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Improving the distribution of food aid to soup kitchens in a locality of Lima. A localization and routing approach

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***Abstract–* This paper presents the formulation and solution of a mixed integer programming model with two phases, the location of food distribution centers (FDCs) and the routing of vehicles for food transportation to reduce the time and costs of the delivery of these goods from the FDCs to the soup kitchens that provide rations to beneficiaries living in monetary poverty in Villa El Salvador, a town in the city of Lima. Different numbers of distribution centers were evaluated to be in a range of four to twelve centers. Savings in the distance traveled in kilometers would range from 7% to 42% with respect to the current food logistics network used in that locality.**

***Keywords–* food insecurity, soup kitchens, mixed integer optimization, location, routing.**

I. Introduction

For several decades, the prevalence of hunger has declined globally; however, the number of hungry people continues to increase because the rate of reduction of hungry people was not sufficient to offset population growth [1].

More recently, one of the Sustainable Development Goals (SDGs) declared "zero hunger" in the world; however, contrasting that goal with some actual figures reveals a challenging current picture. According to the United Nations (UN), in 2022 about 735 million people - 9.2% of the world's population - would be chronically hungry [2]; while that figure was virtually unchanged from 2021 to 2022, it is still well above pre-COVID-19 pandemic levels [3].

A concept that predates the SDGs and is closely related to the goal of "zero hunger" is that of "food security" (FS); this definition highlights the importance of physical, social, and economic access to sufficient food for the individual [4]. Likewise, the Food and Agriculture Organization of the United Nations (FAO) proposes several dimensions of food security, one of which is the "physical availability of food", that is mean the supply that is a function of the level of production, imports, and storage [5, 6]. On the other hand, the FAO Committee on World Food Security refers a few lessons for the purpose of formulating more effective strategies for FS; one of them is to improve rural infrastructure, in particular, storage and transportation [1], both elements of logistics and in turn part of the food supply chain.

The logistics and supply chain for the delivery of nutritious food with an affordable price to vulnerable people has been confronted with various interim and multisectoral measures [7]. Organizations such as school food distribution programs, food banks, food pantries, soup kitchens, shelters, and philanthropic organizations. All of them advocates of the fight against hunger and with a strong voluntary character [8]. In general, these programs and organizations target their services, although not exclusively, to people living in poverty.

Examples of such organizations can be found in various parts of the world. In Florida, United States of America (USA), "Our Father's House Soup Kitchen" is a Christian non-profit organization that has been operating for more than 30 years and in that time has served more than 900 000 meals to people in poverty and delivers an average of 145 meals per day [9]. Also in the USA, "The Soup Kitchen" served 3 million meals and provides home delivery service for people with limited mobility or confined by terminal illnesses; in 2022 they prepared 162 220 servings [10].

In Canada, "The Soup Kitchen Niagara Falls Community Outreach" is a non-profit community organization that operates thanks to donations from churches, businesses, social clubs, and individuals in the community. That organization manages to serve about 148 people per day and in 2020 served about 54 000 people [11]. "The Salvation Army is a Christian organization that operates in 400 communities located in various parts of Canada and in 130 countries, where it provides various types of services such as food banks and conducts lunch programs for school children and community lunches. The latter in 2020 was 2,80 million lunches [12].

In Europe, the "Refugee Community Kitchen" aims to provide food to people in refugee camps in Calais and elsewhere in France. This organization supports its operations with the donations they receive, and operates in other places such as Northern France, London, and Edinburgh. To date they have served around 2 million meals [13]. In Barcelona, Spain, the "Arrels Foundation" provides breakfast, lunch, snacks, and dinner to homeless and destitute people. In addition, it provides shelter, refuge, and health care. This foundation receives donations from individuals and private entities and has a total of 400 volunteers and about 4 000 collaborators [14]. In London, United Kingdom, the "Soup Kitchen London" provides hot meals and donates clothes and toiletries to homeless, elderly, and poor people in the British metropolis [15]. This association serves about 90 people a day and delivers more than 25 000 meals a year [16].

In South America, the purpose of the "Caritas Internationalis" confederation is to promote and lead programs, projects, and interventions to benefit the poorest

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and most vulnerable populations of a country. It is made up of 165 organizations located in more than 200 countries and territories [17]. In Peru during the context of COVID-19 and in response to sanitary emergency declared by the Government to deal with the pandemic, the "Caritas Network in Peru" worked in coordination with Peruvian government agencies such as municipalities, platforms of the National Institute of Civil Defense and other organizations, to distribute humanitarian aid to as many people as possible. Thanks to the coordination of this network, it was possible to collect around 1,8 million dollars; likewise, the "Help us to Help" campaign collected donations valued at around 2,3 million dollars. As a result, the "Caritas Network in Peru" was able to assist more than 1,2 million families in vulnerable situations [18].

In Peru, vulnerable population with scarce economic resources to complete their dietary requirements is organized in the so-called "soup kitchens", which in terms of food distribution supply chains, means a place (home of a villager or community center) where the beneficiaries go to buy food at very low prices. Soup kitchens receive the food as raw materials and the villagers oversee the preparation of meals, they do not receive any payment for this activity. Usually, they are beneficiaries of the soup kitchen and neighbors too. The villagers regularly are females, themselves organize their activities; management, control and administration of the resources used (cooks, kitchen, space, utensils).

In Lima, the capital of Peru, one of its districts is "Villa El Salvador" (VES), a locality at south of Lima. This district is one of the most populous in the capital, with an estimated population of 423 887 inhabitants (in 2020). It is also one of the five districts with the highest monetary poverty in Lima: 20,1% of its inhabitants live in this situation [19].

VES Municipality operates a food logistics network consisting of a Food Distribution Center (FDC) that sends food via vehicles to local FDCs near the soup kitchens. These goods are then distributed from the local FDCs to the soup kitchens, of which there are more than 200 in the district.

This paper aims to contribute to the improvement of food aid delivery to soup kitchens located in VES, through the mitigation of two problems detected in their food distribution logistics network: inadequate delivery times and increased delivery costs. To this end, a mixed integer programming model with two phases is formulated, the first one determines the location and quantity of the distribution centers, and the second one measures the impact of the location in terms of the distance that would be traveled from the distribution centers to the soup kitchens. Mitigating both problems is relevant because the reduction of delivery times contributes to the timely provision of food, an aspect referred to in the Law on Food and Nutritional Security in Peru in the dimension of "availability" [20]. Also, reducing delivery costs is in line with one of the relevant aspects of food security: economic access to food. And contributes to the life span of foods extension, ensuring the quality and freshness of meals.

The remainder of this article is organized as follows. Section II presents the literature review in two parts. In the first part, we review the history of soup kitchens in Peru, the reasons for their creation and their purposes. In the second part, a review of some location and routing models is presented. Section III shows the VES soup kitchen operations and problems. Section IV presents the methodology for the design of the mixed integer programming model and the assumptions made for this formulation. Then, Section V presents the model with two phases: the first one for the location of distribution center facilities and the second one for the routing of vehicles between distribution centers. Section VI presents the solution of the model and the discussion of the results in contrast with the current situation of the VES logistics network. Finally, Section VII summarizes the conclusions as well as future research directions.

II. LITERATURE REVIEW

A. The soup kitchens in Peru

The soup kitchens are social organizations that emerged in Peru in the 1970s in a context of deteriorating purchasing power [21]. They are recognized in Peruvian law as units of entrepreneurship for production whose main activity is the preparation of food and social support; their target population is people in vulnerable situations [22]. These social organizations proliferated in the 1980s in several areas or districts of Peru with high levels of poverty in VES in 2022 there are more than 200 soup kitchens [23].

The soup kitchens play a fundamental role in the fight against hunger in Peru because they provide very low-cost rations that are achieved with savings in the purchase of food and inputs on a larger scale; the subsidies transferred to them by the Peruvian State; the subsidy of the labor force that comes from organized women and the way in which the organization operates [21]. The low costs of the rations provided to the population contribute to the fulfillment of economic access to food for a portion of the population in vulnerable situations in Peru; according to FAO, this economic access is one of the requirements to achieve FS. However, it should be noted that combating food insecurity is not limited to the work carried out by soup kitchens but is a broader and more complex challenge to meet the four dimensions and achieve the objectives of food security referred to by FAO: (1) physical availability of food, (2) economic access, (3) utilization of food, and (4) the stability of the three previous dimensions [5]. A study conducted by the UN determined that Peru between 2019 to 2021 suffered the highest moderate and severe food insecurity in South America [24]; those findings suggest that Peru is still far from achieving the objectives of food security.

B. Facilities location

Warehouse location is a problem that has been investigated by several authors and there is a diversity of models that consider different situations that originate from the change in demand behavior; the variety of products; the cost of locations; warehouse capacity and others. Some developed optimization models are presented, which were reviewed to be used as a reference for the solution proposed in this work.

One of the models is the "Multi-Product Capacitated Plant and Warehouse Location Model" proposed by Pirkul and Jayaraman that contemplates a group of customers demanding multiple products [25]. Those goods are moved from manufacturing plants to warehouses and then to customers. The objective of the model minimizes the fixed costs of warehouses and plants, as well as transportation costs. Also, the model obtains a customer/warehouse and warehouse/plant allocation. Some of the assumptions are that the location and customer demand are known; the number of plants and warehouses to be installed is also known, and that one warehouse can meet the demands of one customer; however, a warehouse can have several suppliers. On the other hand, in the "Fixed Charge Facility Location Problem" the locations and customer demand are known, as well as the unit cost of shipping between a candidate site and a given customer. In addition, a set of candidate locations for distribution centers and their fixed location costs are known. The objective of the model is to reduce the combined location and shipping costs between distribution centers and customers, considering the transfers of multiple products from plants to distribution centers [26].

The Stop-and-Drop Problem model involves one or more depots with known locations and a set of sites that are candidates for the location of the pickup site to which consumers will go to pick up the goods they demand. The vehicles to be used depart only from the depot to the pickup sites selected by the model from among the candidates. In addition, each consumer is assigned a single pick-up site, which are connected to the depots and function as distribution centers. The model seeks to reduce vehicle routing costs and consumer travel costs by assuming that the transportation costs between the depot and the pickup sites and from the consumers to the pickup sites are known, as well as the locations of the candidate sites and the number of consumers. This model was used for resolving a solution for an nonprofit food organization under three different approaches: "the two-phase sequential approximation algorithm"; "Linear programming relaxation-based Bender's decomposition algorithm" and "Logic-based Bender's decomposition heuristic". Of the three methods, the second one generated better result in terms of total cost; however, the disadvantage is that it is the second one that takes more time to obtain a solution [27].

C. *Vehicle routing*

Routing design is influenced by several variables such as vehicle capacity, vehicle types, time windows, and others. The Ekram Vehicle Routing Problem (EkVRP) is a variant of the VRP model proposed for Ekram, this was applied to non-profit organization located in Saudi Arabia, which set out to collect surplus food from donors, place it in warehouses, and then distribute it to people in need. The model aims to reduce the time and effort involved in the surplus collection process. Also, the model assumes only depot (donors) and demand (recipients) nodes and uniform vehicle capacity. The model simulates the execution of two models: a random method and the EkVRP. The indicators obtained showed that the EkVRP provided better results than the random method, both in terms of time and distance and the number of vehicles required [28].

Similarly, the "Unpaired Periodic Pickup and Delivery Vehicle Routing Problem or Unpaired Periodic PDVRP" used to propose a solution to an USA Food Bank distribution assumes that all vehicles start and end at depot "0" whose supply and demand are zero. Each delivery node would be served on as many days as it requires during a given time; however, it is only visited once a day by a single vehicle that picks up and delivers a single product. The product collected from the pickup nodes can be sent to any delivery node, i.e., there are no pairing restrictions. Routes start and end at the depots, therefore, vehicles do not have to return to the depots to load or unload product. The maximum number of routes per day does not exceed the total number of vehicles and the total distance traveled by each vehicle also does not exceed the allowed limit. The model considers a time horizon in days during which the demand of the nodes is served and for each day an assigned schedule is established [29].

III. OPERATIONS AND PROBLEMS OF THE SOUP KITCHENS IN VES

The municipality of VES contracts annually a set of food suppliers who distribute food to the FDC managed by the municipality and in some cases go directly to the local FDCs, in either case these shipments are made by transport carriers. For food supply, municipality staff and suppliers verify the quantity and quality requested. Then the food is delivered following predefined routes where a certain number of local FDCs are located, whose location is known beforehand; these local FDCs are usually located in soup kitchens installed or in Community Centers where soup kitchens also operate, it is from these local FDCs that the food supplier with the control of the municipality delivers the food directly to each person in charge of the soup kitchen, who will use it as raw material to prepare their meals.

Other characteristics of the soup kitchens are that they are assigned a certain number of beneficiaries, with this figure it is possible to calculate the total amount of food needed by each soup kitchen based on the requirements of an already established diet. Since the demand of each soup kitchens assigned to each FDC is known, the amount delivered to that center is equal to the sum of the demands of the assigned soup kitchens plus the demand of the distribution center itself. In this way, the amount of food that each route must distribute during its route is established. On the other hand, the managers of the soup kitchens assigned to the FDCs organize the collection of food from FDC to the soup kitchen.

In the context described above, two problems affect the VES food supply network: long delivery times and delivery costs that are increased by the excessive travel of both suppliers and those responsible for the soup kitchens.

It is important to clarify that although the soup kitchens located in VES are not located in rural areas -places where the FAO advises to increase investment in storage and transportation infrastructure-, it is still relevant to contribute to the solution of delivery time and cost problems because in several urban areas of Lima, and particularly in the district of VES, soup kitchens play an important role in the fight against hunger and food insecurity in Peru. In other words, these social organizations contribute to the goal of achieving food security in the country.

IV. MODEL METHODOLOGY AND ASSUMPTIONS

The model proposed in this research is a mixed integer programming model with two phases.

The first phase consists of selecting the new locations for the distribution centers and then assigning each soup kitchen one of those centers.

The number of distribution centers varies in the range of 4 to 12 locations (pairs only), each value configures a scenario where the model is solved to then evaluate in the second phase how the number of centers impacts on the costs generated because of the vehicles' travel to the centers.

Some public spaces are chosen as candidates to locate “the distribution centers”; these places have the advantage of not causing additional costs in the logistics network. It is possible because in most cases, the carrier contracted by the food supplier delivers the products directly to the beneficiaries at an agreed location, this practice is feasible. Locations that are difficult to access or on the boundaries of the VES district are discarded. Straight lines are assumed to measure the distances between the municipality distribution center, FDCs and soup kitchens. For these calculations, their coordinates in the Cartesian plane are used as a reference and the municipality center is the point of origin, this is done to ensure the control of the food that the local authority carries out as promoters of the food support network in the locality.

Due to the difficulty of establishing reliable cost that are generated when vehicles travel on roads, distances are used as a measure of cost. Often in the literature of integer programming models of location and routing, both fees transport and distances are referred to as "costs", which are parameters that are multiplied by the decision variables (are penalized) in the minimization objective functions. Thus, the cost of shipping food from the general store to the distribution centers and the cost of assigning a soup kitchen to a distribution center is the distance between a starting point and the point of arrival. It is necessary to note again that a group of soup kitchens are assigned to a single distribution center, and so on for the rest of the groups.

The level of demand for each soup kitchen is constant and equal to the sum of the weight of food provided to them during a month.

The second phase consists of a vehicle routing model whose purpose is to find the optimal routes through which vehicles travel to deliver the goods demanded from the warehouse to each distribution center already located in the first phase and where the accumulated demand of each center is also determined. The model is run in the second phase for each of the scenarios of phase 1. With this information, a distance matrix (considering the general warehouse) is elaborated following the same criteria used to determine the distances in phase 1.

The point of departure and arrival for each of the routes is the general warehouse and it is assumed that there is one vehicle for each delivery route. The maximum load capacity of the vehicles is equal to the largest load currently transported per route.

V. PROPOSED TWO-MODEL PHASE

A. *First phase: Localization model*

The model proposed in the first phase (phase 1) to the context of the VES soup kitchen logistics network is an adaptation of the mixed integer program formulated by Pirkul and Jayaraman [25].

Phase 1 seeks to reduce the distances traveled by suppliers from the general warehouse to the distribution centers and the distances of the assigned soup kitchens to their corresponding center.

The set K = {k1, k2, ..., k242} contains the 242 nodes representing the soup kitchens. The set C = {c1, c2, ..., c122} contains the 122 nodes representing the places that are candidates (the "candidate locations") to locate the distribution centers. Also, i and j are nodes, and the pair (i, j) represents the arcs; $i \in K$ and $j \in C$.

Sj is the cost of shipping food from the general store to the candidate location j. Aij is the cost of assigning a soup kitchen i to candidate location j and Di is the demand for food at soup kitchen i. The variable Xj is the sum of the demands at location j. Zj is the binary variable that accounts for and identifies the locations j chosen to locate the distribution centers and Yij is the binary decision variable to assign canteen i to candidate location j.

The variable Xj is integer, Zj takes the value of 1 if location j is chosen to locate a distribution center and Yij takes the value of 1 when soup kitchen i is assigned to candidate location j and takes the value 0 otherwise.

N represents the number of distribution centers, the model is solved for each scenario defined by $N \in \{4, 6, 8, 10, 12\}$ to determine the costs and how they change as the number N changes.

The model for phase 1 is as follows:

Subject to:

$$\text{Min} \sum_{j \in C} S_j Z_j + \sum_{\substack{i \in K \\ j \in C}} A_{ij} Y_{ij} \tag{1}$$

$$\sum_{j \in C} Z_j = N \qquad N \in \{4, 6, 8, 10, 12\} \qquad (2)$$

$$X_j = \sum_{i \in K} D_i Y_{ij} \qquad \forall j \in C \qquad (3)$$

$$\sum_{j \in C} Y_{ij} = 1 \qquad \forall i \in K \qquad (4)$$

$$Y_{ij} \leq Z_j \qquad \forall i \in K, j \in C \qquad (5)$$

$$Y_{ij}, Z_j \in \{0, 1\} \qquad \forall i \in K, j \in C \qquad (6)$$

$$X_j \geq 0 \qquad \forall j \in C \qquad (7)$$

The two costs in the objective function are as follows: the first is the shipping cost S which is the distance the supplier travels to deliver the goods from the general warehouse to the distribution centers. The second is the assignment cost A which is the distance corresponding to the assignment of the soup kitchen to a distribution center. Constraints (2) and (5) establish the number of distribution centers to be used. Constraint (3) establishes the demand Xj of each distribution center as the sum of the demands of its assigned soup kitchens which occurs when Yij is equal to 1 which also activates the sum of the distance Aij in the objective function. The set of constraints (4) ensure that a group of soup kitchens is assigned to a single FDC. In constraint (5) if the variable Yij takes the value of 1, then the variable Zj takes the value of 1 and triggers the sum of the distance Sj in the objective function. Finally, when Zj takes the value of 1 it informs about the candidate locations that have been chosen in the optimization to locate the distribution centers.

B. Second phase: routing model

The model proposed in the second phase (phase 2) is an adaptation of the VRP reviewed in [30].

Phase 2 seeks to obtain the optimal routes to travel to deliver the goods demanded by the soup kitchens and dispatched from the general warehouse to the distribution centers whose location is determined in phase 1 whenever Zj = 1.

The set DC = {0, 1, ..., N} contains the N nodes representing the distribution centers determined in phase 1, in particular, "0" is the general warehouse and is the starting node. In this model i and j are nodes whose arcs are (i, j); i, j ∈ DC and m is an intermediate node, i.e. m ∈ DC - {0}.

The parameter Lij is the distance to travel between distribution centers i, j; i ∧ j ∈ DC - {0}. In addition, V is the carrying capacity of the vehicle traveling the route; Rm is the total demand of distribution center m.

The integer variable Wm represents the cumulative demand when adding a distribution center m to the route and Tij is the binary decision variable representing the trip from distribution center i to center j which occurs when Tij is equal to 1.

The phase 2 model is solved on the scenarios obtained in phase 1 and is as follows:

$$\text{Min} \sum_{i,j \in DC} L_{ij} T_{ij} \qquad (8)$$

Subject to:

$$T_{mm} = 0 \qquad \forall m \in DC - \{0\} \qquad (9)$$

$$\sum_{\substack{i = \\ (i \neq m) \wedge \\ (i = 1 \vee (R_i + R_m \leq V))}} T_{im} = 1 \qquad \forall ; m \in DC - \{0\} \qquad (10)$$

$$\sum_{\substack{j = \\ (j \neq m) \wedge \\ (j = 1 \vee (R_j + R_m \leq V)}} T_{jm} = 1 \qquad \forall ; m \in DC - \{0\} \qquad (11)$$

$$R_m \leq W_m \leq V \qquad \forall m \in DC - \{0\} \qquad (12)$$

$$W_m \geq W_i + R_m - V + V\,(T_{mi} + T_{im}) - T_{mi}(R_m + R_i)$$

$$\forall i, \forall m; i \neq m; i \neq 1; (i, m) \in DC - \{0\} \qquad (13)$$

$$W_m \leq V - T_{0m}(V - R_m) \qquad \forall m \in DC - \{0\} \qquad (14)$$

$$W_m \geq R_m + \sum_{i \in DC - \{0\}} R_i T_{im} \qquad \forall m \in DC - \{0\} \qquad (15)$$

$$T_{ij} \in \{0, 1\} \qquad \forall (i, j) \in DC \qquad (16)$$

$$W_m \geq 0 \qquad \forall m \in DC - \{0\} \qquad (17)$$

The objective function minimizes the total distance of the delivery routes. Constraint (9) prevents the vehicle from entering the loop by visiting the same distribution center and does not consider the warehouse. Constraint (10) sets the warehouse as the starting point and causes the arc from i to m to be used as long as the sum of the demands does not exceed the vehicle capacity. Constraint (11) sets the warehouse as the arrival point and operates similarly to constraint (10). Together (10) and (11) establish the possible combinations of routes starting and ending at the general warehouse, with m being an intermediate node. Constraint (12) limits the range of the value of the accumulated demand at center m: it must not exceed the vehicle capacity V and its minimum value at is greater than or equal to the demand Rm of a center. Constraint (13) ensures that the accumulated demand when traveling to a new point is equal to the accumulated demand at the previous point, plus the demand of the added point; additionally, the constraint prevents the reuse of the same arc (if that were to occur the constraint contradicts itself -it is false-, therefore, (13) avoids that situation). Constraint (14) accumulates the demand when traveling from the warehouse to center m and fixes that this accumulated demand is that of center m; this because at that node, other distribution centers have not yet been visited. Finally, constraint (15) establishes that the accumulated demand if m is visited after visiting point i, must be greater than or equal to the sum of the individual demands of each center.

VI. Solution of the model and discussion of results

The models for both phases were formulated in the AMPLIDE software modeling language and the solution is obtained with the CPLEX 20.1 solver.

The solution of the phase 1 location model specifies both the candidate locations chosen to locate the distribution centers and the soup kitchens assigned to them to supply them with the goods (food) they demand. With these results, the distance traveled by the soup kitchens to pick up their food is determined, as well as the distances traveled from the warehouses to the distribution centers chosen in the location.

Then, with the solution of the routing model of phase 2, the number of routes through which the vehicles travel and the sequence of delivery to each distribution center are obtained. With this information, the distance traveled by the suppliers to deliver the food is calculated.

Table I shows the distance traveled by the vehicles from the soup kitchens to their assigned distribution center ("distance traveled by the soup kitchens"); the distances traveled by the suppliers' vehicles from the general warehouse to the distribution centers ("distance traveled by the suppliers"); the total distance, which is the sum of both; and the number of routes.

TABLE I
Results obtained each scenario

Number of distribution centers (scenario)	Distance traveled by soup kitchens. (km)	Distance traveled by suppliers. (km)	Total distance traveled. (km)	Number of routes
12	122,6	24,9	147,5	3
10	133,6	25,1	158,7	3
8	148,4	25,0	173,4	3
6	172,5	23,2	195,7	3
4	213,1	25,3	238,4	4

The current situation of the VES logistics network has the following characteristics: deliveries to the soup kitchens are made monthly; two routes are served per day; four delivery routes are traveled, and eight distribution centers are installed to serve the 242 soup kitchens. In this network, 256,4 km are currently covered, the structure of which is 227,6 km on the part of the soup kitchens and 28,8 km on the part of the suppliers.

The proposed mathematical model shows that the current locations of the VES FDCs and the soup kitchens assignments that currently operate are inefficient for the following reason: with the new eight FDC proposal by the solution found, the total distance that would be traveled according to the results of the model is 173,4 km (see Table I). However, in the current situation, 256,4 km are traveled, i.e., about 32% more kilometers traveled.

Table I also shows that with 4, 8 and 10 distribution centers the distance traveled by the supplier is very similar to that with 12 centers, but with 6 centers the distance traveled is less; however, it does not compensate for the greater distance traveled by the canteens (172,5 km) with respect to the 122,6 km when there are 12 centers located, which causes the total distance with 6 centers (195,7 km) to be greater than with 12 (147,5 km).

Another aspect observed in Table I is that the distance traveled by the supplier has a smaller impact on the total distance traveled, in contrast to the distance traveled by the canteens, which is significantly greater.

Table II summarizes the percentages of savings generated by the model solution with respect to the current situation for the different scenarios.

TABLE II
Savings percentage by scenarios

Number of distribution centers (scenario)	Savings distance traveled by soup kitchens.	Savings distance traveled by suppliers.	Total savings distance traveled.
12	46,1 %	13,7 %	42,5 %
10	41,3 %	12,9 %	38,1 %
8	34,8 %	13,2 %	32,4 %
6	24,2 %	19,4 %	23,7 %
4	6,4 %	12,2 %	7,0 %

Table II shows that the savings in total distance traveled in the scenarios evaluated range from 7% to 42%. In particular, the scenario with 12 distribution centers generates the greatest savings in total distance compared to the rest of the scenarios, which is equivalent to 109 km of savings. It should be noted again that the distribution centers are public places that do not generate additional costs to the network; therefore, the public budget is not a limiting factor for the implementation of this scenario.

VII. Conclusions

With the mixed integer programming model with two phases, it was determined in all the scenarios evaluated, location and routing proposals with a shorter distance traveled than in the current VES logistics network composed of the general warehouse, the distribution centers, the soup kitchens, and the routes that are traveled. With the implementation of the scenario with 12 distribution centers, 109 km less would be traveled than in the current situation of the VES logistics network, that saving is about 42%. Therefore, with the proposals obtained with the solution of the model, the objectives of this research are achieved: to reduce delivery times and costs; in both cases, through a shorter distance to be traveled.

On the other hand, with respect to the contribution to food security, firstly, the shorter transfer time of food resulting from shorter routes to be traveled contributes to improving the timeliness of food delivery to soup kitchens. Secondly, the shorter distance traveled has the effect of reducing the cost of transportation; this superior performance contributes to more economical access to food. In conclusion, it can be stated that the model solution proposed in this research would at least contribute to preserve or perhaps strengthen the food security of VES because the dimensions of "food availability" -and particularly timely availability- and "economic access" that underline directly the time and cost reduction that would be achieved with the implementation of the model solution and indirectly quality of meals avoiding food losses through an extensive food chain.

Finally, a recommended future research is the exploration of metaheuristic approaches to obtain the impacts in terms of distances because of the increased number of distribution centers to be installed. As the number of centers increases, it is more likely that the problem of computational complexity in the solution of integer programming models. Also, this research did not incorporate the remaining two dimensions of food security: "utilization" and "stability", as FAO points out [5], need to be realized simultaneously to achieve the objectives of food security.

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