Heuristic Techniques to Increase the Efficiency of Dispatching Process in Nurseries

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Abstract The efficiency of dispatch process of plants in a nursery is analysed using a vehicle routing model. Some of the analytical impediments remaining in the earlier nursery studies have been recognised. The present study attempts to develop a more comprehensive analytical framework for examining the relative merits of alternative policies for Australian nurseries. The problem then involves determining in what order each vehicle should visit its locations. The problem is a NP-hard problem. Several heuristic techniques are used to solve a real life nursery sequencing problem. The results obtained by these heuristic techniques are compared with each other and the current sequencing of orders. The model with some minor alterations can be also used to minimise the dispatching and collecting process in different agricultural plants.

1. INTRODUCTION

The dispatch process of plants from production nurseries is the most costly and labour intensive and inefficient operation in the Australian nursery industry. The dispatch process is defined as all the tasks which are performed between the time an order is received to the time the plants are awaiting loading to external transport. This paper is concentrated particularly on the task which involves the transporting of plants from the growing area to the dispatch shed for detailing and packaging.

Main factors effecting a nursery dispatching can be detailed as follows:

- size of the nursery;
- number of plant species in each of the three areas (open, shaded and greenhouse) and number of locations available in each of the three areas;
- number of growing bays required and monthly demands by each species;
- location of the plants in relation to the dispatch shed;
- number of periods at the model;
- number and size of orders;
- tasks involved and logistics (sequence) of plant processing;
- number and type of plants processed and pot size used for these plants;
- number of persons involved in tasks and their duration;
- unproductive time;
- type of equipment available for transport of plants; and
- number of times it is necessary to go to specific location of the nursery.

The efficiency of dispatch process of plants in a nursery is analysed using a vehicle routing model. The objective is to schedule a series of routes such that the minimum number of vehicles is used and the total distance is minimised with all locations being serviced.

The problem then involves determining in what order each vehicle should visit its locations. There is one route per vehicle, which starts and finishes at a central facility. The problem is a NP-hard problem with NP standing for "non-deterministic polynomial". There is currently no known polynomial time algorithm for computing the solution, any correct solution can be verified in polynomial time with respect to the size of the problem (Loshin [1994]).

There are several possible objective functions for the problem. These include minimising distance, minimising travelling time, minimising the number of vehicles and minimising total cost. The basic Vehicle Routing Problem (VRP) ignores a large number and variety of additional constraints and extensions that are often found in real-life problems. There are many extensions of the basic VRP to account for the large number of practical applications. See Christofides [1985] for detailed information. There are many derivatives of the VRP. They are usually of the form of extra constraint or mixtures of constraints. Examples of these can be found in Laporte et al [1992], Dror et al [1994] and Balakrishnan [1993]. Further constraints that can be included are as follows: duration of the route; start and end locations for the route/driver; start times of routes; weight and volumes restrictions on vehicle load; loading constraints and restrictions; rules for split deliveries (pickups) if any; and multiple routes per vehicle. Research into solutions for the VRP have been two pronged, optimal and near optimal (heuristic) solutions. Exact solution techniques used to solve the VRP can be put into three broad categories. These are as follows: tree searches; dynamic programming; and integer linear programming. Details of these techniques can be found in Forster [1976], Christofides [1985] and Laporte [1992].

Kulkarni and Bhave [1985] provide integer programming formulations of vehicle routing problems. Their article introduces several formulations for the travelling salesman problem, the m-travelling salesman problem, the vehicle routing problem and the multi-depot vehicle routing problem. Desrochers et al [1988] improved Kulkarni & Brave [1985] model with additional extensions for time horizon planning.

Heuristic techniques can be grouped into the following classifications, see Osman [1993]: Constructive methods; two-step methods; exact but incomplete tree search methods; and improvement methods. Constructive methods are those that build up vehicle tours by inserting at each step a location according to some savings measure until all locations are served. The most used of these are the Clark and Wright savings method and the sweep algorithm. The sweep algorithm at the location with the smallest angle and continues sweeping until a cluster is complete, with respect to a set of constraints. This is repeated until all locations are assigned to clusters. Some two-step algorithms can be found in Christofides [1985] and Laporte [1992]. Improvement methods iteratively improve a given solution by making local changes. Osman [1993] makes the observation that most iterative improvement methods start by using a constructive method to obtain an initial feasible solution, and uses an improvement technique that reduces the cost of the tour by making the local changes while maintaining feasibility.

2. NURSERY DISPATCHING MODEL

In relation to the nursery sequencing problem the central facility of depot is the dispatch shed. All trailers leave and return to the dispatch shed. The objective is to minimise the travelling distance when collecting orders. The orders are available at the beginning of each morning and consequently the demands for each species are known in advance. The collection of orders is pure pick-ups. In the case of using more than one trailer their capacities are assumed homogenous. Capacity will be measured in terms of the number of 140mm pots that can be transported by a trailer. A conversion factor is used to convert all demands in terms of 140mm pots. Travelling distances between all locations are measured for an input to the model. If the demand for a plant species exceeds the trailer capacity the load will be split into two (or more) full trailer loads and only the remainder considered.

Notations

dem_i: Demand for plant species i.

$dist_{ij}$: The total distance to travel from plant species i to j.

Where i=2,3,......,n. (i=1 refers to the dispatch shed) j=2,3,...,n.

cap: The capacity of a trailer in terms of 140mm pots.

u_i *and* u_j : Arbitrary real numbers

$$x_{ijr} = \begin{cases} 1 & \text{if in route } r \text{ the location of plant } j \text{ is visited} \\ & \text{immediately after the location of plant } i \\ 0 & \text{otherwise.} \end{cases}$$

where r =1,2,........,m.

$$y_{ir} = \begin{cases} 1, & \text{if plant species } i \text{ is visited in route } r \\ 0, & \text{otherwise} \end{cases}$$

The model

Objective function:

$$\text{Minimise } Z = \sum_i \sum_j \sum_r dist_{ij} x_{ijr} \tag{1}$$

subject to:

$$\sum_r y_{ir} = \begin{cases} 1, & i = 1,\ldots\ldots,\mathrm{m} \\ m, & i = 1 \end{cases} \tag{2}$$

Constraint (2) ensures that every plant species is allocated to some route (except the dispatch shed which is visited in every route).

$$\sum_i dem_i y_{ir} \le cap \qquad r = 1,\ldots\ldots\ldots,m \tag{3}$$

Constraint (3) is the vehicle capacity constraint. The number of pots collected in any one route must not exceed the capacity of the trailer.

$$\sum_j x_{ijr} = \sum_i x_{jir} = y_{ir} \; i=1,\ldots..n \;\; r=1,\ldots.m \tag{4}$$

Constraint (4) ensures that if a plant location is visited in a particular route it must also be left in that same route.

$$\sum_{i,j \in S} x_{ijr} \le |S| - 1 \quad \text{for all } S \subseteq \{2,\ldots.,n\} \; r=1,\ldots\ldots m \tag{5a}$$

$$u_i - u_j + n x_{ijr} \le n-1 \quad i,j=2,\ldots\ldots..,n \quad r=1,\ldots\ldots m \tag{5b}$$

Constraint (5a) prohibits any subtours ensuring that whole tours are completed at all times. Constraint (5b) is a more compact alternative to constraint 5(a)

$$y_{ir} \in \{0,1\} \qquad i = 1,\ldots..,n \quad r = 1,\ldots..,m \tag{6}$$

and

$$x_{ijr} \in \{0,1\} \quad i,j = 1,\ldots..n \quad r = 1,\ldots..m \tag{7}$$

Assumptions

The following assumptions were made to simplify the situation:

- At the beginning of each day the orders are sorted and the total number of each species required is known. The different species is divided into groups by locations and recorded the number of plants required in that specific location;
- There exists uniform stock and the selection of plants is not required. This implies that plants are picked one after each other and no sorting through plants is required.
- The distances from the dispatch area to each growing bays are define as the distance travelled from the dispatch area to the midpoint of the front of a growing bay and plus the vertical distance up to the middle of that growing bay.
- All distances travelled are either horizontal or vertical;
- The nursery size is assumed large enough so that there is generally enough of each species to fill at least one trailer or perhaps make allowances for those species in low demand and group these together.
- A conversion factor will set to convert the number of pots of each of the six sizes held by a trailer to 140mm pots.
- It is assumed that regardless of the picking strategy plants should be allocated according to demand. That is, having plants in higher demand closer to the dispatch shed will consequently reduce the distance travelled to collect orders.
- Once a species has been allocated a location in the nursery it stays there until demanded.

3. SOLUTION TECHNIQUES

A vehicle routing problem has been formulated as mixed Integer programming to solve the problem of collecting orders in an efficient manner and solved for a smaller size problem using the Generalised Algebraic Modelling System, GAMS. An optimal solution for a real life problem can not be found by packages like GAMS in a reasonable time period because it would be impractical to wait several hours for a solution when pickers have to commence collecting orders early in the morning. So heuristic techniques have been used to solve the real life nursery sequencing problem which yields a good solution to a problem, but cannot be guaranteed to produce an optimum. Three heuristic techniques, namely Clark and Wright method, sweep algorithm and genetic algorithm has been applied on a real data set. Potential savings that can be achieved by implementing of these heuristic techniques. The results obtained by these heuristic techniques have been compared with the present sequencing of orders.

The **Clark and Wright algorithm** initially constructs routes from the depot and each of the locations (n-1 routes). Then measures of savings are determined by calculating the amount of time/distance saved by linking two locations. The algorithm then joins the pairs in decreasing distance value of savings, subject to constraints (Equations (1) to (7)). Two algorithms are coded one for the parallel version and the other for the sequential version.

The **sweep algorithm** method uses both distances from every location to every other location, and the angle of rotation form the dispatch shed. The method sweeps from a location in order of angle of rotation while the capacity constraints are not violated. The locations included in the sweep become the next cluster. The method continues sweeping until all locations are assigned to a cluster. Once the clusters are assigned, a Travelling Salesman Problem (TSP) is solved for each cluster to arrive at the minimum route distance for that cluster.

In contrast to the Clarke-Wright algorithm, which requires geographical co-ordinates for each location. Sweep procedure should be carried out for all possible starting points, that is starting from each of the different directions, then the whole procedure is repeated in an anticlockwise direction sweeping. The sweep heuristic produces several solutions which can often be advantageous especially when there are other constraints to consider.

Genetic Algorithms (GA) are a subset of what is known as Evolutionary Algorithms. Other major subsets are Evolutionary Programs (EP), Evolutionary Strategies (ES), Classifier Systems (CFS) and Genetic Programming (GP) see Heitkötter (1993). "Genetic algorithms are search procedures based on the mechanics of natural selection and natural genetics" Goldberg [1989].

Genetic Algorithms represent potential solutions to a problem as genotypes. These genotypes (chromosomes) form a population, which undergo processes that resemble natural genetics. The genetic operators refereed to above are generally of two types: crossover and mutations. The crossover operator is the method of transforming a pair of surviving genotypes into a pair of offspring genotypes. The "classical" crossover involves cutting each genotype into two segments and swapping the segments, creating two different genotypes with characteristics from each parent. This carrying of segments allows the possibility of good string segments to be preserved. Although the crossover operator creates different offspring, a mutation operator is usually invoked. Each genotype will have a probability of mutation. "Mutation arbitrarily alters one or more genes of a selected chromosome, by a random change with a probability equal to the mutation rate (Michalewicz [1994]).

The following steps give an overview of the **genetic algorithm** process as implemented:

Step 1 Initialise the GA parameters of potential solutions. Generate the maximum number of generations, the maximum number of chromosomes in a population, population size, population renewal rate, probability of crossover and probability of mutation. Randomly allocate the numbers 1 to the total number of locations for each chromosome.

Repeat (steps 2 - 8) for number of interruptions pre-defined. (Initialisation of the population has been done using a Clark-Wright heuristic.

Step 2 Calculate the distances between gene *i* and *i+1* for each gene in the chromosome.

Step 3 Calculate tour length for each chromosome (summation of distances calculated in Step 2. Compare all tour distances with global minimum , replace global if less than. The tour distance acts as the evaluation function for the fitness of each chromosome.

Step 4 Create probabilities of survival. This gives the probability that a chromosome will survive to be used as a parent to produce offspring for the next generation of the genetic algorithm. `The probability is inversely proportional to the tour distance of the chromosomes, and is calculated by dividing the tour distance of the minimum chromosome by the distance of the chromosome in question, then dividing this by the sum of these divisions. This gives us probabilities summing to one, where chromosomes with small tour distances have greater chance of surviving.

Step 5 Use the probabilities from step 4 to randomly generate the surviving population. Note that chromosomes with high probability of survival can actually increase in numbers causing multiple copies of the chromosome.

Step 6 For the population of surviving chromosomes, pairs are chosen randomly to undergo the crossover operator. The random allocation helps to vary the potential offspring.

Step 7 Crossover is the method that mixes the genes of two parents to obtain off spring. Many method are available in literature but most of them are only suitable for binary coding. Since the routing problem is a permutation problem the choice of crossover method is limited. Firstly two crosspoints are selected randomly between 0 and N. Genes from the first parent that fall between the two crosspoints are copied into the same positions of the offspring. The remaining order is determined by the second parent. Non duplicated genes are copied from the second parent to the offspring beginning at the position follows the second crosspoint. The crossover operator works by choosing a segment of one parent and inserting the segment into the offspring in the same order and position. The surrounding positions are filled from the other parent, keeping where possible the same position and order. If cut points are chosen at 3 and 7 (indicated by |) then examples of two parents could be

P1 = (1 10 4 | 5 2 13 17 16 18 21 19 14 12 15 20 6 9 | 3 7 8 11)
P2 = (8 3 11 | 4 6 18 21 20 13 14 19 17 12 16 15 9 1 | 5 7 10 2)

Then the two offspring would look as follows ('x' represents still to be determined).

O1 = (x x x | 4 6 18 21 20 13 14 19 17 12 16 15 9 1 | x x x x)
O2 = (x x x | 5 2 13 17 16 18 21 19 14 12 15 20 6 9 | x x x x)

The next step is to place locations in offsprings from original parent, provided no conflict is encountered.

O1 = (x 10 x | 4 6 18 21 20 13 14 19 17 12 16 15 9 1 | 3 7 8 11)
O2 = (8 3 11 | 5 2 13 17 16 18 21 19 14 12 15 20 6 9 | x 7 10 x)

The other values are gained by placing the opposite location to that which is causing the conflict. For example the third position of offspring number 1 would have been 4 except that 4 is now at position 4, so position three is replaced with location 5. Other replacements are more complicated and involve following trail until a free value that does not occur exists. An example of this is position one offspring one, this should have been replaced with 9, but, 9 also exists in segment so we choose 6, but, 6 is also in segment so we choose 2. This rule results in the following two offspring:

O1 = (2 10 5 |4 6 18 21 20 13 14 19 17 12 16 15 9 1 | 3 7 8 11)
O2 = (8 3 11 |5 2 13 17 16 18 21 19 14 12 15 20 6 9 | 4 7 10 1)

Step 8 Randomly mutate genes with mutation rate probability. If mutation occurs (only one per chromosome is allowed), two locations will swap in position within the chromosome.

End

4. RESULTS

The above heuristics have been applied to a given days orders. A record of a days orders along with the actual sequence of collection, a map of the stopping places and distances were available.

Different species often require different pot sizes. These pot sizes usually range from 100mm to 350mm. It is for this reason that it has become standard practice within the nurseries to convert all pot sizes to a base unit, this being a 140mm pot. That is, all demands have been converted into the equivalent number of 140mm pots and provided in Table 1. The capacity of a trailer is 360 pots in terms of the number of 140mm pots that it can transport at any one time.

The stopping numbers is provided in Table 2. These numbers show the actual order in which the plants are collected. There are 21 different locations and the distances between each location have been measured and used in the model. At any one location several different plant species are loaded onto the trailer.

The Clarke-Wright savings algorithm has been solved both sequentially and in parallel and the results are provided in Table 3. While the solutions above do give the order of visiting the plant species it is still beneficial to solve the travelling salesman problem for each trailer in the final allocation to obtain the true optimum order of visiting within each subset. Some improvements were found when each subset was solved using the TSP. The results are provided in Table 3. Sweep Algorithm results for sweeping in a clockwise direction and anti-clockwise direction for initial starting direction West are provided in Table 4. Genetic algorithm results are given in Table 5. It is clear that for this particular set of data the Genetic Algorithm provides the best solution. This solution results in a 20.3% savings in travelling distance. It is interesting to note that even after 3.6 million iterations using branch and bound that the solution is not even as good as the worst performing heuristic technique. The optimum solution could not be found because of computer memory limitations and time restrictions.

Table 1: Conversion factors for transporting pot Plants
(base unit = 140mm pot size)

Pot size	100	125	140	175	200	300	350
Transport Factor	0.51	0.80	1.00	1.55	2.04	5.00	13.00

Table 2: Present dispatching process

Stop No	Species and Pot Size	# of Pots	Conversion Factor	Converted Number of Pots
Trailer 1				
1	Dipladenia 140	6	1	6
2	Agapanthus 200	12	2.04	25
3	Bushy Blue 200	31	2.04	63.24
	Gretel 350	2	13	26
	Primrose 350	4	13	52
	Bushy Blue 140	32	1	92
4	Annabel 200	5	2.04	10.2
	Annabel 350	2	13	26
5	Gretel 200	5	2.04	10.2
	Carmella 200	5	2.04	10.2
	Celia 200	5	2.04	10.2
			Total	**333**
Trailer 2				
6	Golden beauty 140	36	1	36
	Pink Numenos	12	1	12
	Evolvulus 140	30	1	30
7	Prima Dona 140	6	1	6
8	Liriope 140	14 4	1	144
9	Vibernum 140	12	1	12
10	Bushy Blue 300	3	5	15
	Ballerina 300	9	5	45
	Duranta 300	1	5	5
11	Red-Riding Hood 200	12	2.04	24.48
	My Fair Lady 200	2	2.04	4.08
12	Scarlet Pimpernal 200	13	2.04	26
			Total	**359**
Trailer 3				
13	Dracellia 100	10	0.51	5.1
	Dryopeteris 100	5	0.51	2.55
	Humata 100	5	0.51	2.55
	Aglamorpha 100	5	0.51	2.55
14	Spathiphyllum 140	6	1	6
	Sandra 140	6	1	6
	Sandra 175	3	1.55	4.65
	Emeraldbeauty 140	12	1	12
15	Gretel 140	6	1	6
16	Primrose 200	1	2.04	3
17	Springfire 300	4	5	20
18	Victoria 175	27	1.55	42
19	Victoria 200	4	2.04	9
20	Swan Lake 140	6	1	6
	Majestic 200	4	2.04	8.16
	Misty Pink 200	4	2.04	8.16
	Golden Yulow 200	10	2.04	20.4
	Pink Parpait 200	10	2.04	20.4
21	Merlin's Magic 200	11	2.04	23
			Total	209

Table 3: Results from the Clarke-Wright algorithm

a) Parallel Version

Trailer	Best tour	
1	Disp-9-5-16-4-3- 2-1-15-Disp *	
2	Disp-10-17-8-7-6-13-14-Disp	
3	(Disp-12-21-20-19-18-11-Disp)	
	Total travelling distance (meters)	2032

b) Sequential Version

Trailer	Best tour	
1	Disp-15-1-2-3-4-16-5-7-9-DISP	
2	DISP-10-17-8-6-18-19-DISP	
3	DISP-11-20-21-12-14-13-DISP	
	Total travelling distance (meters)	2056

* *Sequence of Picking from location*

Table 4: Sweeping algorithm's results

a) Sweeping in a Clockwise Direction

Trailer	Best tour using TSP	
1	DISP-17-2-3-1-15-14-13-DISP	
2	DISP-12-6-7-8-4-10-DISP	
3	DISP-20-21-9-16-5-19-18-11-DISP	
	Total travelling distance (meters)	2155

b) Sweeping in an anti-clockwise direction

Trailer	Best tour using TSP	
1	DISP-12-21-20-9-16-5-19-18-11-DISP	
2	DISP-10-4-8-7-6-17-DISP	
	DISP-13-14-15-1-3-2-DISP	
	Total travelling distance (meters)	2146

Table 5: Genetic algorithm

Trailer	Best tour using TSP	
1	DISP- 13-14- 12- 21-20- 11- DISP	
2	DISP-15-1-2-3-4-19-18-DISP	
3	DISP-10-17-6-7-8-5-16-9-DISP	
	Total travelling distance (meters)	1943

Table 6: Comparison of heuristic techniques' results

Heuristic technique	Travelling distance as meters	Saving as percentage
Benchmark actual distance	2440	0.00%
Clarke-Wright savings algorithm-parallel version	2032	16.72%
Clarke-Wright savings algorithm sequential version	2056	15.74%
Sweep algorithm in a clockwise direction	2155	11.68%
Sweep algorithm in a clockwise direction	2146	12.01%
Branch and bound (360000 iterations)	2192	10.16%
Genetic algorithm	1943	20.37%

5. CONCLUSIONS AND FUTURE WORK

It has been shown that heuristic techniques can reduce the travelling distance substantially. From the results above it can be seen that significant savings can be achieved by implementing a method of collecting daily orders and an improved nursery plant layout. The collecting of orders is a task performed on a daily basis and is by far the area which has the most potential for reducing costs.

There are some practical considerations to address before a heuristic technique can be implemented. After determining the routes for the different trailers another question arises: 'In what order should the trailer loads be collected?' The order will make no difference to the total travelling distance but it will effect the number of trolleys waiting in the dispatch shed.

A quick turnover or species which must be visited regularly for spraying, pruning, or trimming, should be located as close as possible to the operational areas (potting/ propagation, dispatch). Species which have a slow turnover or low maintenance should occupy the furthermost reaches of the nursery. So, before applying these heuristics an optimal plant layout of the nursery should be obtained according to yearly demands

The placement of operational facilities within the nursery (i.e. dispatch, potting/propagation areas) can have a large influence on the total distance walked by nursery workers, or the distance a product is carted, over a given time period.

If the consolidated plant pull sheet is prepared according to orders, consecutive orders collated until a trailer-load of plants is totalled for a pull sheet, then this may results in a substantial degree of retracing steps during pick-ups. Similarly, in the dispatch shed, if numerous plants of one species are detailed together there is less 'stop-start' time compared with detailing order by order. These considerations are particularly important in large nurseries where travelling distances are much more critical than in small nurseries. Then optimum order of plant species collected by trailers will be determined to minimise the distances travelled

When a trailer load is completed it returns to the dispatch shed where it is unloaded and the preparation of individual orders is started. Incomplete orders are stored on trolleys in the dispatch shed. For example, there are five plant species required in a particular order. Three species may be collected in the first trailer load while the other two on the last. This will consequently result in the trolley designated to this order waiting until the last trailer load is completed. Having worked out the routes for each trailer load the idea is to now order the trailer loads to minimise the number of incomplete orders. Ideally it is desirable to have complete orders started and finished on the same trailer but this is often impossible to achieve. The Department of Primary Industries are presently speeding time developing a good measure to select the best way of ordering trailer loads.

As a result of this research it can be concluded that Australian production nurseries need a good vehicle routing and an efficient nursery layout. It is important to note that a changed plant layout will in turn effect the collection of orders and of course the distances used to determine the order of collecting plants. Therefore, firstly the nursery layout should be optimise and then implement a vehicle routing system.

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