Development of Proposals for Routing

To define the plan of routing for collection of used lubricant oils in the city of Pereira, it has determined the location of the generating points of the waste, the monthly amount of oil that is generated at each point, the cost of collection ($ / km), the distance between points generators (km), the capacity of the vehicle to be used for the transport of the waste, the location of the collection center.

Table II develops the proposals of the present study, where the variables previously mentioned were considered and some of the heuristic that is used as methods of a solution for the VRP.

VI. Results

The results obtained in each of the proposals addressed are presented next. Subsequently, a comparison between the six proposals through the implementation of three indicators is made. The results are presented in graphical form. Finally, it identifies the most convenient proposal in terms of optimization of time and cost.

A. Results of the Proposals

Table III shows the results obtained in terms of distance, cost and time for the six proposals developed in this study.

After observing the results obtained in each proposal and specifically in costs, it is evident that there is a big difference between the two scenarios evaluated, Stage 1being the most expensive. For this reason, only the cost analysis in the Stage 2 is contemplated, i.e., which raises the purchase of a new vehicle and takes into account the value of the depreciation of the vehicle, the wage of the driver and the auxiliary of loading and unloading. With that said, the values corresponding to distance, cost and time of each proposal are presented in Fig. 3.

After analyzing the graph above, it is evidence that the fourth proposal is most suitable in terms of distance, cost, and time, compared with the other five proposals. The values associated with this proposal are total distance: 112.4 km, total cost: $155,514. 60 and total time of 615.7 minutes.

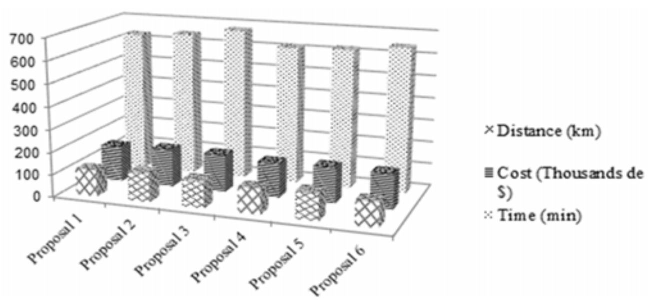

Fig. 3 Results of the proposals

TABLE II
ROUTING PROPOSALS

Proposal	Description	Distribution of groups	Design of routes	Routes
1. Closeness of points	Based on the method of two phases: Cluster first- route second • First, the groups are formed by the technique of closeness of points, i.e. grouping the points generators of ULO that is found more near between itself. For this, it is taking into account the restriction of the capacity of the collector vehicle (3329 gallons) • Second, a route for each group was designed, using the savings algorithm (Clarke and Wright's Heuristic), in	Four groups distributed as follows were obtained • Group 1: is consisting of 17 points generators of ULO, which together total gallons 3196 • Group 2: is composed of 17 points generators and the pent-up demand of ULO are 3092 gallons. • Group 3: is made up of 13 generators of ULO, yielding a	Below, explains the savings algorithm, for each designed routes: **1.** It is made the matrix of distances, in which is located the distance in kilometers, from the collection center to all points generators of ULO and vice-versa. Similarly, the distances between points generators of ULO **2.** The matrix of the cost is constructed. There are may find the cost of the travel from the collection center to all points generators of ULO, and vice-versa, in the	Sequence in which should be visited the ULO generator points: • Group 1: 00-5-27-39-6-12-65-2-29-56-21-45-46-38-24-40-3-11-00 • Group 2: 00-57-4-17-36-67-15-50-31-28-66-49-16-43-64-51-60-7-00 • Group 3: 00-26-34-42-37-41-30-8-9-33-47-58-1-32-00

Proposal	Description	Distribution of groups	Design of routes	Routes
	which all points are visited by the collector vehicle.	cumulative total of 3114 gallons. • Group 4: is composed by 20 points generators of ULO that accumulate in total 2420 gallons.	same way, the distances between points generators of ULO **3.** For each customer i the route is built$(0, i, 0)$. This indicates that each vehicle visits a single customer **4.** It is calculated the savings in cost (S_{ij}) for each pair of generators points i y j, with the following equation [8]: $S_{ij} = C_{i0} + C_{0j} - C_{ij}$ **5.** It is made a list with all the savings S_{ij} and is selected the maximum savings $S_{i^*j^*}$. For the next combinations, is discarded the saving that was selected previously **6.** If still there are savings in the list, it is selected the following maximum saving and the process continues with joining the nodes until to get the route. This procedure was carried out to generate the routes of these proposals.	• Group 4: 00-59-61-19-62-63-10-25-52-13-14-22-35-20-23-44-48-53-18-54-55-00
2.Method of scanning	Based on the method of two phases: Cluster first- route second • First, the sweep method (algorithm Gillet and Miller) was used for the formation of groups, which is to locate a straight line over the collection center and rotates counter clockwise and includes the generators points which are swept away by that straight line, up to the capacity of the collector vehicle. • Second, a route for each group was designed using the savings algorithm (Clarke and Wright's Heuristic), in which all points are visited by the collector vehicle.	Four groups distributed as follows were obtained • Group 1: is consisting of 24 points generators of ULO, which together total gallons 2734 • Group 2: is composed of 10 points generators and the pent-up demand of ULO are 3151 gallons. • Group 3: is made up of 20 generators of ULO, yielding a cumulative total of 3310 gallons. • Group 4: is composed by 13 points generators of ULO that accumulate in total 2627 gallons.		Sequence in which should be visited the ULO generator points: • Group 1: 00-26-34-33-42-25-10-52-13-14-22-35-63-59-61-19-62-20-23-44-48-53-18-9-32-00 • Group 2: 00-1-8-54-55-37-41-30-15-66-67-00 • Group 3: 00-47-7-57-58-39-65-51-5-43-64-16-4-17-36-50-31-28-49-60-27-00 • Group 4: 00-24-38-21-45-46-56-29-2-12-6-40-3-11-00
3.Grand route	Based on the method of two phases: routing first and assign later • At the first phase, the saving method is used to generate a route which includes all the nodes as if they were to be visited by a single vehicle, regardless of the capacity restrictions posed by the problem. • At the second phase, the creation of groups is performed taking the capacity of the collector vehicle as a unique constraint by dividing the Grand route into sub-routes. For the formation of each group or sub-route, the sequence established at Grand Route to visit the points generators of ULO was taken. In the first group, the route starts at the collection center and ends at the point where the sum of the volume of ULO meets or does not exceeds the capacity of the truck. For the second group, it is taken from the following point to the latter that was included in the previous group, and likewise, the sum of the volume of ULO to comply with the restriction of the problem. Likewise, the third and fourth group was formed.	Four groups distributed as follows were obtained • Group 1: is consisting of 26 points generators of ULO, which together total gallons 2814 • Group 2: is composed of 11 points generators and the pent-up demand of ULO are 2828 gallons. • Group 3: is made up of 18 generators of ULO, yielding a cumulative total of 3286 gallons. Group 4: is composed by 1200 points generators of ULO that accumulate in total 2894 gallons		Grand Route: 00-1-32-3-40-11-26-34-9-33-42-25-10-52-13-14-22-35-63-59-61-19-62-20-23-44-48-15-50-31-28-60-67-36-53-18-54-55-37-41-30-8-17-49-4-5-43-64-16-51-60-47-57-58-7-27-39-6-12-65-2-29-56-21-38-45-46-24-00 Sequence in which should be visited the ULO generator points: • Group 1: 00-1-32-3-40-11-26-34-9-33-42-25-10-52-13-14-22-35-63-59-61-19-62-20-23-44-48-00 • Group 2: 00-15-50-31-28-60-67-36-53-18-54-55-00 • Group 3: 00-37-41-30-8-17-49-4-5-43-64-16-51-60-47-57-58-7-27-00 • Group 4: 00-39-6-12-65-2-29-56-21-38-45-46-24-00
4. Closeness of points by model mathematical	Based on the method of two phases: Cluster first- route second • In the first phase, for the formation of groups, the allocation made in proposal 1 was used. • In the second phase, for the design of the route of each group, the model of optimization mathematical of the TSP (Travelling Salesman Problem) was used. This was solved with the GAMS software	Four groups distributed as follows were obtained • Group 1: is consisting of 17 points generators of ULO, which together total gallons 3196 • Group 2: is composed of 17 points generators and the pent-up demand of ULO are 3092 gallons. • Group 3: is made up of 13 generators of ULO, yielding a cumulative total of 3114 gallons. • Group 4: is composed by 20 points generators of ULO that accumulate in total 2420 gallons.	Then, the TSP mathematical model arises from the wording proposed by [19]: • Subscripts: $i = start\ node$ $j = arrival\ node$ • Parameters: $C_{ij} = Cost\ of\ transfer\ node\ i\ to\ node\ j$ $n = Number\ of\ points\ generators\ of\ used\ lubricant\ oils\ (nodes)$ $X_{ij} = decision\ variable\ is\ defined\ as\ follow$ $X_{ij} = \begin{cases} 1, if\ node\ i\ is\ connected\ to\ node\ j \\ 0, and\ otherwise \end{cases}$	Sequence in which should be visited the ULO generator points: • Group 1: 00-24-40-3-11-5-39-6-12-65-46-21-38-45-29-56-2-27-00 • Group 2: 00-7-60-51-43-64-16-50-15-31-28-66-67-49-4-17-36-57-00 • Group 3: 00-1-34-42-37-9-33-8-41-30-47-58-32-26-00 • Group 4: 00-25-52-22-35-20-23-44-48-53-61-19-62-63-14-13-10-59-18-54-55-00
5. Method of scanning by	Based on the method of two phases: Cluster first- route second	Four groups distributed as follows were obtained		Sequence in which should be visited the ULO generator points:

Proposal	Description	Distribution of groups	Design of routes	Routes
mathematical model	• In the first phase, for the formation of groups, the allocation made in proposal 2 was used • In the second phase, for the design of the route of each group, the model of optimization mathematical of the TSP (Travelling Salesman Problem) was used. This was solved with the GAMS software	• Group 1: is consisting of 24 points generators of ULO, which together total gallons 2734 • Group 2: is composed of 10 points generators and the pent-up demand of ULO are 3151 gallons. • Group 3: is made up of 20 generators of ULO, yielding a cumulative total of 3310 gallons. • Group 4: is composed by 13 points generators of ULO that accumulate in total 2627 gallons.	The asymmetric Traveling Salesman Problem may be defined in $G = (V, E)$ where $V = \{0,1,2,3,\ldots,n\}$ represents the set of nodes (n=67 points) y $E = \{i, j\}$ the set of arcs. Taking into account the above, the mathematical formulation of the TSP is presented to solve the VRP for the collection of used lubricant oils in the city of Pereira • Objective function: $Minimize \sum_{i=0}^{n}\sum_{j=0}^{n} C_{ij} X_{ij}$ (1)	• Group 1: 00-32-26-34-33-42-59-35-20-44-48-53-61-19-62-63-22-23-14-13-52-10-25-18-9-00 • Group 2: 00-1-15-66-67-37-54-55-41-30-8-00 • Group 3: 00-47-7-57-58-4-17-36-31-28-50-49-16-64-43-60-51-5-39-65-27-00 • Group 4: 00-40-3-11-6-12-2-29-56-21-38-45-46-24-00
6. Grand route by model mathematical	Based on the method of two phases: routing first and assign later • In the first phase, the model of optimization mathematical of the TSP (Travelling Salesman Problem) was used. This was solved with the GAMS software • At the second phase, the creation of groups is performed taking the capacity of the collector vehicle as a unique constraint by dividing the Grand route into sub-routes. For the formation of each group or sub-route, the sequence established at Grand Route to visit the points generators of ULO, was taken. In the first group, the route starts at the collection center and ends at the point where the sum of the volume of ULO meets or not exceeds the capacity of the truck. For the second group, it is taken from the following point to the latter that was included in the previous group, and likewise, the sum of the volume of ULO to comply with the restriction of the problem. Likewise, the third and fourth group was formed.	Four groups distributed as follows were obtained • Group 1: is consisting of 26 points generators of ULO, which together total gallons 3207 • Group 2: is composed of 13 points generators and the pent-up demand of ULO are 3204 gallons. • Group 3: is made up of 17 generators of ULO, yielding a cumulative total of 2817 gallons. Group 4: is composed by 11 points generators of ULO that accumulate in total 2594 gallons.	• Subject to: $\sum_{j=0}^{n} X_{ij} = 1 \quad \forall\, i$ (2) $\sum_{i=0}^{n} X_{ij} = 1 \quad \forall\, j$ (3) $U_i - U_j + (n-1) X_{ij} \leq n - 2$ $\forall\, i.j \in V : i, j \geq 0, i \neq j$ (4) $U_i \geq 0$ (5) $X_{ij} \in \{0,1\} \quad \forall\, (i,j) \in E$ The (1) represents the objective function, which seeks to minimize the cost associated with the total distance traveled, the restriction (2) indicates that only once reaches each node, (3) ensures get out only once for each node, (4) it eliminates the formation of sub tours, (5) set the dimensions for the variable U_i.	Grand Route: 00-16-5-43-64-1-34-33-9-42-25-10-59-18-55-41-30-8-53-61-19-62-63-22-14-13-52-35-20-23-44-48-66-28-50-15-31-54-37-17-36-67-49-4-57-58-47-7-51-60-27-39-6-12-65-2-29-56-21-38-45-46-24-40-3-11-26-32-00 Sequence in which should be visited the ULO generator points: • Group 1: 00-16-5-43-64-1-34-33-9-42-25-10-59-18-55-41-30-8-53-61-19-62-63-22-14-13-52-00 • Group 2: 00-35-20-23-44-48-66-28-50-15-31-54-37-17-00 • Group 3: 00-36-67-49-4-57-58-47-7-51-60-27-39-6-12-65-2-29-00 • Group 4: 00-56-21-38-45-46-24-40-3-11-26-32-00

TABLE III
PROPOSALS OF ROUTING PROPOSALS

Proposal	Distance (km)	Cost ($) Total, Stage 1	Cost ($) Total, Stage 2	Time (min)
1	117,256	484.942,02	161.224,45	632,014
2	128,601	500.310,53	169.672,12	645,526
3	120,031	515.377,38	168.553,95	677,125
4	112,401	470.923,77	155.514,60	615,793
5	120,376	479.715,81	161.223,19	621,813
6	109,43	487.996,29	157.497,19	645,254

B. Evaluation with Indicators

The proposals are compared starting from three indicators that evaluate the distance, the cost and the time of each route with respect to the number of points generators of ULO visited. The equations of these indicators are described below:

- Distance indicator: through this indicator the average distance (km) that traveled by visited generator point is obtained.

$$ID = \frac{Total\ distance\ traveled}{\#\ visited\ generator\ points} = \frac{km}{Generator\ point}$$

- Cost indicator: through this indicator the average cost ($) by visited generator point is obtained.

$$IC = \frac{Total\ cost\ of\ the\ route}{\#\ visited\ generator\ points} = \frac{\$}{Generator\ point}$$

- Time indicator: through this indicator the average time (min) it takes in visiting each generator point is obtained

$$IT = \frac{Total\ time\ of\ the\ route}{\#\ visited\ generator\ points} = \frac{min}{Generator\ point}$$

In Fig. 4, represented by the type of indicator, the values obtained in each proposal are presented, in order to determine which presents the best results in these items.

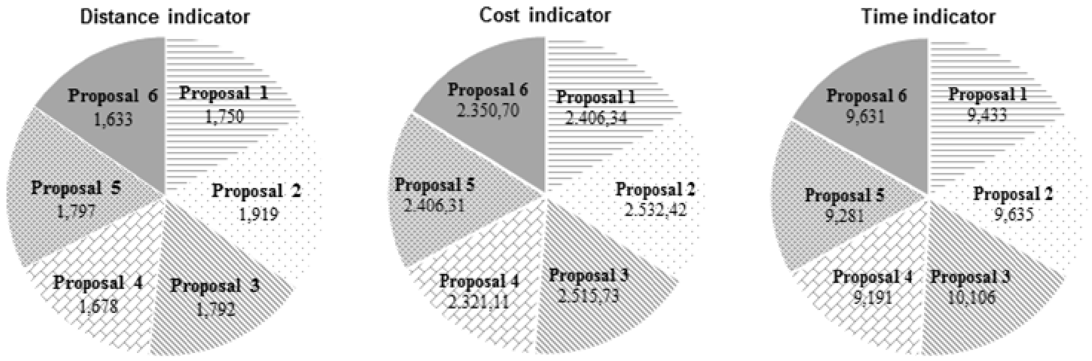

Fig. 4 Graphical representation of indicators

With regard to distance indicator, it can be seen that proposal six and proposal four the proposal have the lowest value of this indicator, with an average 1,633 km and 1,678 km per visited generator point, respectively.

Regarding the cost indicator, it is possible to distinguish that the proposal four has indicator value most convenient, being 2,321.10 pesos per visited generator point. Second, is the proposal six, with 2,350.70 pesos per visited generator point.

In terms of the time indicator, the proposal four with an average of 9,191 minutes per visited generator point, is the most convenient, followed by proposal five with an average of 9,281 minutes per visited generator point.

C. Final Results

Taking into account the above results of the proposals and the evaluation with indicators, it is concluded that the proposal four Closeness of points by model mathematical is that presents the most convenient route with respect to the three factors assessed, these being: total distance 112.4 km, total cost $155,514.60 and total time 615.7 minutes. With regard to the results of the indicators, it obtained the value more favorable in the indicators of cost and time, 2.321,1 pesos per generator point and 9,191 minutes per generator point respectively; and the second value more favorable in the indicator of distance with 1,678 km per generator point

The proposal six Grand route by the mathematical model, is that which presents the second most suitable value in distance and cost with 109.4 km and $157.497, 1 respectively. The time total of this route is 645, 2 minutes. In relation to the indicators presents the value more favorable in the distance indicator with 1.633 km per generator point, with regard to the cost indicator, is the second more favorable with $2,350.70 pesos per generator point and the third in the time indicator with 9,631 minutes per generator point.

Thirdly, the proposal five Sweep method for the mathematical model with the third is better value in terms of cost and time at $161,223.10 and 632 minutes. respectively. In fourth and fifth place, is proposal one, Closeness of points and the proposal three, Grand route, with a cost of $161,224.40 and $168,553.90, respectively.

Finally, the less suitable proposal is that of two, Method of scanning that presented the less favorable values in distance 128,601 km and cost $169,672.10. The time of this proposal is 645,526 minutes, the second less favorable. In terms of indicators, it presents the least appropriate values in regard to distance of 1,919 km and a cost of $2,532.40 pesos per generator.

A comparison between the cost of proposal four (the most convenient) to the cost of other methods was carried out in order to establish the percentage difference between them. The following results were obtained: proposal six is 1.267% more expensive, proposals five and one are 3.605% more expensive, proposal three is 8.047% most expensive and proposal two 8.707% is more costly.

VII. Conclusions

Proposal four, which was developed by the method of closeness of points for the formation of groups and the Traveling Salesman mathematical model for route design, is the most convenient in terms of the optimization of times and costs for the design of route planning for the collection of used lubricant oils in the city of Pereira, with a total time of 615.7 minutes and a total cost of $ 155,514.60.

Proposals four, five and six, whose routes were solved by means of the Traveling Salesman mathematical optimization model, showed better results in the three variables evaluated in comparison to the proposed one, two and three which were developed with the saving algorithm. This difference is due to the fact that the mathematical model includes the entire set of possible combinations that can occur between nodes.

Taking into account that the collection time obtained in the proposal four is 10.2 hours, Stage 2, which raises the purchase of a new vehicle, is economically viable provided it is used in conjunction with other activities during the month; otherwise, Stage 1, which proposes to rent the service of the vehicle, is recommended.

Since the percentage difference at the level of costs between proposal four and proposal one (the more convenient proposal among those developed with the Savings algorithm) is 3.605%, whereas this difference is not significantly high. It is worth considering that GAMS software was used to obtain the solution of the mathematical model. This software requires a license to access problems with many variables and a person trained in using the system, which means incurring additional costs. While the Savings algorithm can be solved in an Excel spreadsheet.

This work is relevant as a contribution to the technical evaluation of various heuristics as the resolution of VRP with the conditions discussed here. Since it works with a combination of heuristic techniques and constrained optimization of vehicle capacity through analysis in two phases; thus, facilitating the management of logistics operation for the collection of polluting substances such as used lubricant oils. In this way, the best technical method with regard to the three variables evaluated (distance, costs and time) within a large group of options is addressed (six proposals), to establish the VRP solution for the collection of used lubricant oils in the city of Pereira, Colombia.

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