

## **Logistics model for collection and distribution of critical foods. Valle del Cauca case.**

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### **Abstract**

In Colombia, one of the main business concerns is to locate products within the reach of the consumer, especially in areas of difficult access, given the country's geographical conditions and road conditions make distribution operations difficult by this means.

This document presents the results of the system characterization for collection and distribution of essential products in Valle del Cauca department within a pilot company, through an applied logistic model. The study concluded, among others, that last-mile operations have multiple inconsistencies, which make it difficult to deliver products to the consumer in a timely manner and in the expected conditions due to the way the supply chain is managed, where it is the consumer who goes to a distant geographical point to have access to basic products, and, these do not respond to consumer expectations.

The proposed model is bi-helix, has an operative-functional component of the distribution system; and a mathematical component, which minimizes operating costs. This model serves as a reference for the development of on-site information collection instruments to recognize the configuration of the chain and the roads.

### **Keywords**

Logistics model for transport, urban distribution, last mile.

### **1. Introduction**

In Colombia, food security is a constitutional right especially for children. That is why it is necessary that logistics distribution systems are properly aligned to contribute to the achievement of this national objective, especially in areas of difficult access which is where the most vulnerable and most need access to food of high nutritional value and low cost.

Given these conditions, a project was executed in Valle del Cauca in which the problem of distribution of a critical food product for populations in poverty condition was analyzed. The analysis evaluated (i) the demand and consumption of the product, (ii) the level of service and (iii) the access and availability of the product at low cost.

Subsequently, in the project development, the design of a logistic system of regional collection and distribution was proposed, for which the conceptual model of logistics and product distribution was carried out in the first instance through on-site work and the operations model was formulated for the supply chain and the mathematical model. Finally, the different logistic operation scenarios were evaluated in the model and implementation recommendations were proposed.

As a complement to the development of this project, we used a specialized software for the routes design, as the product in question is perishable, during the transport operation it is subject to progressive deterioration and has an expiration date [1] which must be taken into account within the delivery time window, and the Valle del Cauca area presents geographical and operational difficulties for the food transport industry, [2] which are characteristic of Latin American countries. Among the software used there were Route4me® and RouteXL®

## **2. Methodology.**

First, an approach was taken into the state of the art for the bibliography published between the years 2005 and 2015 concerning: (i) the design of routes with an emphasis on the distribution of non-refrigerated perishable products, (ii) (iii) mathematical models of various characteristics used for the distribution of products, (iv) the use of ICT in transportation, (v) the software identification for routes design and (vi) the characteristics and challenges of transporting perishable goods in developing countries.

Then, an on-site investigation was carried out with the company in charge of the product's manufacturing and distribution, interviewing several of its collaborators for the supply chain recognition. Later, the department's roadways were identified with the objective of developing a logistic system in accordance with the conditions of the department and based on theories raised by other authors. Finally, the research was complemented with a characterization of the software for the design and optimization of transport routes available in Colombia and that could be applied to the project.

### **2.1 Logistics and distribution conceptual model.**

In the approach to the state of the art, four elements were identified in the model formulation [3]: (i) variables, (ii) outputs, (iii) structure and (iv) data. Within the framework of logistics and transportation, which is the subject of this project, the following components of the model were identified: (i) cargo generation nodes (a company in Cartago municipality), (ii) (40 of the 42 municipalities of Valle del Cauca department, except La Cumbre and Vijes), (iii) the access roads to each municipality and the cross roads to the department, as well as the nodes (toll points, balances, rest areas, etc.) and (iv) the altimetry of municipalities because this aspect was determined to affect fuel use and the engine power of vehicles. Then, based on this information, a distribution proposal was made in which an 8-ton truck was used to distribute the product in as many municipalities as possible, complying with the following restrictions:

- The route had to have as starting and arrival point the manufacturing plant in the municipality of Cartago.
- The complete route should take 8 hours or less.
- The truck had to be loaded to at least 90% of its capacity

Also, the routes within each municipality are specified in a sample of five municipalities of Valle del Cauca department, for which the software Route4Me and RouteXL were used in their test version. Thus, according to the information gathered above, the mathematical model describing the behavior of this distribution network was carried out using a model proposed by Kewei, Zhiqiang and Xiaoming [4] and adapted to the identified logistics network.

The investigation revealed that in Valle del Cauca there are two main routes that cross it from north to south, these are: (i) the western trunk or national route 25 that runs from Cartago to Palmira and from there it is divided into three ways which covers the municipalities of Cali, Candelaria, Pradera and Florida, and (ii) the national route 23 or via panorama which goes from Ansermanuevo to Cali and works in parallel with the western trunk. Likewise, the national route 40 or transverse Buenaventura-Puerto Carreño, crosses the department from east to west from Zarzal to Buenaventura. This information can be seen in Figure 1.

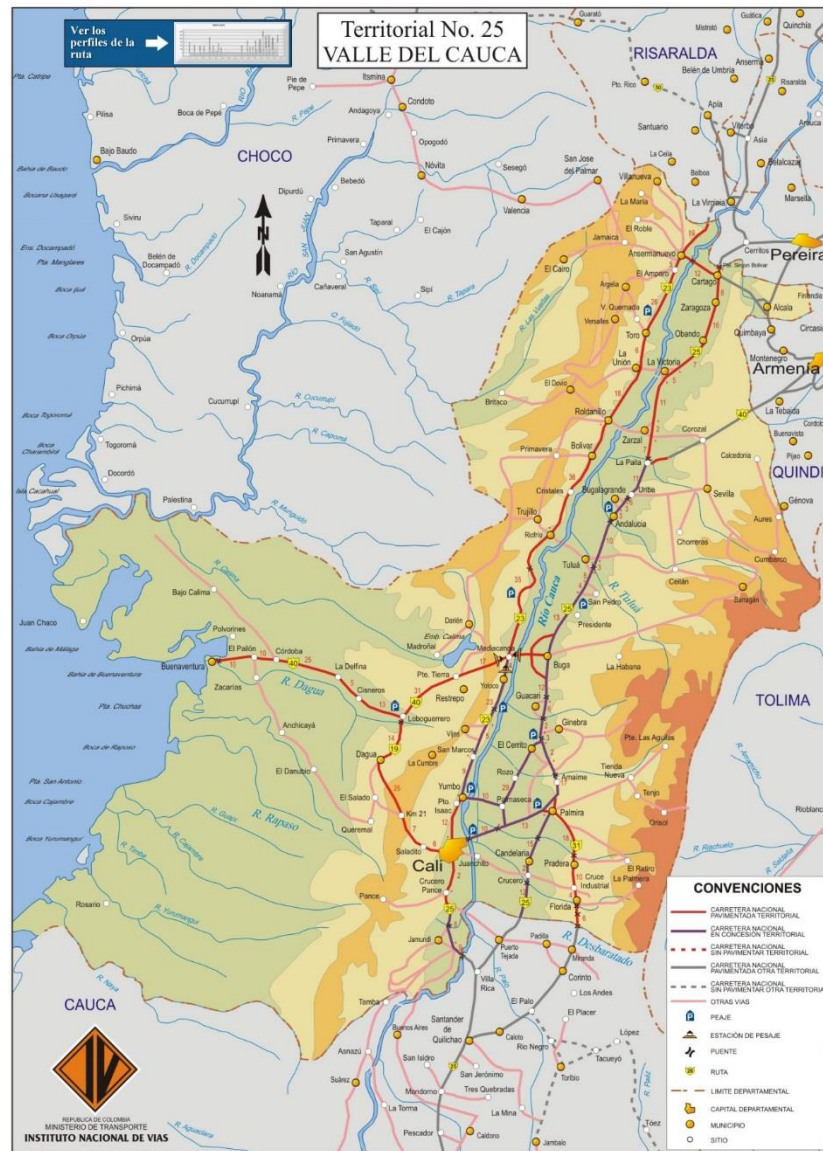


Figure. 1. Road map of Valle del Cauca. [5]

## 2.2 Logistics operation characterization.

At this point, a tour across Valle del Cauca was executed in order to identify the state of the main access roads to the municipalities of the department, the available infrastructure nodes and the characteristics of the product's customers to be distributed. For this, more than 16 hours of videos were captured along the roads, at intervals of 15 minutes each in order to characterize the vehicular typology that moves through the tracks of the department. Also, drivers and available personnel were surveyed with the objective of determining the type of load that moves along the tracks.

On the other hand, since demand is the initial element of the logistic operation, the most recent demand for the product, which is shown in Table 1, was investigated.

Table 1. Monthly product demand for the year 2015

| <b>MUNICIPALITIES</b> | <b>JANUARY</b> | <b>FEBRUARY</b> | <b>MARCH</b> | <b>APRIL</b>  | <b>TOTAL</b>    |
|-----------------------|----------------|-----------------|--------------|---------------|-----------------|
| Alcala                | 22,5           | 45              | 2            | 90            | <b>159,5</b>    |
| Ansermanuevo          | 517,5          | 202,5           | 1            | 135           | <b>856</b>      |
| Argelia               | 247,5          | 112,5           | 2            | 90            | <b>452</b>      |
| Bolivar               | 360            | 360             | 2            | 202,5         | <b>924,5</b>    |
| Buenaventura          | 16537,5        | 10080           | 24           | 16222,5       | <b>42864</b>    |
| Buga                  | 180            | 450             | 5            | 382,5         | <b>1017,5</b>   |
| Bugalagrande          | 247,5          | 112,5           | 3            | 45            | <b>408</b>      |
| Caicedonia            | 22,5           | 90              | 1            | 112,5         | <b>226</b>      |
| Cali                  | 49432,5        | 43830           | 148          | 42075         | <b>135485,5</b> |
| Calima                | 0              | 67,5            | 1            | 90            | <b>158,5</b>    |
| Candelaria            | 5445           | 10102,5         | 4            | 39870         | <b>55421,5</b>  |
| Cartago               | 3442,5         | 4680            | 20           | 3712,5        | <b>11855</b>    |
| Dagua                 | 675            | 315             | 6            | 517,5         | <b>1513,5</b>   |
| El aguila             | 180            | 67,5            | 1            | 45            | <b>293,5</b>    |
| El cairo              | 225            | 112,5           | 2            | 202,5         | <b>542</b>      |
| El Cerrito            | 720            | 450             | 4            | 832,5         | <b>2006,5</b>   |
| El dovio              | 382,5          | 270             | 1            | 292,5         | <b>946</b>      |
| Florida               | 742,5          | 585             | 5            | 472,5         | <b>1805</b>     |
| Ginebra               | 270            | 405             | 3            | 427,5         | <b>1105,5</b>   |
| Guacarí               | 90             | 135             | 1            | 45            | <b>271</b>      |
| Jamundí               | 405            | 652,5           | 6            | 562,5         | <b>1626</b>     |
| La Unión              | 495            | 405             | 1            | 360           | <b>1261</b>     |
| La Victoria           | 292,5          | 247,5           | 2            | 315           | <b>857</b>      |
| Obando                | 135            | 337,5           | 2            | 427,5         | <b>902</b>      |
| Palmira               | 990            | 1755            | 11           | 2340          | <b>5096</b>     |
| Pradera               | 135            | 135             | 1            | 247,5         | <b>518,5</b>    |
| Restrepo              | 22,5           | 45              | 1            | 112,5         | <b>181</b>      |
| Riofrío               | 22,5           | 67,5            | 1            | 135           | <b>226</b>      |
| Sevilla               | 2520           | 2632,5          | 3            | 427,5         | <b>5583</b>     |
| Toro                  | 337,5          | 292,5           | 1            | 225           | <b>856</b>      |
| Trujillo              | 90             | 67,5            | 3            | 45            | <b>205,5</b>    |
| Tuluá                 | 4680           | 5332,5          | 13           | 3847,5        | <b>13873</b>    |
| Versalles             | 180            | 225             | 1            | 135           | <b>541</b>      |
| Yotoco                | 45             | 67,5            | 1            | 0             | <b>113,5</b>    |
| Yumbo                 | 2272,5         | 2025            | 15           | 1665          | <b>5977,5</b>   |
| Zarzal                | 1507,5         | 1575            | 1            | 1372,5        | <b>4456</b>     |
| <b>TOTAL</b>          | <b>93870</b>   | <b>88335</b>    | <b>299</b>   | <b>118080</b> | <b>300584</b>   |

### 2.3 Mathematical modeling and use of ICTs in transport.

On the other hand, in order to develop a mathematical modeling that describes the behavior of the logistic operation of distribution of the perishable product for the region of Valle del Cauca, investigations of models previously used in similar distribution typologies were done. From the reviewed literature it was found that there are several routing models, one describes the multi-objective problem [6] in which one seeks to optimize more than one characteristic or variable at a time, such as cost and distance; another describes a problematic vehicle fleet heterogeneous [4], and another described the use of time windows in a non-linear model in which the merchandise was distributed from a single distribution center to where vehicles were to return [7]. A mathematical model is then proposed which is composed of an objective function that minimizes the total cost of the route. For this purpose we define:

Model initiation data:

|  |   |
|--|---|
| $P = \{1, 2, \dots, n, s, e\}$                         | The set of stop points in Valle del Cauca from 1 to $n$ , a start point $s$ (start) and an end point $e$ (end).   |
| $A = \{(p_i, p_j)   (\forall j, j \in I   i \neq j)\}$ | The arcs between a point $p_i$ and a point $p_j$ . The distinction is made that $j$ will always be a point other than $i$ and that $j$ belongs to the same set as $i$ . |
| $T = \{1, 2, \dots, n\}$                               | The arcs between a point $p_i$ and a point $p_j$ . The distinction is made that $j$ will always be a point other than $i$ .   |
| $K = \{1, 2, \dots, n\}$                               | Vehicle type.   |
| $\forall (p_i, p_j) \exists d_{ij}$                    | Vehicle number.   |
| $W_t$  | Specifies that for every arc there is a distance $d$ .  |
| $C_t$  | Weight capacity for the vehicle type $t$ .  |
| $cd$   | Volume capacity for the vehicle type $t$ .  |
| $cf_t$   | Cost per distance unit.   |
| $\forall p_i \exists D_{wc}$                           | Fix cost of truck type $t$ .  |
| $N_t$  | It states that for all stop points $p$ there is a demand $D$ of weight $W$ and volume $C$ .   |
|  | Number of vehicles available.   |

The objective function:

$$\text{Minimize}_{cost} = \sum_{k \in K} \left[ (cd \cdot \sum_{i \in I} \sum_{j \in I, i \neq j} d_{ij} \cdot \tau_{ij}^k) + (cf_t \cdot \sum_{t \in T} \sigma_{kt}) \right]$$

Subject to:

$$\sum_{k \in K} \mu_{ik} = 1 \quad \forall i \in I \quad (1)$$

$$\sum_{t \in T} \sigma_{kt} = 1 \quad \forall k \in K \quad (2)$$

$$s = e; \quad \forall \sum (p_i, p_j) \exists [(p_s, p_i) \neq (p_i, p_e)] \quad (3)$$

$$\sum_{j \in I, j \neq i} \tau_{ij}^k - \sum_{j \in I, j \neq i} \tau_{ji}^k = 0 \quad \forall i \in I / (s, e), \forall k \in K \quad (4)$$

$$\sum_{i \in I} \mu_{ik} \cdot W_i \leq \sum_{t \in T} \sigma_{kt} \cdot W_t \quad \forall t \in K \quad (5)$$

$$\sum_{k \in K} \sigma_{kt} \leq N_t \quad \forall t \in T \quad (6)$$

The decision variables are:

$$\mu_{ik} = \begin{cases} 1 & \text{If vehicle } k \text{ serves customer } i; \\ 0 & \text{else;} \end{cases}$$

Decides which customers  $i$  are served by which truck  $k$ .

$$\sigma_{kt} = \begin{cases} 1 & \text{If vehicle } k \text{ is a type } t; \\ 0 & \text{else;} \end{cases}$$

Decides the type  $t$  of vehicle  $k$  used.

$$\tau_{ij}^k = \begin{cases} 1 & \text{If the arch } (p_i, p_j) \text{ is served by the vehicle } k; \\ 0 & \text{else;} \end{cases}$$

Decides the sequence of visits of the truck.

$$\mu_{ik} = \sum_{j \in I} \tau_{ij}^k \quad \forall i \in I, \forall k \in K$$

The restriction (1) indicates that any customer  $i$  can be served by a single vehicle  $k$ . The constraint (2) establishes which vehicle  $k$  is of type  $t$ . The constraint (3) imposes that the starting point  $s$  is the same as the point of arrival  $e$  and that in all combinations of arcs  $(p_i, p_j)$  there must first exist an arc  $(ps, pi)$  from the start point  $s$  toward the first client  $i$  and finally an arc  $(pi, pe)$  from the last client  $i$  of that route to the point of arrival  $e$ . The restriction (4) restricts the vehicle type  $k$  that once it has served client  $i$  and  $j$  returns to client  $i$ , except at the start and end points  $e$ . The restriction (5) prevents that in the vehicle type  $k$  the weight capacity of the vehicle is exceeded. Finally, restriction (6) limits the allocation of vehicles beyond the available fleet.

When looking at the complexity of the solution for the mathematical model such as those described above, it was necessary to investigate what types of technologies have been used in recent years to facilitate the work of constructing a routing process. From this it was obtained that there are around the world diverse software for the design of distribution routes [8] that, fed by a database, can generate routes of distribution of merchandise of diverse characteristics, among them are: SINMAF, Axiadis, Servicing, Roadnet Technologies, SAIP, RouteXL, Routist and Route4Me; it was also recognized the application of various technologies such as GPS, which was used to establish the location of collection centers in a blackberry production area in Huila [9] and the RFID that was used as a tool to evaluate the impact of an intelligent transport system on a distribution network [10]. Table 2 summarizes the most important characteristics of the software that were found.

Table 2. Characterization of route design software available in Colombia

|                                       | SINMAF<br>SND | Axiadis | Axiopack | Axiotrans | Axiomobil | Roadnet | Roadnet<br>Anywhere<br>routing | Transcad | Route4Me | RouteXL | Routist |
|---------------------------------------|---------------|---------|----------|-----------|-----------|---------|--------------------------------|----------|----------|---------|---------|
| Route design                          | x             | x       | x        | x         |           | x       | x                              | x        | x        | x       | x       |
| Route<br>simulation                   |               | x       |          |           |           |         |                                | x        | x        | x       |         |
| Route planning                        |               |         |          | x         |           | x       | x                              |          | x        | x       |         |
| Route<br>optimization                 | x             | x       |          |           |           | x       | x                              |          | x        | x       | x       |
| Time windows                          |               | x       |          | x         |           |         | x                              |          | x        | x       | x       |
| Weight and<br>volumen<br>restrictions |               |         | x        |           |           |         | x                              |          | x        | x       |         |
| Homogenous<br>fleets                  |               |         |          |           |           |         |                                |          | x        | x       | x       |

|  | SINMAF<br>SND | Axiadis | Axiopack | Axiotrans | Axiomobil | Roadnet | Roadnet<br>Anywhere<br>routing | Transcad | Route4Me | RouteXL | Routist |
|--|---------------|---------|----------|-----------|-----------|---------|--------------------------------|----------|----------|---------|---------|
| Heterogenous<br>fleets                   | x             | x       |          |           |           |         | x                              | x        | x        | x       | x       |
| Costs analysis                           |               |         |          | x         |           | x       |                                |          | x        | x       |         |
| Cargo<br>optimization                    |               |         | x        |           |           | x       | x                              |          |          |         |         |
| Multi-modal                              | x             |         |          | x         |           |         |                                | x        |          |         |         |
| Mobile App                               | x             |         | x        |           | x         |         | x                              |          | x        | x       | x       |
| Vehicle tracking                         |               |         |          | x         | x         |         |                                |          | x        | x       | x       |
| Driver tracking                          |               |         |          | x         | x         | x       |                                |          | x        | x       |         |
| Messenger<br>service                     |               |         |          |           | x         | x       |                                |          | x        | x       |         |
| Delivery control                         |               |         |          | x         | x         |         |                                | x        |          |         | x       |
| Satellite traffic<br>information         |               |         |          |           |           |         | x                              | x        |          |         |         |
| P2P satellite<br>information             |               |         |          | x         |           |         | x                              |          |          |         |         |
| Geographical<br>information              |               |         |          |           |           |         |                                |          |          |         |         |
| CO2 emissions<br>calculation             |               |         |          |           |           |         |                                |          |          | x       |         |
| Technical<br>assistance in<br>Colombia   | x             |         |          |           |           |         |                                |          |          |         |         |
| International<br>technical<br>assistance |               | x       | x        | x         | x         | x       | x                              | x        | x        | x       | x       |

### 3. Results.

There are 314 primary product delivery points in Valle del Cauca, as shown in Figure 2, of which 48% are in the municipality of Cali and 7% in the municipality of Buenaventura.

Since production takes place in the north of Valle del Cauca, a sample route was proposed for six municipalities adjacent to the factory with the objective of determining the travel times and the amount of cargo that could be

delivered in an eight-hour day. This sample showed that up to 100% of the requirements of each department could be covered with a truck with eight tons of capacity in a workday equal to or less than eight hours depending on the software used. Based on this, a mathematical model was developed that aims to minimize the total cost of the route.

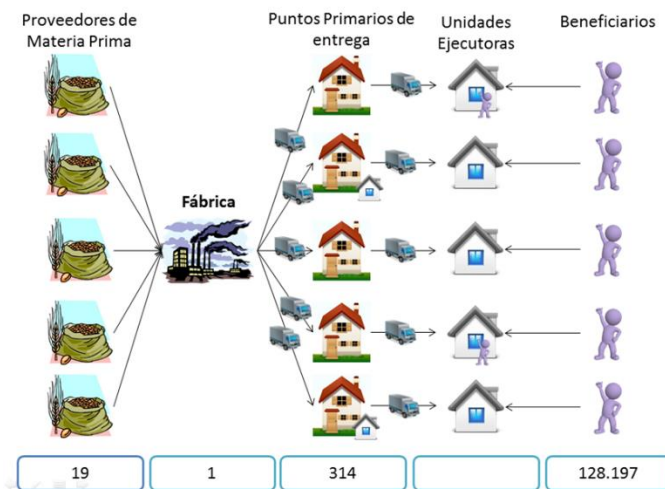


Figure 2. Diagram of the supply chain of the product in the Valle del Cauca

It was determined that each municipality has product delivery points distributed as follows:

Table 2. number of product delivery points per municipality

| Municipality | Product delivery points by municipality by 2015 |
|--------------|---|
| Alcalá       | 2   |
| Andalucía    | 1   |
| Ansermanuevo | 1   |
| Argelia      | 2   |
| Bolívar      | 2   |
| Buenaventura | 24  |
| Buga         | 5   |
| Bugalagrande | 3   |
| Caicedonia   | 1   |
| Cali         | 151   |
| Calima       | 1   |
| Candelaria   | 4   |
| Cartago      | 19  |
| Dagua        | 6   |
| Dosquebradas | 57  |
| El Águila    | 1   |
| El Cairo     | 2   |
| El Cerrito   | 4   |
| El Dovio     | 1   |
| Florida      | 5   |
| Gacarí       | 3   |
| Ginebra      | 1   |

| Municipality | Product delivery points by municipality by 2015 |
|--------------|---|
| Jamundí      | 7   |
| La Cumbre    | 0   |
| La Unión     | 1   |
| La Victoria  | 2   |
| Obando       | 2   |
| Palmira      | 12  |
| Pereira      | 139   |
| Pradera      | 1   |
| Restrepo     | 1   |
| Riofrío      | 1   |
| Roldanillo   | 0   |
| San Pedro    | 0   |
| Sevilla      | 4   |
| Toro         | 1   |
| Trujillo     | 3   |
| Tuluá        | 13  |
| Ulloa        | 0   |
| Versalles    | 1   |
| Vijes        | 0   |
| Yotoco       | 1   |
| Yumbo        | 15  |
| Zarzal       | 1   |



#### **4. Discussion.**

At this point it can be considered that most of the existing routing software has a programming that allows them to function properly in the geographies of countries such as the United States and Europe, countries where its development is conceived, however, the available software presents problems to recognize the Colombian directions and to locate some municipalities and smaller towns that are not totally digitalized. Likewise, and because they are specialized, they have high costs, making it difficult to access all of their capacity and possibilities even for academic studies, so we used the trial versions for the sample of routing of this project which, although it presents very good characteristics, is very limited in its functions and benefits.

In order to gather information relevant to the project, field work, interviews and direct relationship with the agents of the chain closest to the client were used, since they had first-hand information about the operation and its conformation. The distribution logistics network is flexible in terms of the number and denomination of agents in each link.

It is intended that this project serve as a model for the development of similar proposals in other parts of the country, that also serves as a basis for future IT routing platforms that are specifically developed to operate in Colombia, or that the available routing platforms can be upgraded to develop specific modules for Colombia and especially for Valle del Cauca.

#### **5. Acknowledgements**

To Universidad Autónoma de Occidente and GICPE research group.

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## **7. Biographies**

**Valentina Restrepo Peláez**, is an industrial engineer from Universidad Autónoma de Occidente, a young researcher attached to the GICPE group (Research Group on Competitiveness and Business Productivity in Spanish), recognized by COLCIENCIAS in category B. She has experience in structuring projects. Has participated in research projects at the regional level. Currently, the design of a business logistics innovation system for Valle del Cauca is being developed.

**Nelson Ricardo Becerra Escobar**, is an industrial engineer from the Universidad Autónoma de Occidente and a young researcher of GICPE group, has participated in research and business projects of competitiveness and productivity at the regional level. Currently, the design of a business logistics innovation system for Valle del Cauca is being developed.

**Gloria Mercedes López Orozco**, is an Industrial Engineer, associate teacher in the Operations and Systems department, coordinator of the GICPE research group. Master in Integral Logistics, Master in Advanced Models for the Direction of Operations in Supply Chain Management, Ph.D in Engineering. She has business experience of more than 10 years in the logistics and transportation sector.