Vehicle routing problem with simultaneous pickup and delivery for milk collection in Galeras, Sucre

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Abstract*– Raw milk collection is a very important process in the dairy supply chain. The quality and safety of the product must be ensured throughout the transport process. In this sense, vehicle routing problems (VRP) are considered an effective tool for decision-making in the procurement process. There are several variants of this problem that are applied according to the context, such as simultaneous pickups and deliveries. This approach is highly applied in reverse logistics and processes that involve loading and unloading products at the same point. In this paper, we develop a vehicle routing model that considers simultaneous pickup and delivery, multi-depot, heterogeneous and capacity fleet for milk collection in the dairy supply chain. Real instances of raw milk collection from the municipality of Galeras, Sucre were used to validate the model. A 6.98% reduction in costs was obtained in the route evaluation.

Keywords-- Routing, simultaneous pickup and delivery, multi-depot, milk.

I. Introduction

In Colombia the National Planning Department (by its Spanish acronym DNP) is responsible to manage, promote and assess the oriented politics to drive on rural and farming development of the country throughout: the design and implementation of the strategic planning tool, the formulation of the National Development Plan, the elaboration of documents CONPES in subject matter related to the rural development, farming, forest and fishing, among others. In consequence, CONPES 3675 had the aim to improve the competitive of the Colombian dairy sector with the development of oriented strategies to reduce the cost of production, increase the productivity, promote the outlines of collaboration and strength the institutional administration of the sector.

In the country the most part of the milk is produced in farms with a production system of double purpose (meat and dairy products) located in tropical low lands. However, the specialized milk herd is located in the coldest zone with variable levels of automatization [1].

Milk as highly perishable product [2]. The quality of the finished dairy products starts with the raw milk. In this sense, the quality of the raw milk which is received in the milk processing plant depend on different factors (e.g., animal health, conditions and milk procedures, cleaning of milking equipment, milk storage tank, absence of a disinfectant residual, temperature control from the milk point to the milk storage tank in the milk processing plant, and good practice of handling in the whole points of process) [3].

However, the biggest obstacle for the supplying the raw milk in Colombia is the lack of adequate transportation in order to send the products to the processing centers because it does not have a cold chain in order to delay or avoid the growing of pathogen microorganism, physiological (maturation), biochemical (enzymatic oxidation, lipids oxidation) and or physics in the product [4]. In the Department of Sucre this situation is evidenced by the implementation of the inadequate vehicle fleet, the high collection periods in which milk is delayed without refrigeration. This leads to bacterial proliferation and loss of product quality conditions [5]. In addition, the organization processes of the recollection routes are carried out in the empirical mode affecting the growth of transportation cost [6].

One of the challenges when designing a distribution network, and in particular for raw milk, is the seasonal and geographical fluctuations in production, as well as the variability of product demand due to unstable economic conditions [4]. The decisions of the planning respect to the supply chain comprise the short-time decisions, the dispatch and the vehicle routing, the long-time decisions as the definition of the enterprise mission [7].

Authors such as [8] and [9] confirm that in the current supply chains and highly competitive markets, the enterprises should guarantee the efficiency of their resources, increasing the services level to the customers and reducing the lead times and stocks. Similarly, [10] and [11] declare that global optimization of the supply chain has become in the principal purpose for many industrial companies especially the logistic distributions which aim is to reduce the cost and the productivity gain.

The decision on the supply chain net design has a significant impact on its performance itself due to these decisions affect the total inventory and the cost of transportation in long-term [12]. That's why long-term strategy for the planning of the supply chain, the enterprises is addressed to a global system through the integration of the location decisions of the installations, the inventory and the routing [13].

In this sense, the vehicle route models are shown to be an effective tool when organizing product distribution or procurement processes. This may cause the consideration of all contextualized variable of the problems and generate efficient solutions even optimal [14].

One of the most common applications of the operation research are the vehicle routing problems (VRP) which was

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set by Clarke and Wright [9] as a service net to the customer distribute in the different geographic point, with the utilization of fleet truck in various carrying capacity; VRP model are efficient tools to be applied in real context transport problems considering the several variants that are associated [15]. The most analyzed variables within of vehicles routing models are the heterogeneous fleet which are based on the used vehicles in the routing have different characteristics [16]. Multi-depot, considers several depots at the moment to organize the routes [17]. Stochastic Models show parameters that can take value probability [18]. Capacitated, determines each vehicle has a specific capacity of carrying [17]. Pickup and Delivery is supposed that in each customer is unload and load products at the same time [19]. Among others variants as the multiproduct, divide and regular delivery.

Several authors have been developed this kind of research in different supply chain; for example, [20] published a study on VRP with two echelons (two-echelon vehicle routing problem with simultaneous pickup and delivery, 2E-VRPSPD) in which the operations of pickup and delivery are performed simultaneously with the same vehicle delivering the whole orders from the storage to the destination site and from the destination site to back to the storage point.

Similarly, [21] mention that the capacitated vehicle routing problem (CVRP) provides a solution with minimum costs with a closed route itinerary, unique customer service by vehicle and that the total demand should be not exceeded the assigned capacity of the vehicle.

The routing model that it takes in consideration the simultaneous pickup and delivery represents an alternative which allow not only to decreases the cost of transportation but also the recollection time of the product in each productive unit. This approach is achieved under the philosophy that at each point the full recipient of milk is loaded and the empty recipient of milk is discharged and will be filled with the product in the milking process the next day.

The model is applied to real situations for the supply of milk in Sucre. The model shows great efficiency in minimizing the costs associated with the collection process.

The remainder of this paper is structured as follows. Section 2 provides a background on the VRP and VRPSPD. Section 3 presents the model developed. Section 4 summarizes the results obtained. Finally, section 5 presents the conclusions and future research directions.

II. Background

To be able to talk about the variant of simultaneous pickups and deliveries, we must know the first authors and their contributions to the general VRP methodology. In this sense, we can identify as the first contribution to the VRP literature the work of [22] who made a solution method for a TSP (Travelling Salesman Problem) on a large scale. Followed by [23] who incorporated more than one vehicle in their work, thus generating the VRP as it is known today [24].

After this, several works were carried out around this theme, gradually strengthening the objective to offer better solutions. Authors such as [25] were the first to publish their work with the phrase "Vehicle Routing", in which they developed modified and extended vehicle routing heuristics algorithms, compared with the techniques of Clarke & Wright, Gillett & Miller, and Tyagi, to solve problems that affect hundreds of demand points in a faster way.

The VRP has a large number of variants, which arise as problems of real contexts are modeled and which have been reviewed through various research works. As stated [17] there are several studies that have carried out reviews that analyze the published models of: Heterogeneous Fleet (HFVRP), which consider different types of vehicles to carry out the routes [26]; Time Window (TWVRP), that can be of soft type, allowing the violation of the restrictions of time; hard time window, that do not allow to arrive before or after the time established to the client [27]; Multidepot (MDVRP), where there is more than one deposit to which the vehicles are assigned to carry out the routes [28]; Vehicle Capacity (CVRP), which restricts the load that a vehicle can carry [29]; Stochastic (SVRP), which establishes some probabilistic parameters generally demands [30]. Likewise, those of Pickup and Deliveries (VRPPD), which consider that goods can be delivered and collected at the same point [31].

In the literary reviews of multi-objective models carried out by [30] where more than one objective is considered that aims to minimize, maximize or combine these. The authors propose a division of the VRP models: 1. shortest route, 2. problems of transportation, 3. assignment problems, 4. transshipment problems, 5. vehicle routing problems, 6. optimal network design problem, 7. expansion tree problem, 8. network flow problem. Also, [32] performs a VRP classification into seven categories, which is not very coherent and can be summarized only in three categories: 1. TSP, 2. VRP and 3. Problem of the Chinese Postman. Therefore, [24] propose seven categories that are shown in Fig. 1.

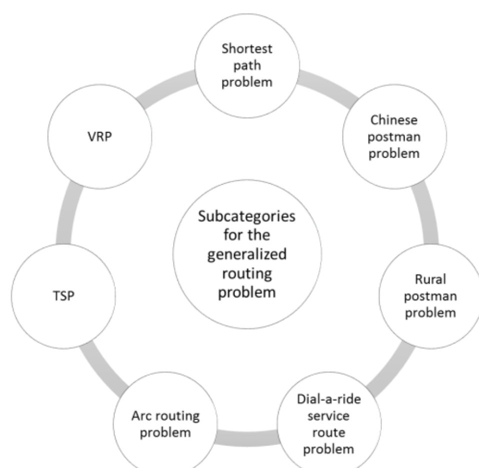

Fig. 1. Categories of Vehicle Routing Problems
Source: Adapted from [24].

A. *Vehicle Routing Problem with Simultaneous Pickup and Delivery (VRPSPD)*

The vehicle routing model with pickup and delivery (VRPPD) is a variant of VRP applied in reverse logistics. This is because it allows the loading and unloading of goods to be considered by satisfying a set of requests, both in demand and in supply [33]. VRPPD can be directed to both goods and people transport; the latter, under the term dial-a-ride, without the first contributions to a problem of bus routes developed in [34]. Pickup and delivery can be simultaneous (VRPSPD), mixed (Mixed VRPDP) or first delivery and second pickup according to the problem under study [35].

III. Proposed Model

Nowadays, the processes of milk recollection are carried out in an empirical way treating with the physiochemical characteristics of the product [6]. Consequently, a routing model was developed in order to reduce the cost of transportation according to the rounds distance.

At the beginning the process of the current supply of the Municipality of Galeras was characterized by its position in the place seventh out 26 municipalities related to the numbers of bovine cattle in 2017 with a total of 54879 and represent the 5.3% of the total cattle which 12478 are in milk and produce a total of 1366340 litres of milk every year [36].

In addition, a mixed integer programming mathematic model was designed for the consideration of simultaneous pickup and delivery. Moreover, this model is also delimited within friendly models with the environment related to the utilization in the reverse logistic [37]. The model is implemented under the discipline that at the time of performing the milk collection process, empty containers was unloaded and full containers are loaded at the same time to reduce service time. This is to reduce the service time that is displayed directly proportional to quantity of milk that is recollected as shown in Fig. 2.

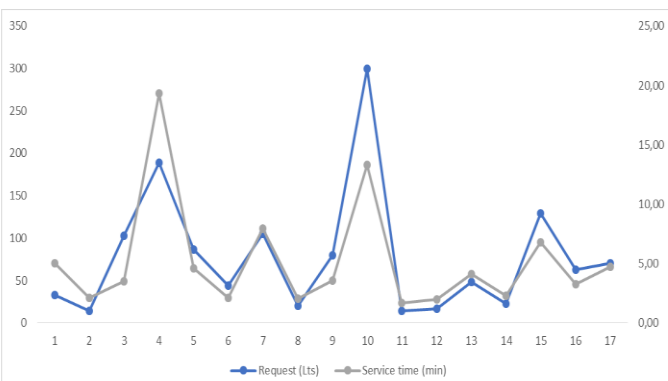

Fig. 2. Relation between recollection time and milk quantity.
Source: Authors' elaboration with real data.

This type of mixed integer programming mathematics model for the application in the vehicle routing solution are Np-Hard. Consequently, when considering the application of several variants and a large set of nodes, the calculation time to obtain a solution is increased. Therefore, the implementation of heuristic algorithms is needed to obtain solutions in short computational time.

The specific problem in this research is a simultaneous pickup and delivery vehicle routing problem which aim is to reduce the total cost of the distribution system with a total of 17 milk productive units and 2 milk processing enterprises. The routing is performed with 3 heterogeneous capacity vehicles.

B. *Conceptual Model*

The vehicle routing problem can be represented by an oriented graph $G(N,V)$, where N represents a set of vertices. At the same time this divided into two subset: $N_e = \{n_1, n_2, n_3 \dots n_1\}$ is the set of nodes in which will be performed by simultaneous pickups p_j and deliveries d_j within of a time window $[a_i, b_i]$. In addition, $N_c = \{n_{n+1}, n_{n+2}, n_{n+3} \dots n_{n+e}\}$ they are depots. Consequently, we have that $N = \{N_e \cup N_c\}$. There is a vehicles fleet $V = \{k_1, k_2, k_3, \dots, k_n\}$ with limited capacity Q_k as it is shown in Fig. 3.

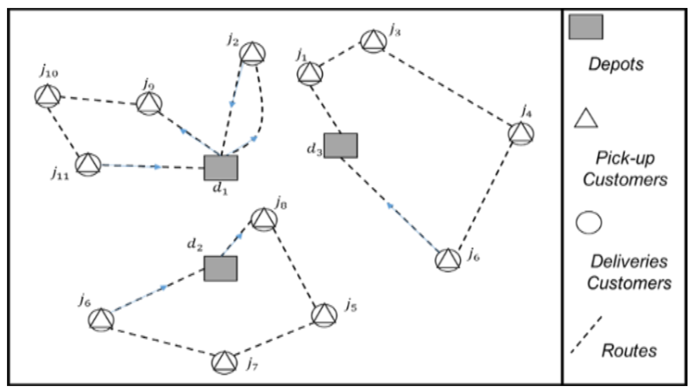

Fig. 3 VRPSPD Representation.
Source: Authors' own work.

C. *Mathematic Model*

The sets, parameters, constrains and objective function are detailed as follow.

Index and sets

i, j, h Customers index or depots

k Vehicle index

N_e Set of depots $\{1,2,3 \dots u\}$

N_c Set of customers $\{1,2,3 \dots d\}$

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N Set of customers and depots $N = N_u \cup N_d$

K Fleet of Vehicles $\{1,2,3\ldots k\}$

Parameters

F_k Fixed Cost for using the vehicle $k \in K$

Q_k Vehicle capacity $k \in K$

V_k Variable cost for using the vehicle $k \in K$

C_{ij} Distance between nodes $i \in N, j \in N$

p_i Sale of the product to pick up in customers $i \in N_u$

d_i Demand to discharge in customers $i \in N_u$

Variables

X_{ijk} Vehicle assignment k in the arc (ij)

Y_{ijk} Quantity of product to be collected by the vehicle k during the arc (ij)

Z_{ijk} Quantity of product to be discharged by the vehicle k during the arc (ij)

Objective Function

$$Min\, Z = \sum_{d}\sum_{j}\sum_{k} F_k X_{djk} + \sum_{i,j \in N: i \neq j} \sum_{k} (V_k C_{ij}) X_{ijk} \qquad (1)$$

Subjet to

$$\sum_{j \in N: j \neq i} \sum_{k \in K} X_{ijk} = 1; \forall i \in N_e \qquad (2)$$

$$\sum_{i \in N: i \neq h} X_{ihk} = \sum_{j \in N: j \neq h} X_{hjk}; \forall k \in K, \forall h \in N \qquad (3)$$

$$\sum_{d \in N_c} \sum_{j \in N_e} X_{djk} \leq 1; \forall k \in K \qquad (4)$$

$$\sum_{i \in N: i \neq j} \sum_{k \in K} Y_{jik} - \sum_{i \in N: i \neq j} \sum_{k \in K} Y_{jik} = p_j; \forall j \in N_e \qquad (5)$$

$$\sum_{i \in N: i \neq j} \sum_{k \in V} Z_{ijk} - \sum_{k \in V} \sum_{k \in V} Z_{ijk} = d_j; \forall j \in N_e \qquad (6)$$

$$Y_{djk} = 0; \forall d \in N_d, \forall j \in N_u, \forall k \in K \qquad (7)$$

$$Z_{idk} = 0; \forall d \in N_d, \forall j \in N_u, \forall k \in K \qquad (8)$$

$$Y_{ijk} \leq MX_{ijk}; \forall i, j \in N : i \neq j, \forall k \in K \qquad (9)$$

$$Z_{ijk} \leq MX_{ijk}; \forall i, j \in N : i \neq j, \forall k \in K \qquad (10)$$

$$Y_{ijk} + Z_{ijk} \leq Q_k X_{ijk}; \forall i, j \in N : i \neq j, \forall k \in K \qquad (11)$$

$$X_{ijk} \in \{0,1\} \qquad (12)$$

$$Y_{ijk}, Z_{ijk} \in Z^{+} \qquad (13)$$

The equation (1) suggests the minimization of the fixed cost by the vehicle's assignation and variable cost. Constrain (2) assures that a customer be visited exactly once with only a vehicle. Constrain (3) is of flow. Constrain (4) assures that a vehicle can be assigned a sole depot. Constrains (5) and (6) assures the load and unload in every customer. Constrains (7) and (8) establish that it makes impossible to load in the depot and from the site depot is came out with load to be discharged in every customer and the whole recollection is discharged in the depot. Constrains (9) and (10) assure that if an arc is performed by a vehicle then a quantity should be loaded and discharged. Constrain (11) avoids the violation of the capacity. Constrains (12) and (13) define the nature of the variables.

IV. Results

D. *Model Validation*

The mathematic model VRPSPD for the milk recollection planning in the municipality of Galeras – Sucre was validated with created initials instance using GAMS and optimally determined by the Solver CPLEX. For this, a computer is used with RAM memory 4 GB, Intel processor Core i7-5500 CPU@ 2.40 GHz and 64 bits operating system.

Nowadays, in the municipality of Galeras Sucre. The milk recollection has a total of 17 milk productive units and 2 processing enterprises as its shown in E_1 and E_2 . The recollection of milk is carried out with 3 vehicles (V_1, V_2, V_3) with carrying capacity of 1200, 1100 y 1000 kg, respectively. The geographic location of productive units and processing enterprises as it's shown in Fig. 4.

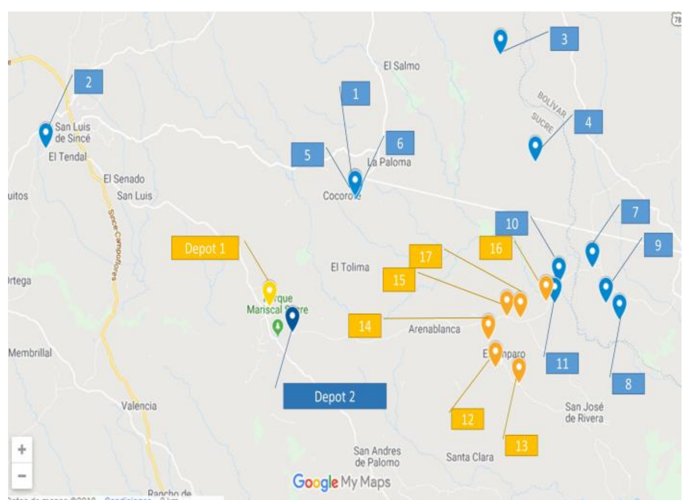

Fig. 4. Productive units and enterprises of the region.
Source: Authors' own work.

Similarly, in this municipality is used three (3) routing for the milk diary recollection in the supply chain. In this case, the routing number one (R_1) start in the transformer company two and, follow its travel by the productive unit one, two to the six and finish the travel in the same company. Therefore the routing number two (R_2) start in E_1 passing by the productive unit seven to eleven finishing in E_1. Lastly, the routing number three (R_3) start from E_2 travelling the productive units 12 to the 17 and finish in E_2 as it is shown in Fig. 5.

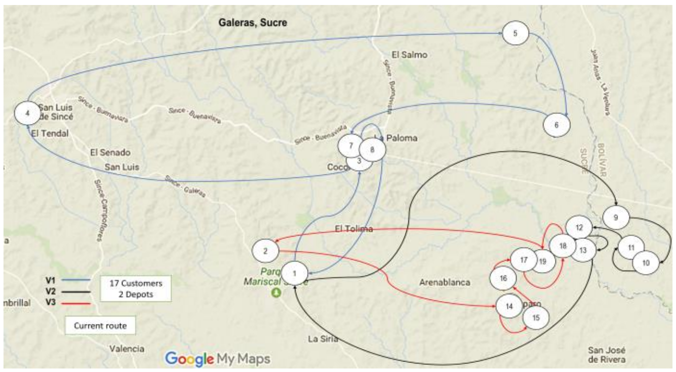

Fig. 5. Current route of milk recollection in Galeras, Sucre.
Source: Authors' own work.

In this sense, in daily average is travelled 202 kilometers of distance for the milk recollection in the milk in the supply chain in the municipality of Galeras, Sucre; which represents $ 226755.6 as it is shown in table 1.

TABLE 1.
CURRENT ROUTING FOR THE MILK RECOLLECTION IN GALERAS

Routing	Distance (km)	Costs
R_1	120.63	$101556.3
R_2	40.73	$92154.6
R_3	40.65	$33044.7
Total	202.01	$226755.6

Source: Authors' own work.

In the recollection of the product during the supply chain in study is an incurred cost in fixed or variable. In this sense, currently the company has three operators in the transport area, a driver/assistant who does the task at the same time as a dealer and assistant in charge of goods delivery. To calculate the variable cost of the vehicle, oil consumption and tyre wear costs were considered. In addition, the fixed costs were calculated in terms of consumption fuel and workers payment per day of work as it is shown in table 2.

TABLE 2.
FIXED COST AND VARIABLES IN THE ROUTING OF GALERAS

Vehicles	Driver/Assistant Cost - COP	Fuel Cost- COP	Oil Cost- COP	Cost in Tyre - COP
V1	$50000	$40000	$4583	$6972
V_2	$50000	$40000	$1059	$1095
V_3	$10000	$20000	$1219	$1825

Source: Authors' own work.

E. *Obtained Solution with the Model*

For the model solution was considered the whole obtained data in the characterization of the supply process of the raw milk in the municipality of Galeras. The mathematic model VRPSPD for the milk recollection planning involves 6499 variables, between simple and discrete, also of 3520 restrictions.

The obtained solution affirms the application of three routing (one per each vehicle) with a total cost of $ 210992.6 COP, and a GAP of 0%. El result is obtained in a total of 8.22 minutes. The routing is shown as in Figs. 6, 7, and 8.

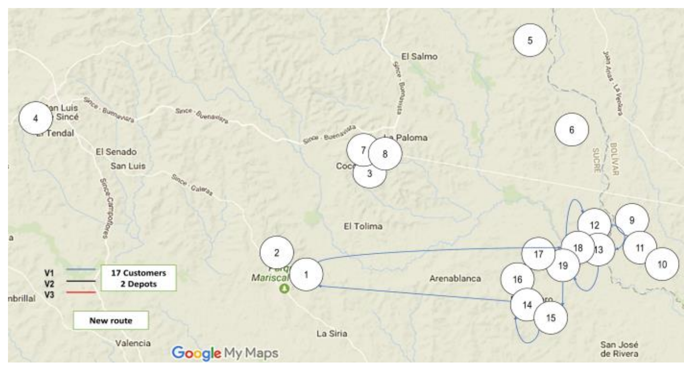

Fig. 6. Routing for the vehicle *v1* calculated with the mathematic model.
Source: Authors' own work.

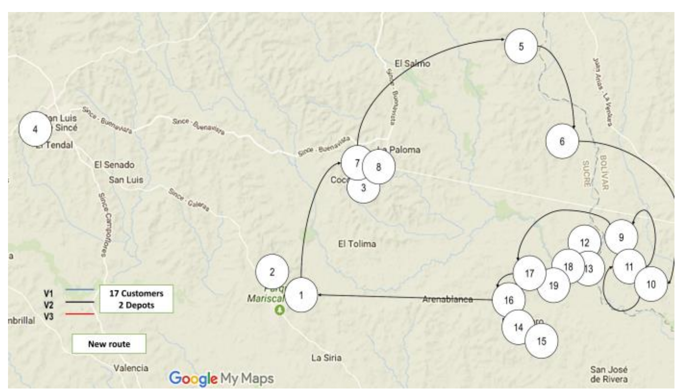

Fig. 7. Routing for the vehicle *v2* calculated with the mathematic model.
Source: Authors' own work.

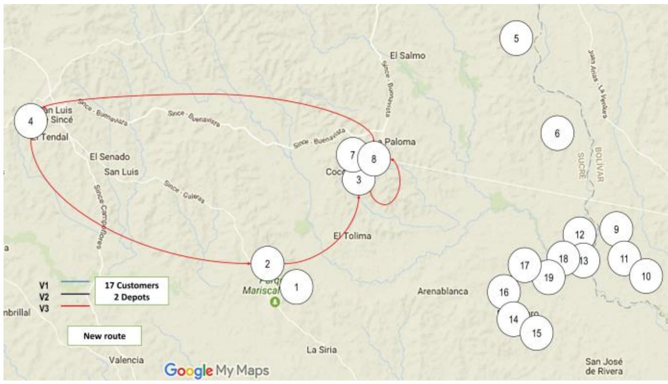

Fig. 8. Routing for the vehicle *v3* calculated with the mathematic model. Source: Authors' own work.

In this case, the developed model showed solutions in low computational times which it was solved by an exact method obtaining an optimal solution. The costs reduction is $ 15833 COP for the daily collection of the product as it is shown in Fig. 9, which represents a decrease of 7% of the costs stated. This cost reduction projects an annual saving of $5699880 COP in the milk supply chain in the municipality in study.

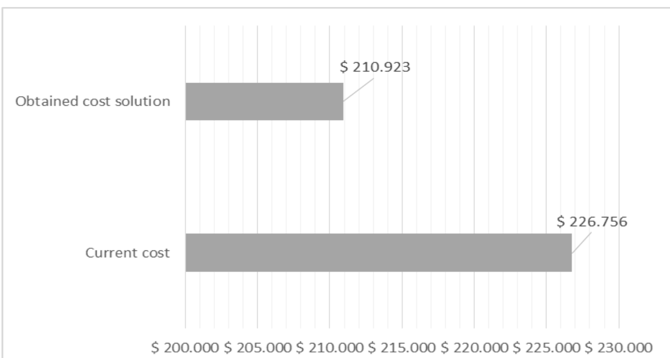

Fig. 9. Total Cost of milk recollection in the municipality of Galeras – Sucre. Source: Authors' own work.

V. Conclusions

The vehicle routing problem allow the organization of the good distribution considering the diverse variants in which are involved under the problem in context (e.g., different types of vehicles, diverse depots, time windows, simultaneous pickups and deliveries, and multiproduct) [17].

With the design of this model was reached the routing optimization for the raw milk recollection in the supplies process of the dairy supply chain reducing the costs in 6.98%. In addition, the computational time for the obtaining of the results was of 8.2 minutes. In consequence, the methods heuristics should be considered in order to obtain results in short computational time.

Given this model can be applied in a dairy chain as well as another type of chains which presents similarity in this routing structure. Then this model will help to the obtaining of optimal solutions under a median number of nodes.

Now taking in consideration this type of model that it is delimited in the called Np-Hard [35]. We recommend metaheuristics such as genetic algorithms, interactive local search, particle swarm optimization, among others, such as the hybrid approach (e.g., combination of exact and approximate methods, combinations of two or more approximate algorithms, or the combination of approximate methods and simulation) in the case of increasing the number of nodes.

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