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Design of an optimization model for fruits and vegetables supply from agricultural farms to a district's primary schools

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The implementation of a School Feeding Program, that provides lunch during the scholar year, can benefit to the primary school by the better performance and assistance of their students. But in some countries, like in Paraguay, the lack of efficient mechanisms in the supply management can affect the correct operation of the program [1]. For the case of fruits-and-vegetables supply from agricultural family farms to the schools in a city [1], this work approaches it as a Vehicle Routing Problem with Pickup and Delivery (VRPPD) but considering the product purchase problem at the same time (VRPPD+PP).

Given the VRPPD is complex, we proposes to solve it in two consecutive parts: the VRP with Pickup and Product Purchase(VRPP+PP), and then the VRP with Delivering (VRPD). In the first part, a Linear Programming Mathematical model was developed [2] to find the optimum recollection route of products harvested in family farms subject to the truck maximum capacity. In the second part, VRPD is the classical Traveling Salesman Problem (TSP) given that only is necessary one truck and all primary school have to be visited one time for our real context. Therefore, the standard TSP model is taken of [2] and is not explained given that it was extensively studied in the literature.

Let G = $[N, A, Ct, Cp]$ be a complete non-directed graph, where N is a set of nodes, A is a set of arcs, Ct is the transportation cost and Cp is the product cost. The parameters are the quantity of products k that each farm i provides ($ofer_{ik}$), the quantity of product k required for each school (dem_k), the cost of buying products from each farm ($costp_{ki}$), the cost of products transportation from farm i to farm j ($costot_{ij}$), the capacity of the transportation truck (cap), a high cost for purchases made from another city ($cext$) and a very large number (M). The variables are: quantity of product k to be transported from farm i to farm j (x_{kij}), the binary variable that takes value 1 if the arc (i, j) is used, and 0 otherwise (y_{ij}), the additional quantity of product k to be bought to meet the demand ($xext_k$) and the auxiliary variable for the no generation of sub-tours (u). The following is the proposed model for VRPP+PP:

$$\text{Min } Z = \sum_{k=1}^{K}\sum_{i=1}^{N}\sum_{j=1}^{N} x_{kij} * costp_{ki} + \sum_{i=1}^{N}\sum_{j=1}^{N} y_{ij} * costot_{ij} + \sum_{k=1}^{K} xext_k * cext \tag{1}$$

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subject to:

$$\sum_{\substack{j=1\\ j\neq i}}^{N} y_{ij} \leq 1 \qquad \forall i = 1,2,\dots,N \tag{2}$$

$$\sum_{\substack{i=1\\ i\neq j}}^{N} y_{ij} \leq 1 \qquad \forall j = 1,2,\dots,N \tag{3}$$

$$x_{kij} \leq ofer_{ik} \qquad \forall i,j = 1,\dots,N; k = 1,\dots,K \tag{4}$$

$$\sum_{\substack{i=1\\ i\neq s}}^{N} y_{is} - \sum_{\substack{j=1\\ j\neq s}}^{N} y_{js} = 0 \qquad \forall s = 1,\dots,N \tag{5}$$

$$\begin{aligned} &u_i - u_j + n * y_{ij} \leq n-1 && \forall i \neq j; j \neq 1\\ &u_1 = 1 && \\ &2 \leq u_i \leq n && \forall i \neq j \end{aligned} \tag{6}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} x_{kij} + xext_k = dem_k \quad \forall k = 1,\dots,K \tag{7}$$

$$\begin{aligned} &\sum_{i=1}^{N} y_{i1} = 1\\ &\sum_{j=1}^{N} y_{1j} = 1 \end{aligned} \tag{8}$$

$$\sum_{k=1}^{K}\sum_{i=1}^{N}\sum_{j=1}^{N} x_{kij} \leq cap \tag{9}$$

$$x_{kij} \leq M * y_{ij} \qquad \forall k,i,j; k = 1,\dots,K; i,j = 1,\dots,N \tag{10}$$

$$\begin{aligned} &x_{kij} \ \geq 0 && \forall k,i,j; k = 1,\dots,K; i,j = 1,\dots,N\\ &y_{ij} \in \{0,1\} && \forall i,j; i,j = 1,\dots,N \end{aligned} \tag{11}$$

The objective function (1) minimizes the total cost of products purchase and transport relative to the farms. Constraints (2) and (3) ensure that each farm is visited at most once. (4) does not allow to exceed the offer of each product in each farm; (5) indicates that the truck must leave the farms to which they arrived. (6) ensures the non-formation of sub-tours and (7) represents to fulfill the demand for each product. With (8), the tour start-and-end at the same node (warehouse) is ensured, (9) indicates that the capacity of the collection truck should not be exceeded. (10) allows the activation of the variable related to the transport. Finally, (11) represents the nature of the variables.

Solving both models for one district with 60 family farms and 14 schools in Paraguay, an optimal plan of the decisions of purchase, collection and distribution of fruits and vegetables is calculated. The optimal minimum cost is USD 10,912.15. Approximately 92% of the costs correspond to the purchase and collection of products from family farms (first part) and 8% to the distribution to schools (second part). In addition, the product quantities that have to be purchased externally (to the district) to fulfill the local demand was obtained.

References

[1] Resolution No. 15.866. *Administrative technical guidelines and standards for the implementation of the school feeding program*, Asuncion, Paraguay, 2015.

[2] G. Dantzig and R. Fulkerson and S. Johnson. *Solution of a large-scale traveling-salesman problem*, Operations Research, 1954, 2, 393–410

