URBAN FARMING COORDINATED LOGISTICS AND TRANSPORTATION OF FARM PRODUCE

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Abstract

Urban farming is important for food security and addressing socio economic challenges. Urban framing yields small crop sizes and is spread out throughout the city. Farming can be done year round under controlled conditions. There is the challenge of collecting the farm produce and getting it to the market within some economic constraints. In this project we model the problem as a split multi-commodity vehicle routing problem. The model allows a coordinated logistics and transportation of farm produce. The preliminary results obtained using a heuristic method (local search 2-opt technique) are promising.

1 Introduction

Around the world, urban farming has significantly increased, Johannesburg is no exception to this phenomenon. Food gardens are springing up on the inner city roof-top. The motivation is due to basic food security, employment creation and a multitude of socio-economic opportunities. Unlike traditional farming, urban farming yields small crop sizes and is spread throughout the city. It can be done year round as it is farmed under controlled conditions. Plants are grown in greenhouses to protect them from extreme temperatures, wind and pests. The produce of farms has to be collected and transported to the market. There is a large number of small farms in contrast to the norm of one or

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two large farms. These farms are often not in close proximity with each other. As such there is a challenge of collecting the farm produce from the farms and getting it to the market within some economic constraints.

The challenge is mainly due to lack of coordination among the farmers. Urban farmers, spend considerable time in coordinating logistics and transporting their produce to the market. A sizeable amount of their produce is destroyed before it reaches its destination. In business terms this translates to a significant lost of revenue. There are a few options that can be taken to address this challenge.

Firstly, a coordinated system has the potential of improving the logistical operations of the farmers giving them time to focus on cultivation and processing of their crops. A coordinated system that optimizes the routes between farms during collection of produce is sought after. This problem forms the basis of the well researched vehicle routing problem [1].

Secondly, since farming can be done throughout the year, farmers are required to optimize the planting and harvest times. This has to be coordinated over a large number of farms producing a range of products. Pricing of products at different times of the year may influence the amount of produce. Coordination among farmers will avoid overflow of the same product at the same time to the market. This can in turn increase the revenue of farmers. A predictive price model can be coupled with transportation of farm produce for a better coordinated logistics among farmers.

The report is organised as follows: In Section 2, we outline the problem. In Section 3, we present two approaches used to model the problem, a mathematical model and a heuristic model. Section 4 discusses the results obtained during the Study Group.

2 Problem statement

The challenge of coordinated logistics and transportation of farm produce is modelled as a classical vehicle routing problem with additional constraints. The specific vehicle routing problem consists of a fleet of capacitated heterogeneous vehicles available to serve a set of farms. Farms have known demand of collection of different produce. Different produce requires different vehicles, for example, strawberries require refrigeration which is not available in all vehicles. Thus there are two sets of vehicle capabilities: refrigerated vehicles and non-refrigerated vehicles. A refrigerated vehicle has the flexibility of carrying any set of produce. Each farm can be visited more than once and by different vehicles. The collection demand of each farm may be greater than the vehicle capacity. There is a single depot. Each vehicle must start and end its tour at the depot. The objective is to find a set of vehicle routes that serve all the farms such that the sum of produce collected in each tour does not exceed the capacity of the vehicle and increases the economic viability of transportation of produce. For simplicity we restrict the economic viability to minimizing the distance travelled by each vehicle.

3 Literature review

Vehicle routing problems have been studied extensively in the literature, dating back to 1959 when Dantzig and Ramser [1] introduced an algorithmic approach for petrol deliveries. Often the problem is in the context of delivering goods (having the same value) from a central located depot to customers, and each customer is required to be visited exactly once. There have been lots of variations, like the *split delivery vehicle routing* problem and the *multi-commodity vehicle routing* problem, which relate to the present problem.

In the split delivery vehicle routing problem the restriction that each customer has to be visited exactly once is removed, allowing split deliveries. The problem was introduced in the literature by Dror et al. [2, 3], who motivated that allowing split deliveries can generate savings. Applications of the split delivery problem includes the work of Mullaseril et.al [4] who discuss the problem of managing a fleet of trucks for distributing feed in a large livestock ranch. In [5] Archetti and Savelsbergh consider a waste collection problem where vehicles have a small capacity and customers have a collection demand larger than the capacity. Heuristic methods for solving the split delivery vehicle routing problem are presented in [2, 3]. Local search algorithms are proposed. For example, Archetti, Hertz and Speranza [6] present a tabu search and Archetti, Savelsberg and Speranza [7] present an optimization based heuristic.

The classical vehicle routing problem deals with goods assuming the same value. In contrast to the vehicle routing problem the multi-commodity problem considers goods to be of different value. Two classes of decisions are involved in this problem: routing vehicles to customers and quantifying commodities to be collected at each customer. Research done in this area includes the work of Letchford and Salazar-Gonzalez [8] and references therein for further related work.

4 Model formulations

In this section, we will present the model formulations that were discussed during the Study Group. We start by establishing the baseline model based on the local search technique. This gave suboptimal results. We will then present the mathematical model formulation based on the split multi-commodity vehicle routing problem. The model is expected to give optimal results if it can be solved efficiently.

4.1 Mathematical model

We present the mathematical model based on the split-multi commodity vehicle routing problem. The problem can be modelled by a graph $G = (F, E)$, with vertices $F = \{0, 1, 2...n\}$ where 0 represents the depot while other vertices represent the farms, and E is the set of edges. The edge $(i, j) \in E$ denotes the transversal from farm i to farm

j with the associated cost of c_{ij}. The collection demand d_{im} of produce m is associated with each farm $i \in F - \{0\}$. There is a limited number of v vehicles available, each with compartmental capacity Q_{mk} - capacity of produce m in vehicle k. Each vehicle must start and end its route at the depot. The collection demand of the farms must be satisfied, and the quantity collected in each tour cannot exceed the vehicle capacity Q_{mk}. The problem can be modelled as an integer programming problem by defining the following variables:

$$x_{ijk} = \begin{cases} 1 & \text{if vehicle } k \text{ travels along the edge } (i,j) \\ 0 & \text{otherwise} \end{cases}$$

$$y_{imk} = \begin{cases} 1 & \text{if vehicle } k \text{ collects produce } m \text{ from farm } i \\ 0 & \text{otherwise} \end{cases}$$

Hence the split-multi commodity vehicle problem is modelled as:

$$\min \sum_{k=1}^{v} \sum_{j=0}^{n} \sum_{i=0}^{n} c_{ij} x_{ijk} \tag{1}$$

subject to :

$$\sum_{j=0}^{n} x_{0jk} \leq 1 \quad \forall k; \qquad \sum_{i=0}^{n} x_{i0k} \leq 1 \quad \forall k \tag{2}$$

$$\sum_{i=0}^{n} \sum_{k=1}^{v} x_{ijk} \geq 1 \quad \forall j \tag{3}$$

$$\sum_{i=0}^{n} x_{ijk} = \sum_{i=0}^{n} x_{jik} \quad \forall j; \forall k \tag{4}$$

$$\sum_{i \in S} \sum_{j \in S} x_{ijk} \leq |S| - 1 \quad \forall k; S \subseteq F - \{0\} \tag{5}$$

$$\sum_{k=1}^{v} y_{imk} = 1 \quad \forall i; \forall m \tag{6}$$

$$y_{imk} \leq \sum_{j=0}^{n} x_{ijk} \quad \forall i; \forall m; \forall k \tag{7}$$

$$\sum_{i=0}^{n} d_{im} y_{imk} \leq Q_{mk} \quad \forall m; \forall k \tag{8}$$

$$\sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij} x_{ijk} \leq C_{max} \quad \forall k. \tag{9}$$

The objective function (1) represents the total routing cost to be minimized. Constraints (2) - (5) are classical vehicle routing constraints: constraint (2) ensures all vehicles start and end their routes at the depot, (3) imposes that each farm is visited at least once, (4) ensures the conservation of flow, while (5) eliminates the subtours. Constraints (6) - (8) concern the collection and allocation of demand among the vehicles: constraint(6) imposes that produce m at farm i must be collected by a single vehicle, (7) imposes that vehicle k can only collect produce m from farm i if it passes through i, and (8) ensures the quantity collected by each vehicle does not exceed the capacity of the vehicle. Constraint (9) restricts each vehicle to the maximum allowed distance of C_{max}.

4.2 Heuristic approach

We adopt the k-opt as a local search method to find the optimal routes. Since we have a heterogeneous fleet with v vehicles we first cluster the farms into v clusters. All farms that produce products that require a refrigerator are clustered together and a refrigerated vehicle is dedicated to serve them. The remaining farms are clustered into $v-1$ groups and each group is assigned a vehicle to serve that group. A k-mean clustering algorithm is used to cluster the farms based on their proximity.

The k-mean is one of the simplest unsupervised learning algorithms that solve the clustering problem. The procedure follows a simple and easy way to classify a given set of objects into k clusters, where k is fixed a priori. The main idea is to define k centroids for each cluster, in this case $k = v - 1$. The next step is to take each object from the set and associate it to the nearest centroid. When no object is pending, the new centroid is computed by taking the average of each group and repeating the process. The algorithm is composed of the following steps:

1. Place k points into the space represented by the objects that are being clustered. These points represent the initial group centroids.
2. Assign each object to the group that has the closed centroid.
3. When all objects have been assigned, recalculate the positions of the k centroids.
4. Repeat steps 2 and 3 until the centroids are no longer moving. This produces a separation of the objects into k groups.

Once the clusters are found, the 2-opt algorithm is used on each cluster to find the optimal route. The 2-opt involves repeated breaking of two edges and reconnecting them in other ways until no positive gain 2-opt move can be made. Given the route x, a sequence at which the farms are visited and two farms i and j, the main operation of the 2-opt is the following swapping mechanism:

1. Take $x[0]$ to $x[i]$ in that order, add them to the new route.
2. Take $x[i+1]$ to $x[j]$ in revere the order, add them to the new route.
3. Take $x[j+1]$ to $x[n]$ in that order, add them to the new route.

The above swapping mechanism is repeated for all possible 2-opt connections in a given route. At each step we keep the route that gave the best objective value, which is returned as the optimal solution by the completion of the algorithm. We present the results of the above heuristic in the next section.

5 Results

In this section, we present the results from the heuristic approach. The problem specification presented by the industry representative is as follows: We have capacitated a heterogeneous fleet of three vehicles with the following capacity - there are two non-refrigerated a vehicles with capacity two ton and one ton respectively, the third vehicle is refrigerated with capacity of half a ton. The geographical locations of 50 farms were presented in terms their longitude and latitude coordinates. The farms span the area of Johannesburg inner-city, Johannesburg South and Soweto, see Figure 1. The location of a single depot situated near the flea market at the Johannesburg inner-city was presented as longitude and latitude.

We first constructed the distance matrix between the farms using the actual distances from Goggle Map API. All farms with the requirement of a refrigerated vehicle where removed from the list, see Figure 2 and the refrigerated vehicle is dedicated to serve them. The remaining farms where clustered into two groups, see Figure 3. The cluster with large demand is served by the vehicle with large capacity, while the other cluster was served by the vehicle with small capacity. The optimal routes for each of the three groups is presented in Figure 4. The objective is to minimize the total distance - the optimal value using 2-opt local search is 612.42 km.

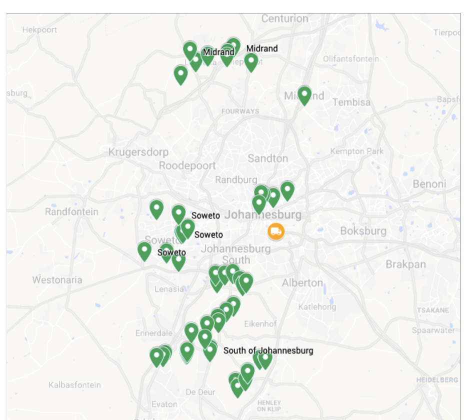

Figure 1: Location of the fifty farms.

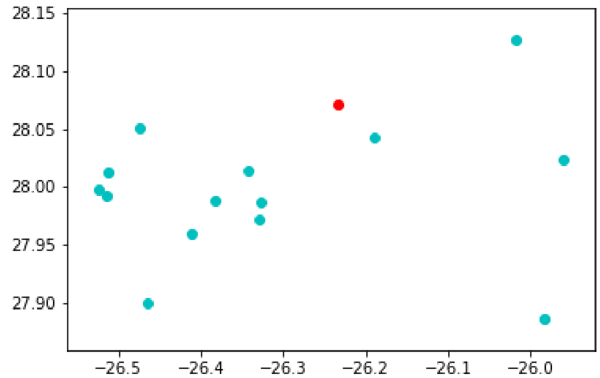

Figure 2: Location of all farms with requirement of a refrigerated vehicle.

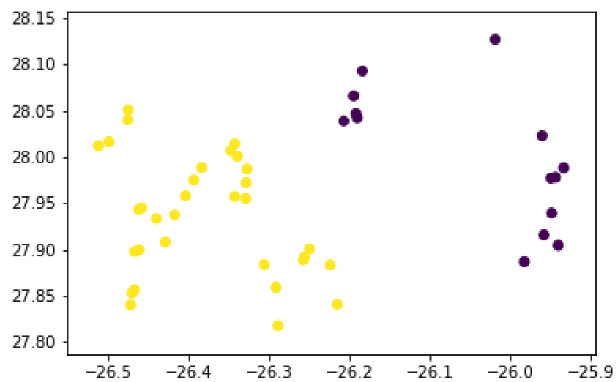

Figure 3: Location of farms which do not require a refrigerated vehicle clustered into two groups depending on demand.

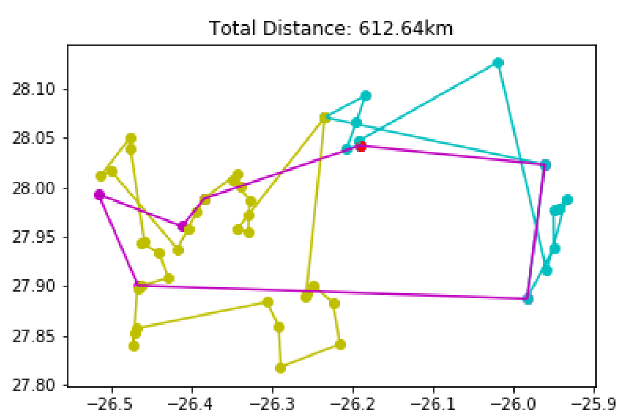

Figure 4: Optimal routes for the three groups.

6 Conclusions

In this work we have modelled the problem of coordinating the transportation of farm produce as a split multi-commodity vehicle routing problem. We have presented the heuristic model to solve the problem. We first group the farms and apply the local search algorithm 2-opt to find the optimal route of each group. The results can be used as a benchmark for the mathematical model formulation problem. Some work still has to be done to improve the above results. The main points to improve are:

(1) formulating and finding an effective solution of the predictive price model for planting and harvesting times,

(2) find efficient solution of the mathematical model for routing planning,

(3) possibly combine the two models to have a better coordinated logistics system among the farms.

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