Ingeniería Solidaria

Assignment and routing model for the planning of fruit and vegetable supply operations in the southern part of Bogota

Modelo de asignación y ruteo para la planeación de la operación de suministro de alimentos al sur de Bogotá, caso de frutas y verduras

Modelo de alocação e roteamento para o planejamento da operação de abastecimento de alimentos ao sul de Bogotá, caso de frutas e legumes

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Abstract

This paper is a product of the research; Design of the logistics operation of food distribution in different locations south of Bogotá based on a multistage model, developed in the Bogotá District University in the year 2014.

Introduction: Bogota City has a big problem in its food supply, framed by the inefficiency in the capillary distribution, raising costs to households, which generates difficulties in accessing food for Stratas 1 and 2.

Method: An analysis of the behavior of the system proposed within the "Master Plan for Food Supply and Security in Bogotá" was carried out, using a correlational descriptive method for the analysis of the variables, from the characterization of food in 4 locations and other secondary sources.

Results: In the Phase 1 of this model, the allocations of the load to be distributed from three logistic platforms, towards 4 localities, based on mixed integer mathematical programming, were determined. In the second phase, a basic VRP model was developed that determined the routing of vehicles with the remaining fruit and vegetable loads to be delivered.

Conclusions: The work is relevant as a contribution to the optimal management of food supply through the use of mathematical models, given that it covers fixed costs both for deliveries and for the use of vehicles, with a two-phase model. This can contribute to food security through greater access to food with reduced prices and timely availability in the target areas of study.

Originality: Staged models that complement each other to define the complete food supply operation.

Limitation: A minimum of knowledge on the subject is necessary for the models to be successfully used.

Keywords: Fruits and Vegetables, Distribution Logistics, Phased Model, Mixed Integer Programming, Vehicle Routing.

Resumen

El artículo es producto de la investigación; Diseño de la operación logística de distribución de alimentos en diferentes localidades al sur de Bogotá con base en un modelo multietapa, desarrollado en la Universidad Distrital de Bogotá en el año 2014.

Introducción: La ciudad tiene una problemática frente al abastecimiento de alimentos enmarcada por la ineficiencia en la distribución capilar, elevando los costos a los hogares, lo que genera dificultades de acceso de alimentos principalmente a los estratos 1 y 2.

Método: Se realizó un análisis del comportamiento del sistema planteado por el Plan Maestro de Abastecimiento y Seguridad Alimentaria de Bogotá, utilizando un método descriptivo correlacional para el análisis de las variables a partir de la caracterización de alimentos en 4 localidades, y otras fuentes secundarias.

Resultados: En la primera fase de este modelo, se determinó las asignaciones de la carga a distribuir desde tres (3) plataformas logísticas hacia 4 localidades basada en programación matemática entera mixta. En la segunda fase se desarrolló un modelo de VRP básico que permitió determinar el ruteo de vehículos con las cargas restantes por entregar de frutas y verduras.

Conclusiones: El trabajo es relevante como aporte a la gestión óptima de abastecimiento de alimentos mediante el uso de modelos matemáticos, dado que abarca costos fijos tanto para los depósitos como para el uso de los vehículos, con un modelo de dos fases. Este puede contribuir a la seguridad alimentaria a través de un mayor acceso a los alimentos con reducción de precios y disponibilidad oportuna en las localidades objeto de estudio.

Originalidad: modelos por etapas que se complementan para definir la operación completa de abastecimiento de alimentos.

Limitaciones: los modelos deben ser utilizados con un mínimo de conocimientos en el tema.

Palabras clave: Frutas y Verduras, Logística de Distribución, Modelo por fases, Programación Entera Mixta, Ruteo de Vehículos.

Resumo

O artigo é produto de pesquisa; Desenho da operação logística para distribuição de alimentos em diferentes locais ao sul de Bogotá com base em um modelo multi-etapas, desenvolvido na Universidade Distrital de Bogotá em 2014.

Introdução: O município apresenta um problema de abastecimento de alimentos, marcado pela ineficiência na distribuição capilar, elevando os custos para as famílias, o que gera dificuldades de acesso aos alimentos principalmente para os estratos 1 e 2.

Método: Foi realizada uma análise do comportamento do sistema proposto pelo Plano Diretor de Abastecimento e Segurança Alimentar de Bogotá, usando um método correlacional descritivo para a análise das variáveis da caracterização de alimentos em 4 localidades e outras fontes secundárias .

Resultados: Na primeira fase deste modelo, as atribuições da carga a ser distribuída de 3 (três) plataformas logísticas para 4 localidades foram determinadas com base em programação matemática inteira mista. Na segunda fase, foi desenvolvido um modelo básico de VRP que permitiu determinar a roteirização dos veículos com as cargas restantes de frutas e verduras a serem entregues.

Conclusões: O trabalho é relevante como contributo para a gestão óptima da oferta alimentar através da utilização de modelos matemáticos, uma vez que abrange os custos fixos tanto dos armazéns como da utilização de viaturas, com um modelo bifásico. Isso pode contribuir para a segurança alimentar por meio de maior acesso a alimentos com preços reduzidos e disponibilidade oportuna nas localidades em estudo.

Originalidade: modelos por etapas que se complementam para definir a operação completa de abastecimento de alimentos.

Limitações: os modelos devem ser utilizados com um mínimo de conhecimento sobre o assunto.

Palavras-chave: Frutas e Hortaliças, Logística de Distribuição, Modelo de Fases, Programação Inteira Mista, Roteirização de Veículos.

1. INTRODUCTION

The food supply in Bogotá D.C. is disorganized. Approximately every day 26,300 producers deliver food products to 140,000 different operators, with an average of 3 intermediaries that do not add value but add cost per chain, representing 21% of the final price of the food [1]. This has a negative effect in consumers, especially in those with fewer resources; even more in Bogotá, characterized by a marked socio-economic inequality in which Strata 1, 2 and 3 stand out, representing 84.5%. For 2013, the population of the city was projected as having 7,831,159 inhabitants, of which 48.8% belong to Strata 1 and 2, [2]. In this context, the district created the Master Plan for Food Supply and Security in Bogotá (PMASAB for its Spanish acronym), which, faced with the logistics issue, seeks to overcome the traditional intermediation in supply chains in order to ensure that the actors located in the extremes of the chain (farmers and shopkeepers) come closer, thereby reducing inefficiencies of the current chain in such a way that the consumer benefits from a notable reduction in prices.

Within the framework of the PMASAB, the inclusion of logistical platforms is proposed, of which one was built in the Plaza de Lucero Tesoro [3]; it is proposed to create other logistical infrastructures in other locations. At present, there are no designs for the logistics operation of food distribution in the localities of Ciudad Bolívar, San Cristóbal, Bosa and Usme. This work proposes, via the use of a phased model under the PMASAB approach, an efficient logistics operation proposal for "fruver" (fruits and vegetables) food supply activity in the southern area of Bogotá DC, The correlational analysis of information, obtained through historical data and by direct observation, was used as a method [4] in order to establish theoretical-practical judgments regarding the problem, classifying this research as descriptive correlational in the field [5].

In this way, a partitioned model was designed in two phases as a way to carry out the planning of the fruver food supply activity in the south of Bogotá, contributing, if it is implemented in the future, to increased food security through greater access to these foods with price reduction and timely availability in the localities under study. The document begins with a review of the literature and the methods or procedures used, followed by a description of the design of the proposed model and its results, finishing with the discussions and conclusions.

2. LITERATURE REVIEW

2.1. Model for the Analysis for the supply chain by phases

A model is the simplified representation of reality by a mathematical system that helps to improve the level of understanding of its functioning [6], given that there are models with some algorithmic complexity, a phased solution strategy is proposed. It consists of a piecewise division of the problem, solving each part separately. This method has already been employed when defining the location of a logistic platforms; the initial phase being to locate the central platform, and then selecting the means of transport and the number of trips that must be made [7]. Other applications seek to minimize the costs of inventories along the supply chain (SC) with non-linear restrictions [8], along with problems of variability in safety inventories with cyclical demand [9]. There are studies of cost distribution in the SC where a stochastic mathematical model is proposed for the analysis in multiple-phase networks [9]; as are there studies for problems of interdependence of orders at the different levels of the SC, formulating a mathematical model of the stochastic network for the analysis of the order and the distribution of costs [10].

2.2. Mathematical Model and Solution Method

The global problem, studied in its context of application, is part of the vehicle routing problem (VRP), classified as a problem with multiple tasks with a heterogeneous fleet HFMDCVRP [11], which can be summarized with a mathematical model of mixed integer linear programming MILP (Mixed Integer Linear Programming). The problem includes travel limitations and fixed costs for both vehicles and deposits. Since it is a matter of supplying several clients from different platforms or deposits, the problem is a "multi-deposit" VRP (MDVRP); as the vehicles have different capacities, the problem also involves a heterogeneous fleet.

Regarding the solution technique, when dealing with MDVRP, most of the exact algorithms to solve the VRP are difficult to adapt to the MDVRP [12]. According to [13], these problems are more common and easier to understand, developing formulations based on integer programming. Recently in [14], mathematical formulations were proposed to solve several types of VRP including the MDVRP, while in [15] an integer linear program is presented to solve the MDVRP with a heterogeneous fleet within a certain time span. On the other hand, in [16] a heuristic of three phases is proposed: First, a pre-processing for the node grouping, then a more compact formulation of the MILP problem, and then a cluster for its development. In [17], an MILP model is proposed to minimize the cost of transport in a monolithic optimization framework for the routing of vehicles with cross docking in the management of the CS VRPCD-SMC. Based on [18], an MILP model and a branch-and-bound procedure for the MDVRP with a fixed fleet with collection and delivery is proposed. Another configuration of the MDVRP with development of exact algorithms is the one described in [19], where the trained MDVRP with route length limitations is studied. In [20], an MILP model is presented for the problem in which a heterogeneous fleet of vehicles is available and with the maximization of the total net income as an objective function, while establishing restrictions of maximum and minimum demands. Taking into account this revision and to facilitate the solution of the problem in question, a two-phase model was designed separately; the first establishes the assignment of loads to be distributed from each warehouse or logistics platform and in the second one, the specific routing for the delivery of the surplus amounts assigned in Phase I.

3. METHODS

According to the district of Bogotá, the food supply system (FSS) for the fruit and vegetable chains was established to the south of the city. Thus, based on the PMASAB proposal, the FSS was characterized in four localities (Ciudad Bolívar, Bosa, San Cristóbal and Usme) [4], thereby defining the factors and variables of their behavior and information, relevant for its modeling (Phase 1), through a mathematical scheme that served to assign the quantities to be distributed from each of the platforms of the four locations and later (in a second phase), define the routing of vehicles for the delivery of remaining food products through a classic VRP model. This research development is part of a quantitative methodology using various techniques for the study of the variables of interest in the respective analysis unit [21], based on historical data, direct observation and secondary sources of information, working with previously validated theoretical foundations. A descriptive, comprehensive and finally purposive level was made when establishing the model´s design [22].

The methodological phases are summarized in Figure 1, where each one of them provides a practical and theoretical contribution to the research; each from the Investigation of operations and from statistics with approaches that enrich the methods used.

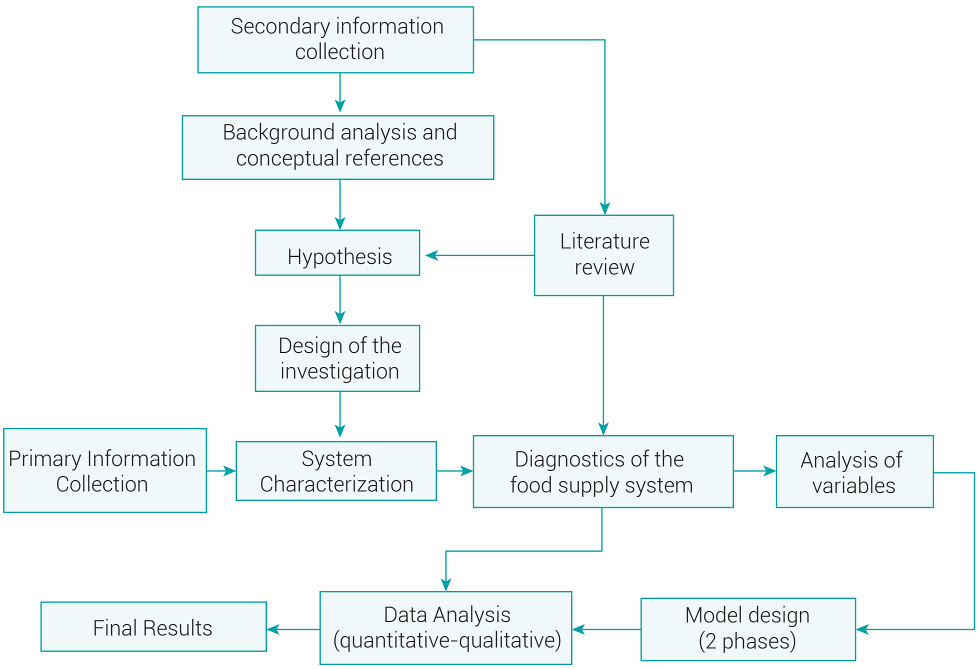

Figure 1. Methodological phases developed in this work
Source: Own work

Table 1 summarizes the type of information obtained and specifies the phase of analysis.

Table 1. Source, Treatment and Use of the Information by Phase

Data type	Source type	Obtained from	Medium or Tool used	Phase
Times and distances between clients	Secondary information	Web Application	Google Maps, satellite geo positioning systems (G.P.S.)	1-2
Demand Offer	Secondary information	Specialized information centers: Mayor's Office of Bogotá, Secretary of Planning, Secretary of Economic Development	Website and Libraries	1-2
Variable and fixed costs	Secondary information	Specialized information centers: Corabastos	Monthly price bulletins.	1
	Secondary information	Chief of Operations of Corabastos	Direct interview	
Allocation of loads of Platforms to Shopkeeper Centers	Optimization Model	Computational Application	Gams	1-2
Vehicle Routes	TSP Model	Computational Application	Gams	2

Source: Own work

4. MODEL DESIGN AND SOLUTION PROPOSAL

The model was designed considering the previous establishment of three logistics platforms geographically located in the localities of Ciudad Bolívar (Lucero-Tesoro), Usme and Bosa where food, supplied by the farmers, will be distributed to Shopkeeper Centers (CT) or units of sale to the final consumers located in the Localities; San Cristóbal, Ciudad Bolívar, Bosa and Usme. This model, when applied, would allow for less food handling (food security) by not including intermediaries, thus reducing transport and intermediation costs, contributing in turn to reduced prices for the final consumer.

4.1. Description of the System and the overall Model.

The distribution of food would be made from the three platforms to each of twenty seven Shopkeeper Centers (CT) distributed in the four study locations according to the location of the Zonal Planning Units (these are intermediate urban areas between neighborhoods and localities, whose function is to allow urban development planning at the zonal level), taking into account their distance to the respective platforms, capacity, coverage and demand. The type of vehicle to be used is contemplated according to their capacity and the number of trips allowed. The model establishes that the supply to each CT is made by a single platform without exceeding its capacity, although this is not the one of its location.

The design of the logistics operation of food distribution is established through a model split into two phases to simplify the operational complexity of the system. In Phase 1, the assignments of the complete load are determined by families of products to be distributed from each platform. With this information, programming is performed for the distribution with full loads to each CT for the Fruver food chain. The second phase develops a model based on the TSP (Traveling Salesman Problem), as the basic foundation of the VRP, in order to determine the routing of vehicles for the distribution of the partial loads that have been distributed in the TC. The characteristics of the model are presented in Table 2.

Table 2. Stages of the Model for the logistics operation and its characteristics

Phase	Objective-Scope	Result	Assumptions	Model-application used
No.1	Determine the allocation of the cargo to be transported from the platforms to the CTs taking into account their capacities and demands respectively, considering that a platform can supply CTs outside of their locality, as global costs are minimized by having distribution systems throughout the system.	1. Determine the type and number of vehicles needed for each of the platforms loaded at 100% capacity. 2. The programming of the distribution depending on the working hours of both the platform and the CTs.	Arrangement of two types of vehicle; Type 1 of 5200 kg and Type 2 of 9000 kg capacity. The Source period as a planning unit is the day.	Model based on Mixed Integer Programming, solved in GAMS.
No. 2	Based on the results of the previous stage, the specific routing for the distribution of the remaining products is developed.	Routing of the vehicles by platform with the remaining quantities to be delivered.	Use of the vehicle below its maximum capacity, according to the remaining quantities to be distributed.	Basic model of VRP solved in GAMS.

Source: Own work

4.2. Mathematical Statement for Phase 1

The following model is constructed from the operating conditions of the FSS south of Bogotá and supported by formulations reported in the literature review. The model represents the transport of products in a network with "n" sources and "M" destinations according to [23]. The Objective Function (1) contemplates both variable costs and fixed costs. The variables contemplate the distribution value of the products that include fuel consumption for the mobilization of said vehicle and maintenance costs. There are two fixed variables: First, the management costs for the logistics platform "i" assigned by the shipment from that platform to the CT "j", it contemplates the constant expenses of use of the facilities, the labor for the loading of the vehicles and the indirect periodic expenses that are presented by the use of infrastructure; Second, the fixed costs of use for each type of vehicle, which are given by the rent of the same vehicle and the cost of the driver, while taking into account the respective distances between the platforms and the CTs.

The restrictions are defined as follows: Equation (2) defines a single source per destination, with a design of distribution routes to several clients using several system sources [24] and [25]. Supported by [26] and [27] is, (3) establishes the best allocation of fixed costs per platform, with a fixed maximum cost limitation for the use of each platform. (4) defines the supply constraint in the conventional transport mode [23], [28]. Taking into account multiple deposits, the demand equation by type of vehicle is established as (5), together with Equation (6) that ensures that the demand for any of the vehicles to be used is met. (7) establishes the maximum number of trips allowed per type of vehicle. (8) defines the activation of the fixed costs by the use of the respective type of vehicle. An unrestricted non-negative variable (9) and two binaries (10) are considered, so that there is a general design that is part of the mixed integer mathematical programming [15], [29]. Next, the specific structure of the proposed model is presented:

Sets:

ρ = Type of vehicle. $\forall\ \rho = 1 \ldots \delta$

i = Logistics Platform. $\forall\ i = 1 \ldots \mathrm{n}$

j = Shopkeeper's center. $\forall\ j = 1 \ldots \mathrm{m}$

Variables of the model:

$X\rho ij$ = Number of units to be transported in the vehicle type "ρ" from platform "i" to shopkeeper's center "j" in the Source period

Yij = Binary variable that activates the use of the platform "i" to serve the shopkeeper's center "j" in the Source period

$Z\rho ij$= Binary variable that activates the fixed costs of the vehicle type "ρ" for its use in transportation from the platform "i" to serve the store center "j" in the Source period.

Parameters:

Cfij = Fixed costs of handling by logistic platform assigned by the shipment from said platform “i” to the shopkeeper’s center “j”

Cfmaxi = Maximum fixed cost allowed for transportation through the platform “i”

Cuij = Unit transport costs from platform “i” to shopkeeper’s center “j”

Cfρij = Fixed cost of Use of Vehicle type “ρ”, for transport from platform “i” to shopkeeper’s center “j”

ai = Offer or capacity of the platform “i”

bj = Shopkeeper’s center demand “j”

Cρ = Vehicle capacity type “ρ”

Nvρ = Number of vehicles type “ρ”

VMρ = Maximum vehicle trips type “ρ” in the Source period

Vρ = Vehicle trips type “ρ” in the Source period

Trvρ = Average travel time of the vehicle type “ρ” in minutes

Tvρ = Average time per trip of the vehicle type “ρ” in minutes

Td = Average time available for transport in the Source period in minutes

M = Constant coefficient with large value above the highest value of “Xpij”

Equivalences:

$Tv\rho = Trv\rho * 2$

$VM\rho \approx\downarrow (Td * Nv\rho) / Tv\rho \in \mathbb{Z}$

Mathematical Model:

Objective Function:

$$Minimize \sum_{i=1}^{n}\sum_{j=1}^{m} Cfij\, Yij + \sum_{i=1}^{n}\sum_{j=1}^{m} Cuij\, X\rho ij + \sum_{i=1}^{n}\sum_{j=1}^{m} Cf\rho ij\, Z\rho ij \quad \forall\, \rho$$

Constraints:

s.a

$$\sum_{i=1}^{n} Yij = 1 \quad \forall\, j \tag{2}$$

$$\sum_{j=1}^{m} Cfij\, Yij \leq Cfmaxi \quad \forall\, i \tag{3}$$

$$\sum_{\rho=1}^{\delta}\left[\sum_{j=1}^{m} X\rho ij\right] \leq \; ai \quad \forall\, i \tag{4}$$

$$X\rho ij \;\leq\; bj\, Yij \quad \forall\; i,j,\rho \tag{5}$$

$$\sum_{\rho=1}^{\delta}\left[\sum_{i=1}^{n} X\rho ij\right] = bj \quad \forall\, j \tag{6}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} X\rho ij \;/\; C\rho \;\leq\; VM\rho \quad \forall\, \rho \tag{7}$$

$$X\rho ij \;\leq\; M\, Z\rho ij \quad \forall\; i,j,\rho \tag{8}$$

$$X\rho ij \;\geq 0 \tag{9}$$

$$Yij, Z\rho ij \;\in \{0,1\} \tag{10}$$

4.3. Phase 2 Approach

In this phase, we want to determine a set of routes for a fleet of vehicles that start from a tank or platform in this case, to satisfy the demand of several customers, geographically dispersed in a region. The main objective is to deliver the demand to all customers by minimizing the total distance generated by the routes, having a fleet of vehicles with a certain transport capacity. Each route is made by a single vehicle that starts and ends on the platform so that customer requirements and operational restrictions are met; essence of VRP [30], [31]. It is important to note that the nodal network on which the routing was performed is of an asymmetric type, since the distance between the logistics platform "i" and the shopkeeper's center "j" is not the same in both directions, say *dij ≠ dji* [32]. By using a VRP model, optimized trajectories are obtained with which cost and time savings are achieved [34]. In this phase, the routing of the vehicles is defined below their maximum capacity for the dispatch of the remaining products to be distributed, after they are shipped in vehicles loaded at 100% capacity (Phase one).

Next, the mathematical model of the TSP is derived from the formulation proposed by Miller, Tucker and Zemlin taken from [33], [34] and [35]. Equation (1) represents the objective function, minimizing the cost associated with the total distance traveled. The restriction (2) indicates that only one time is reached at each node, (3) assures that the vehicle only leaves only once from each node, (4) eliminates the formation of subtours, (5) establishes the dimensions for the variable U_i, and (6) sets the binary condition of the variable:

Sets:

U_i = starting node

j = arrival node

Parameters:

C_{ij} = Transfer distance from node i to node j

n = Number of CTs to make the delivery (nodes)

Variables of the Model:

X_{ij} = Decision variable, is defined as follows

$$X_{ij} = \begin{cases} \text{1, if the node i is connected to a node j} \\ \text{0, otherwise} \end{cases}$$

U_v= Real fictitious variable that defines the stage in which a respective node of the set V is visited

The asymmetric problem of the Traveling Agent can be defined in a graph G = (V, E), where V = {0,1,2,3, ..., n} represents the set of nodes and E = {i, j} the set of arches.

Mathematical Model:

Objective Function:

$$Minimize \sum_{i=0}^{n} \sum_{j=0}^{n} C_{ij}\, X_{ij} \tag{1}$$

Constraints:

s.a.

$$\sum_{j=0}^{n} X_{ij} = 1 \quad \forall\ i \tag{2}$$

$$\sum_{i=0}^{n} X_{ij} = 1 \quad \forall\ j \tag{3}$$

$$U_i - U_j + (n-1)X_{ij} \ \leq\ n-2 \quad \forall\ i.j\ \in\ V : i,j \geq 0, i \neq j \tag{4}$$

$$U_i \geq 0 \tag{5}$$

$$X_{ij}\ \in\ \{0,1\} \qquad \forall\ (i,j) \in E \tag{6}$$

5. RESULTS

The model was run in the Gams application, obtaining the assignments of the loads to be transported from each of the three platforms to the 27 shopkeeper's centers (CTs) located by each Zone Planning Unit (ZPU) in the four study locations; this was done by type of vehicle, sees Figure 2.

As shown in Table 3, the Lucero platform (P1) in the locality of Ciudad Bolívar is assigned to supply 11 CTs, equivalent to 100% of its own locality, with 8 Type 1 vehicles of 5200 kg and 1 Type 2 vehicle of 9000 kg, in addition to 1 CT of the locality of Bosa (ZPU Apogeo) and 1 CT of the locality of Usme (town of Usme); Bosa's platform supplies 4 of 5 CTs, 80% of its own locality, with 37.27% distributionin Type 1 vehicles and 62.3% in Type 2 vehicles; Finally, the Usme platform supplies 6 of 7 CTs equivalent to 85.7% of its locality, in addition to 6 CTs in the locality of San Cristóbal.

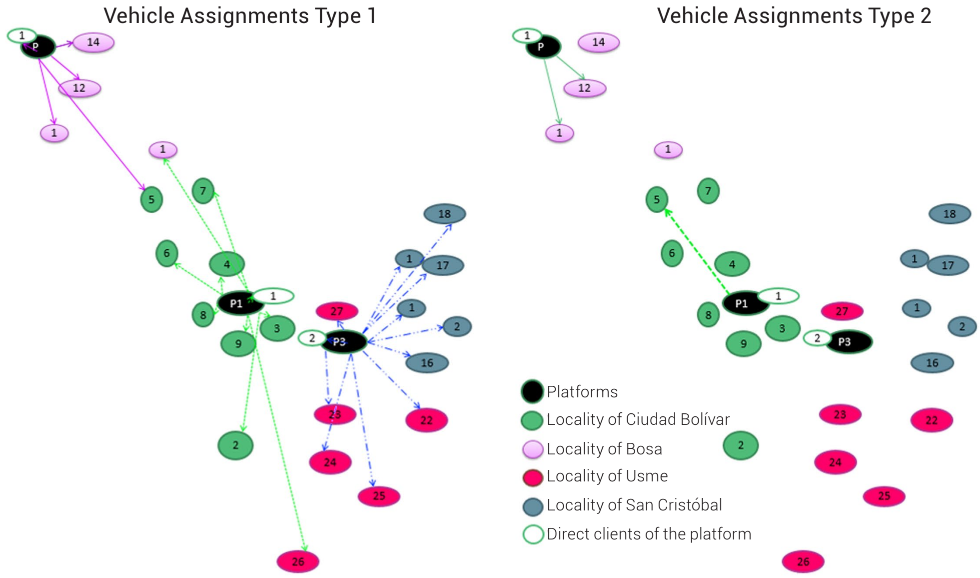

Figure 2. Assignment of Loads to be transported by Type of Vehicle
Source: Own work

Faced with the results of Phase 1 of the logistics operation, the following summary data is available for each of the platforms: for the Luceros, 11 CTs were supplied, covering 38.1% of the total demand, while the platform of Usme supplied 12 CTs (6 from the town of San Cristóbal and 6 from its own locality) covering 40.3% of the total demand, while the Bosa platform supplied 4 CTs with 21.7% of the total demand, all from the same locality of Bosa. With these results, it can be seen that the Bosa platform, even though it has the highest supply capacity, was the one with the lowest load allocation.

Based on these assignments, the number of vehicles to be used loaded to 100% of their capacity was defined, thus having a requirement of 42 Type 1 vehicles to make the distribution from the silver-shape of the stars, of which 38 would be used in Ciudad Bolívar, 3 to replace the Apogeo CT in Bosa and 1 for the Usme City CT in the town of Usme. Compared to the use of the Type 2 vehicle, 8 vehicles are required to meet the demand of the CT of Ismael Perdomo in the locality of Ciudad Bolívar.

Table 3. Summary of Cargo Assignments to be Transported by Platform and Vehicle Type

	Platforms Lucero				Platforms Bosa				Platforms Usme			
	Veh. Type 1		Veh. Type 2		Veh. Type 1		Veh. Type 2		Veh. Type 1		Veh. Type 2	
	kg./day	CT visied	kg./ day	CT visied	kg./day	CT visied	kg./day	CT visied	kg./day	CT visied	kg./ day	CT visied
L. Ciudad B.	214,331	8	79,586	1	0	0	0	0	0	0	0	0
L. Bosa	20,384	1	0	0	118,829	4	200000	2	0	0	0	0
L. Usme	5,626	1	0	0	0	0	0	0	138,207	6	0	0
L. San Cristobal	0	0	0	0	0	0	0	0	142,626	6	0	0

Source: Own work

For the Bosa platform, 20 Type 1 vehicles are required to supply 4 CTs of its same locality and 22 Type 2 vehicles to complete the demand requirement in the Central and Western Bosa CTs, distributed by 11 vehicles in each one respectively, all of them loaded to 100% capacity. On the other hand, the Usme platform requires 23 Type 1 vehicles to supply the demand of 6 of 7 CTs of its same locality and 25 remaining vehicles to meet the demand of 5 CTs in the town of San Cristóbal; this platform does not require the use of a Type 2 vehicle.

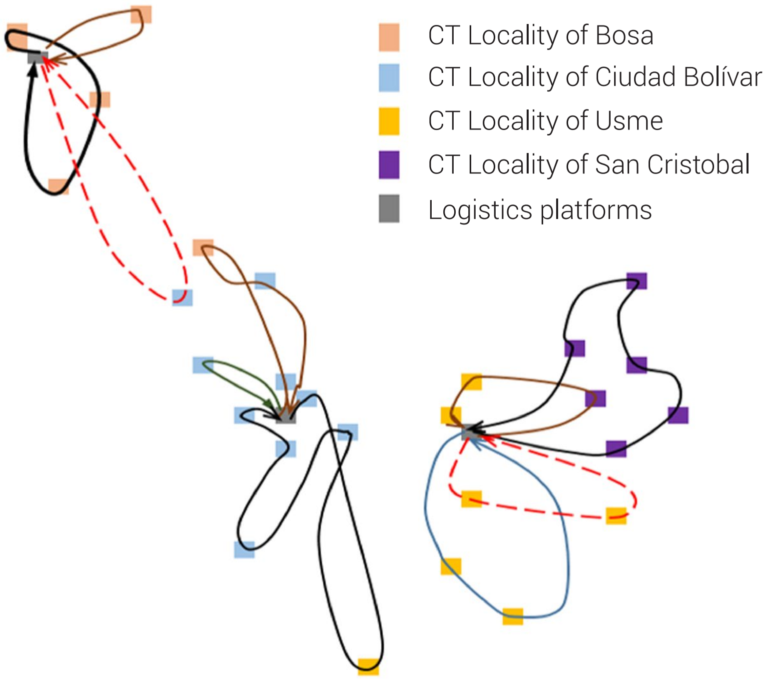

Figure 3. Definition of Routes for the Supply of Remaining Products
Source: Own work

The specific routes for each of the platforms can be seen in Figure 3. The optimal routes for the delivery of the remaining fruver products established in Phase 2 were obtained with Type 2 vehicles, with two exceptions, with the red dotted lines representing the Type 1 vehicles. For the platform of the Luceros of Ciudad Bolívar there are three routes: the first runs through 6 centers of CTs in the order 10-26-3-2-9- 8, the second travels to 3 CTs in the order 4-13-7, and the third travels to only one CT, number 6; all of them total a distribution of 29,531 kg. For the Usme platform, four routes were optimally defined: the first runs through 5 CTs in the order 21-20-22-23-19 all within the locality of San Cristóbal, the second route covers 3 CTs in the order 18-24-25, the third visits 2 CTs in the order 17-16, and the fourth travels to CTs 15-25; all of these total a distribution of 31,240 kg. It should be noted that the fourth one is performed out in a Type 1 vehicle of 5,200 kg of capacity. Finally, in the Bosa platform, 3 routes were defined: the first one travels to 3 CTs in the order 10-12-11, the second delivers only to CT 13, and the third to CT 5 of Ciudad Bolívar in a Type 1 vehicle. When this type of vehicle is used, it is because the amount of distribution is lower than its capacity, that is, 5,200 Kg

6. RESULTS DISCUSSION

When establishing a logistics design with a phased model, its analysis and structuring is simplified by first defining the allocation of loads to be transported, contemplating the activation of platforms or deposits to the different clients, and then establishing the specific routing through a VRP optimization model; the second phase simplifies the modelling of the time restrictions for transfer times and accessibility. Faced with the definition of specific routes, and particularly when working with very large systems, one can contemplate the use of heuristics or meta-heuristics as solution techniques.

On the other hand, it is important to bear in mind that the entire programming model of Phase 1 can contemplate the restriction of fixed costs per platform; and not only a fixed maximum cost limitation for the use of these, but also the variable of transfer times or distances between platforms and CTs. This makes the use of the model more flexible for the optimization of assignments to be made in Phase 1. For further work, it is important that the model considers the type of product, as a decision variable, in order to include various food chains. In this same context, the time variable of the distribution operation must be incorporated, with loading and unloading times so that the total time of the logistics operation can be defined.

In the review of the literature there are several documents published on trained problems, [36], [37], [38], [39], [40] as in the case of models with a heterogeneous fleet of vehicles [41], [42], [43] [44], of which only one considers the evaluation of routes for vehicles with multiple trips, with results against this technique [45]; however, the case of multiple deposits is not contemplated [46]. Nor are there jobs that cover fixed costs for both deposits and for the use of vehicles among existing models with a heterogeneous fleet in problems with multiple deposits [29]. All this makes this work very important as a contribution to the "phased" VRP technique for systems with the conditions discussed here.

7. CONCLUSIONS

A phased model has been developed that takes into account restrictive considerations of the system, such as the number of trips per type of vehicle, the time of travel, number and capacity per type of vehicle, the time available for transportation and the restriction of connectivity. A shopkeeper's center can be supplied by a single platform, which adapts very well to the characteristic behavior of the system, thus obtaining an application tool among the operations research models for the planning of the food distribution operation south of Bogotá.

The planning of the logistics supply operation through a model developed by phases applied to the localities of Bosa, Ciudad Bolívar, Usme and San Cristóbal in the south of Bogotá, helps subdivide its analysis into less complex parts for its representation and later modeling, obtaining results that are easier to incorporate into the operation, where the output information of the Phase 1 model serves as input information for the development of the Phase 2 model. In this way, a simpler analysis of the integer system is achieved, thus improving response times to the inherent dynamics and making the operation of food supply more efficient in the study areas. This strategy of system analysis provides a technical use of mathematical models in a focused manner for planning, which results in a quantitative tool for decision making and analysis of the food distribution system.

By establishing the design of the logistics operation through the use of mixed integer programming as a mathematical model of optimization, it is guaranteed to reduce the time and use of the resources involved in supplying fruits and vegetables to the localities under study; the goal established by the district in the Master Plan for Supply and Food Security of Bogotá. In this way, and according to the results of the model proposed in this paper with their respective considerations and Source values, a value of 1,237 million is taken as the cost of the daily supply operation without taking into account the cost of distribution for the remaining amounts established in the routing model.

The work is relevant as a contribution to phased routing techniques between models with a heterogeneous fleet in problems with multiple deposits, given that it covers fixed costs both for deposits and for the use of vehicles, with a two-phase model, that facilitates the management of the logistics operation of the food systems with the conditions discussed here.

REFERENCES

[1] Unidad Ejecutiva de Servicios Públicos UESP, "Documento soporte técnico del Plan maestro de abastecimiento de alimentos y seguridad alimentaria de Bogotá," Unidad Ejecutiva de Servicios Públicos UESP, Bogotá, pp. 59, 2005.

[2] Secretaría Distrital de Planeación de Bogotá, "Inventario de Información en Materia Estadística sobre Bogotá," Secretaria Distrital de Planeación, Bogotá, pp. 18, 2011.

[3] J. A. Orjuela Castro, H. A. Diosa and M. E. Calderón, *Sistema de Abastecimiento de Alimentos para Bogotá, Localidad Ciudad Bolivar, Primera fase: Diseño, Dimensionamiento e Implementación, UESP-UD*. Ed., Bogotá: Universidad Distrital Francisco José de Caldas, pp. 400, 2006.

[4] Secretaria de Desarrollo Económico, "Caracterizaciones de alimentos mercado comercial, mercado solidario," Universidad Distrital Francisco José de Cladas, pp. 34, 2010. [Online]. Available: http://www.alimentabogota.gov.co/index.php?option=com_phocadownload&view=category&id=30:mercado-comercial&Itemid=187.

[5] R. Hernández Sampieri, C. Fernández Collado and M. d. P. Baptista Lucio, *Metodología de la Investigación*, Mexico D.F.: Mc Graw Hill, pp. 92-93, 2014.

[6] A. Y. Estrada Perea, *Modelación de la Distribución del Transporte de carga por carretera de Productos Colombianos,* Universidad Nacional de Colombia, Ed., Medellín, Antioquia: Universidad Nacional de Colombia sede Medellín, pp. 17, 2008.

[7] D. Kalenatic, C. A. López Bello, L. J. González Rodríguez and F. J. Rueda Velasco, "Modelo para la localización de una plataforma de cross docking en el contexto de logística focalizada," *Ingeniería,* vol. 13, no. 2, pp. 36-44, 2008. doi: https://doi.org/10.14483/23448393.2668

[8] L. Liu, L. Xiaoming and D. D. Yao, “Analysis and Optimization of a Multistage Inventory-Queue System,” *Management Science,* vol. 50, pp. 365-380, 2004. doi: https://doi.org/10.1287/mnsc.1030.0196

[9] C. Li, “An analytical method for cost analysis in multi-stage supply chains: A stochastic network model approach,” *Applied Mathematical Modelling,* vol. 38, pp. 2819–2836, 2014. doi: https://doi.org/10.1016/j.apm.2013.10.056

[10] C. Li and S. Liu, “A stochastic network model for ordering analysis in multi-stage supply chain systems,” *Simulation Modelling Practice and Theory,* vol. 22, pp. 92–108, 2012. doi: https://doi.org/10.1016/j.simpat.2011.12.001

[11] L. B. Rocha M, C. Gonzalez L and J. A. Orjuela C, “Una revisión al estado del arte del problema de ruteo de vehículos: Evolución histórica y métodos de solución,” *Ingeniería,* vol. 16, no. 2, pp. 35-55, 2011. doi: https://doi.org/10.14483/23448393.3832

[12] J. R. Montoya Torres, J. López Franco, S. Nieto Isaza, H. Felizzola Jiménez and N. Herazo Padilla, “A literature review on the vehicle routing problem with multiple depots,” *Computers & Industrial Engineering,* vol. 79, pp. 115-129, 2015. doi: https://doi.org/10.1016/j.cie.2014.10.029

[13] R. Kulkarni and P. Bhave, “Integer programming formulations of vehicle routing problems,” *European Journal of Operational Research,* vol. 20, no. 1, pp. 58–67, April 1985. doi: https://doi.org/10.1016/0377-2217(85)90284-X

[14] R. Baldacci and A. Mingozzi, “A unified exact method for solving different classes of vehicle routing problems,” *Mathematical Programming,* vol. 120, no. 2, pp. 347-380, 2009. doi: https://doi.org/10.1007/s10107-008-0218-9

[15] S. Nieto Isaza, J. López Franco and N. Herazo Padilla, “Desarrollo y Codificación de un Modelo Matemático para la Optimización de un Problema de Ruteo de Vehículos con Múltiples Depósitos,” in Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning*: Proceedings of the 10th Latin American and Caribbean Conference for Engineering and Technology*, Panama City, 2012.

[16] R. Dondo and J. Cerda, “A cluster-based optimization approach for the multi-depot heterogeneous fleet vehicle routing problem with time windows,” *European Journal of Operational Research,* pp. 1478-1507, 2007. doi: https://doi.org/10.1016/j.ejor.2004.07.077

[17] R. Dondo, C. A. Mendez and J. Cerda, “The multi-echelon vehicle routing problem with cross docking in supply chain management,” *Computers & Chemical Engineering,* vol. 35, no. 12, pp. 3002–3024, 2011. doi: https://doi:10.1016/j.ejor.2004.07.077

[18] A. G. Kek, L. R. Cheu and Q. Meng, “ Distance-constrained capacitated vehicle routing problems with flexible assignment of start and end depots,” *Mathematical and Computer Modelling,* vol. 47, pp. 140–152, 2008. doi: https://doi.org/10.1016/j.mcm.2007.02.007

[19] C. Contardo and R. Martinelli, “A new exact algorithm for the multi-depot vehicle routing problem under capacity and route length constraints,” *Discrete Optimization,* vol. 12, pp. 129–146, 2014. doi: http://dx.doi.org/10.1016/j.disopt.2014.03.001

[20] F. Cornillier, F. Boctor and J. Renaud, “Heuristics for the multi-depot petrol station replenishment problem with time windows,” *European Journal of Operational Research,* vol. 220, pp. 361–369, 2012. doi: http://doi:10.1016/j.ejor.2012.02.007

[21] A. Hueso and M. J. Cascant, Metodología y Técnicas Cuantitativas de Investigación, Valencia España: Ed Universitat Politécnica de Valencia, pp. 4, 2012. http://hdl.handle.net/10251/17004

[22] L. Poleo Castillo, “La Holística y la Investigación,” *UCSAR,* vol. 1, no. 1, pp. 101-113, 2009.

[23] J. M. Izar Landeta, *Investigación de Operaciones*, Ciudad de Mexico: Trillas, 2ª Edición, pp. 178, 2014.

[24] Herrera, O. and Fonseca, I. “Model of Transhipment and Routing Applied to the Cargo Sector in Small and Medium Enterprises of Bogotá, Colombia,” *International Journal of Industrial and Manufacturing Engineering*, 12(5), pp. 622 - 628, 2018. doi: http://doi.org/10.5281/zenodo.1316716

[25] S. N. Kumar and R. Panneerselvam, “A Survey on the Vehicle Routing Problem and Its Variants,” *Intelligent Information Management,* vol. 4, pp. 66-74, 2012. doi: http://doi:10.4236/iim.2012.43010

[26] O. Díaz Parra and M. A. Cruz Chavez, “El Problema del Transporte,” *Centro de Investigación en Ingeniería y Ciencias Aplicadas*, Cuernavaca, Morelos, pp.1, 2006. [Online]. Available: http://www.gridmorelos.uaem.mx/~mcruz/surveykoko.pdf

[27] S. Chopra and P. Meindl, *Administración de la Cadena de Suministro. Estrategia, planeación y operación*. Nacaupal de Juárez: Pearson Educación 5ta Edición, pp. 51, 2008.

[28] S. Samanta and M. K. Jha, "Multi depot probabilistic vehicle routing problems with a time window: Theory, solution and application," in *Optimizing, Innovating, and Capitalizing on Information Systems for Operations*, IGI Global, pp. 151, 2013. doi: http://doi:10.4018/Joris.2011040103

[29] J. R. Montoya Torres, "Planeación del transporte y enrutamiento de vehículos en sistemas de producción. Panorama actual de trabajos y algunas proposiciones," *Revista Científica Ingeniería y Desarrollo,* no. 13, pp. 85-97, 2003. [Online]. Available: https://www.redalyc.org/articulo.oa?id=85201307

[30] C. E. Torres Pérez, E. Olivares Benitez and J. L. Martínez Flores, "Revisión y programación de modelos de optimización como una plataforma en GAMS-CPLEX para problemas de ruteo de vehículos," in *IV Taller Latino de Investigación de Operaciones*, Puebla, Mexico, pp. 1, 2011.

[31] N. Herazo Padilla, "Modelación matemática del problema de ruteo de vehículos con restricciones de múltiples depósitos, flota heterogénea de vehículos y ventanas de tiempos," CUC, Barranquilla, pp. 39, 2012.

[32] A. Yepes Cañada, *Diseño de itinerarios para el reparto de gases embotellados mediante una flota heterogénea de camiones*. Barcelona España: Universitat Politécnica de Catalunya, pp. 16, 2014.

[33] E. M. Toro Ocampo, R. I. Bolaños and M. Granada Echeverri, "Solving the multiple traveling salesmen problem solved by heuristics," *Scientia et Technica ,* vol. 19, no. 2, pp. 174-182, 2014.

[34] M. D. Gracia, J. Mar-Ortiz and O. Laureano Casanova, "A Computational Analysis of the Traveling Salesman and Cutting Stock Problems," *Ingeniería Investigación y Tecnología,* vol. 16, no. 1, pp. 59-70, 2015.

[35] K. Stoilova y T. Stoilov, "Transportation modelling and solving Travelling Salesman problem," de *IOP Conf. Series: Materials Science and Engineering*, Sofia, Bulgaria, pp. 2, 2008. doi: http://doi:10.1088/1757-899X/878/1/012026

[36] K. Pinar, "An optimization algorithm for a capacitated vehicle routing problem with time windows," *Sadhana - Academy Proceedings in Engineering Sciences,* vol. 41, no. 5, pp. 519-529, 2016. doi: https://doi.org/10.1007/s12046-016-0488-5

[37] O. J Herrera Ochoa, P. A. Bedoya, A. F. Forero, "Diseño de Rutas Escolares a través de un Modelo Heurístico programado en Visual Basic," *Avances: Investigación En Ingeniería*, vol.18, no. 1, pp. 4, 2021. doi: https://doi.org/10.18041/1794-4953/avances.1.7395

[38] J. F. Cordeau, G. Laporte, M. W. Savelsbergh and D. Vigo, "Vehicle Routing," in *Handbooks in Operations Research and Management Science*, vol. 14, Amsterdam: North-Holland, In C. Barnhart & G. Laporte (Eds.), 2007, pp. 367–428. doi: https://doi.org/10.1007/978-0-387-77778-8_7

[39] M. Gendreau, G. Laporte and J.-Y. Potvin, "Metaheuristics for the capacitated VRP," in *The vehicle routing problem. SIAM moonographs on discrete mathematics and applications*, Philadelphia: SIAM, vol 9, In P. Toth & D. Vigo (Eds.), 2002, pp. 129-154. doi: https://doi.org/10.1137/1.9780898718515.ch6

[40] G. Laporte and F. Semet, "Classical Heuristics for the capacitated VRP," in *The vehicle routing problem. SIAM monographs on discrete matematics and applications*, Philadelphia: SIAM, vol. 9, In P. Toth & D. Vigo (Eds.), pp. 109-128, 2002. doi: https://doi.org/10.1137/1.9780898718515.ch5

[41] A. Şen and K. Bülbül, "A survey on multi trip vehicle routing problem," in *VI. International Logistics and Supply Chain Congress*, Istanbul, Turkey, pp. 2, 2008.

[42] R. Baldacci, M. Battarra and D. Vigo, "Routing a Heterogeneous Fleet of Vehicles," in *The Vehicle Routing Problem: Latest Advances and New Challenges*, Berlin, vol. 43, Springer US, pp. 3-27, 2008. doi: https://doi.org/10.1007/978-0-387-77778-8_1

[43] R. Baldacci, P. Toth and D. Vigo, "Recent advances in vehicle routing exact algorithms," *4OR. A Quarterly Journal of Operations Research,* vol. 5, no. 4, pp. 269–298, 2007. doi: https://doi.org/10.1007/s10288-007-0063-3

[44] R. Baldacci, P. Toth and D. Vigo, "Exact algorithms for routing problems under vehicle capacity constraints," *Annals of Operations Research,* vol. 175, no. 1, pp. 213–245, 2010. doi: https://doi.org/10.1007/s10479-009-0650-0

[45] G. Laporte, "Integer programming formulations for the multi-depot vehicle routing problem: Comments on a paper by Kulkarni and Bhave," *European Journal of Operational Research,* vol. 39, no. 2, pp. 227, 1989. doi: https://doi.org/10.1016/0377-2217(89)90107-0

[46] G. Nagy and S. Salhi, "Heuristic algorithms for single and multiple depot vehicle routing problems with pickups and deliveries," *European journal of operational research,,* vol. 162, no. 1, pp. 126-141, 2005. doi: https://doi.org/10.1016/j.ejor.2002.11.003