Optimization of Solid Waste Collection: Two ACO Approaches

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ABSTRACT

This paper presents the use of the ant colony optimization algorithm (ACO) for the optimization of solid waste collection in Ciudad Universitaria (CU), National Autonomous University of Mexico (UNAM). This is formulated as an Asymmetric Capacitated Vehicle Routing Problem (ACVRP). In order to solve this problem, two ACO algorithms have been proposed: a Max-Min Ant System (MMAS) and an Ant Colony System (ACS). Obtained results are compared against existing routes for collecting solid waste and show improvements in terms of re-design of routes and distance minimization.

CCS CONCEPTS

•Applied computing → Transportation;

KEYWORDS

Ant Colony Optimization, VRP problems, MMAS, ACS

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1 INTRODUCTION

Ciudad Universitaria is the main campus of National Autonomous of Mexico (UNAM) located in Mexico City. It has an area of 730 hectares. In this campus, there is a population of more than 150,000 students (undergraduate and graduate) and it is estimated that 15 tons of solid waste are generated daily. Thus means, 0.1 kg per person daily. In order to collect solid waste, six routes (R#) have been established (details of these routes are presented in 1). These routes are divided into two clusters due to operative rules. The first cluster is the one where students are more concentrated and it is called Scholar Zone. The second one corresponds to Cultural Zone where most of the museums, theatres, music hall are located. Six vehicles are available for collecting solid waste for the two clusters, having a maximum capacity of $16.5m^3$ each vehicle. It is also included the distance travelled for each vehicle from the starting point to the final deposit and the way back. However, it is assumed that existing routes can be improved due to these routes were defined years ago and from that time, new collecting points have been added. Including new nodes does not guarantee that routes will be the best. Also, generation of solid waste has also been increased (student and academic populations) and vehicles has limited capacity. Thus, by means of ACO algorithms, design and travelled distance can be improved. Formulation of the problem is then given in next section.

Table 1: Current defined routes in CU

	Scholar Zone				Cultural Zone	
	R1	R2	R3	R4	R5	R6
Nodes	16	22	23	24	13	17
%Nodes	18.8	25.9	27.1	28.2	43.3	56.7
Dist.(km)	43.4	38.7	32.1	41.8	22	26.5
%Dist.	27.8	24.8	20.6	26.8	45.4	54.6
Vol.	11.3	16.3	14.3	18.4	15.3	15.3
%Vol.	18.7	27	23.7	30.5	50	50

2 PROBLEM FORMULATION

The first task consists in obtaining the different distances between each collecting point. Second, a complete graph $G(V, A)$ were designed with a set of nodes $V = \{0\} \cup \{1, 2, \ldots, n\}$ and a set of arcs $A = \{i, j \forall i, j \in V\}$ Moreover, the collecting points are represented by $V' = \{1, 2, \ldots, n\}$. Finally, the final deposit and the transfer station are $D = \{0\}$. The number of vehicles are K with capacity Q. What is more, a binary variable x_{ij} is $x_{ij} = 1$ if (i, j) is in the solution of the route of vehicle k and $y_{ij} = 1$ if the collecting point i is visited by vehicle k. Mathematical formulation of the problem is shown as follow, where the objective function is defined as the minimization of the total cost given by the total travelled distance of obtained routes.

$$Min \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} c_{ij} x_{ij}^k \tag{1}$$

s.t.

$$\sum_{k \in K} y_i^k = 1 \forall i \in V \tag{2}$$

$$\sum_{k \in K} y_0^k = K \tag{3}$$

$$\sum_{j \in V, j \neq i} x_{ij}^k = \sum_{j \in V, j \neq i} x_{ji}^k = y_i^k \forall \mathrm{i} \in \mathrm{V}, \mathrm{k} \in \mathrm{K} \tag{4}$$

$$u_{ik} - u_{jk} + Q x_{ij}^k \leq Q - q_j \forall i, j \in V', i \neq j \in K \tag{5}$$

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$$q_i \leq u_i^k \leq Q \forall i \in V', k \in K \quad (6)$$

$$x_{ij}^k \in \{0,1\} \forall i,j \in V', k \in K \quad (7)$$

$$y_i^k \in \{0,1\} \forall i \in V', k \in K \quad (8)$$

where c_{ij} is the distance. Additionally, each collecting point has an associated demand q_i^k collected by vehicle k where $q_i^k < Q \forall i = 1,\ldots,n$ and u_i^k represent a subtour.

3 ANT COLONY ALGORITHMS

In order to solve the problem of optimizing solid waste collecting routes, two variants of ACO have been proposed: Ants Colony System (ACS) and Max-Min Ant System (MMAS) [1–3]. Regarding initialization process, both approaches start from a solution generated by means of the nearest neighbor algorithm. k ants are considered where k is also the numbers of nodes (collecting points). Each ant builds a feasible solution by successively adding a collecting point until the ant has visited all the nodes. Also, an ant moves to an unvisited collecting point if it satisfies the capacity restriction (Eq. 6). To determine the next collecting point into the route, ACS and MMAS use different transition rules. MMAS uses a random proportional rule defines as:

$$p_{ij}^k = \begin{cases} \dfrac{{\tau_{ij}}^{\alpha} {\eta_{ij}}^{\beta}}{\sum\limits_{u \in N_i^k} {\tau_{ij}}^{\alpha} {\eta_{ij}}^{\beta}} & \text{if } j \in N_i^k \\ 0 & \text{otherwise} \end{cases} \quad (9)$$

where τ is the pheromone trail, η is the heuristic information to choose with probability p_{ij} to move an ant k to node j from node i. The tabu list (cities that ant k can visit when it is on city i) is represented with N_i^k. Parameters α and β are parameters that balance the contribution of pheromone and heuristic information, respectively. Whereas ACS uses a pseudo-random rule as shown as follow.

$$j = \begin{cases} \arg\max_{l \in N_i^k} \left({\tau_{ij}}^{\alpha} \eta_{ij}^{\beta} \right) & \text{if } q \leq q_0 \\ J & \text{otherwise} \end{cases} \quad (10)$$

where j indicates the next node for visiting, q is an uniform random variable between $[0,1]$, q_0 is a parameter between $[0,1]$. J denotes the way to follow using Eq. 9. Also, local search techniques such as 3-opt [4] and relocation and interchange heuristics [5] were included. The relocation operator (set a node i of a route $R1$ in another route $R2$) and the interchange operator (interchange k nodes of two different routes) are local heuristics that help ACO algorithms to improve the result. Once that ants constructed a solution, it is possible apply these local methods. If the solution was improved, the MMAS and ACS continue their procedure.

4 EXPERIMENTAL RESULTS

Parameters were set as follows. In the case of Cultural Zone, parameters were defined as ($m = n - 1$, $\alpha = 1$, $\beta = 3$,$\tau_0 =$, $\rho = 0.1$, $LC = 15$) and ($m = n - 1$, $\alpha = 3$, $\beta = 3$,$\tau_0 = 1/nC_{nn}$, $\rho = 0.1$, $LC = 15$, $\varphi = 0.1$, $q_0 = 0.9$) for MMAS and ACS, respectively. For Scholar Zone, parameters were ($m = n - 1$, $\alpha = 1$, $\beta = 3$,$\tau_0 = 1/nC_{nn}$, $\rho = 0.1$, $LC = 15$) and ($m = n - 1$, $\alpha = 1$, $\beta = 10$,$\tau_0 = 1/nL_{nn}$, $\rho = 0.1$, $LC = 15$, $\varphi = 0.1$, $q_0 = 0.9$) for MMAS and ACS, respectively. Results are shown in 2, showing means (μ), standard deviation (σ) and best solution based on 30 runs.

Table 2: Results of two CU Zones

Zone	Algorithm	μ	σ	min
Scholar	MMAS	123768.9	1232.12	120746
	ACS	122336.13	514.82	120743
Cultural	MMAS	47857.27	726.93	46076
	ACS	47434.23	616.73	45986

5 CONCLUSIONS

In this paper, ACO algorithms were proposed to solve the problem of recollecting solid waste at UNAM. This problem was formulated as an asymmetric CVRP. ACS approach generated a slightly better solution than MMAS, but the different is not relevant (less than 0.2%). However, routes of ACS and MMAS solutions are quite different. This fact is because there are many collecting points that are quite close one to each other, and it is possible to interchange one or more points between two routes without increasing the total travelled distance. The most significant improvement was observed for Scholar Zone, were there was a 22.6% reduction of distance between the original route and the one proposed by ACO algorithms. In the case of Cultural Zone, reduction was of 5.3% for ACS and 5.5% for MMAS. These results then show that it can be possible to improve the routes of the solid waste collecting system by minimizing the total travelled distance.

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