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Application of ant colony optimization for the shortest path problem of waste collection process

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Abstract

The search for the shortest path of the waste collection process is an interesting topic that can be applied to various cases, from a very practical basic problem to a complex automation system development. In a dense settlement, the waste collection system can be a challenging process, especially to determine the most optimized path. The obstacles can be circling streets, impassable roads, and dead-end roads. A wrong choice of method can result in wasteful consumption of energy. A possible method to solve the problem is the traveling salesman problem using ant colony search optimization, considering its relatively fast optimization process. Therefore, this paper proposes an application of ant colony and traveling salesperson problem in determining the shortest path of the waste collection process. The case study for the optimization algorithm application is the path UGM Sekip Lecturer Housing is considering. Firstly, the data was collected by measuring the distance between points. Then, the paths were modeled and then compared with the actual route used by waste transport vehicles. The last step is implementing the ant colony optimization and traveling salesman problem by determining the cost function and the parameters. The optimization process was conducted several times, considering the random generator within the algorithm. The simulation results show the probable shortest path with a value of about 752 meters so that the use of fossil fuels in waste transport vehicles can be more efficient. The results show that the algorithm can automatically recommend the minimized path length to collect waste.

1. Introduction

The efficiency improvement of the waste collection process in a dense settlement can be a considerable challenge without the right innovation for the technology or plan [1][2][3]. For example, energy consumption can be high and produce air pollution, especially if fossil fuels are still utilized as the main energy source [4]. The innovation for technology can be the engine's direct modification, such as the engine downsizing [5][6]. These alternatives are quite expensive and need more resources. Another possible cheaper method is by pre-determining the vehicle's travel route to be as short as possible. The path that the vehicle passes requires careful planning for collecting waste. Start at one point, then circle the housing and return to the starting point. If the path covered by the vehicle can be the shortest path taken when collecting the trash, the diesel fuel usage can be more efficient.

It is necessary to calculate the shortest possible path by a waste vehicle so that diesel oil becomes more efficient without wasting unnecessary routes so that savings can be made. The searching of the waste collection process route can be considered as one of the combinatorial discrete related problems. This kind of problem can be solved using the traveling salesman problem (TSP) [7][8][9][10][11]. The possible optimization methods that can be applied are particle swarm optimization [12][13][14][15], ant colony algorithm [7], and genetic algorithm [16]. Particle swarm optimization (PSO) inspired from the bird movement and coordination has been known for its advantage of simple algorithm and fewer parameters to adjust compared to genetic algorithm [17]. The method's drawbacks are the high possibility of being trapped in a local solution and the low convergence rate. On the other hand, a genetic algorithm can usually achieve a general solution and have acceptable performance [18]. Opposite to PSO, genetic algorithms is usually taking more time and have more hyperparameters. Nevertheless, both methods can take a considerable time to solve the TSP case.

TSP case usually contains several destinations, in the waste collection process is pick up points, and the computational burden will increase exponentially as more destinations are targeted [8]. From the previous studies, heuristic methods can be considered powerful tools to solve salesman problems because of the fast optimization process [7]. Ant colony optimization is one of the well-known heuristic methods to optimize the TSP Problem [19][20]. Ant colony optimization is faster than PSO and genetic algorithms despite the lack of accuracy. Various improvements of ACO also have been provided in the literature, such as the involvement of the Taguchi design method [1]. However, the algorithm application needs to be further studied, especially in the uncertain dense resident area. The right method should be selected, which is not too complex but also should have acceptable performance. The case study for the applied method is to find the shortest possible route for waste vehicles at UGM Sekip Lecturer Housing. Currently, the waste transportation has wandered around the resident area with a random pattern, and the fuel consumption is not consistent, sometimes are quite high while in another time quite low.

Therefore, this paper proposed a combination of traveling salesperson problems with ant colony optimization to determine the minimum path of the waste collection process. The proposed method should provide the most efficient operation for the waste collection process and provide indirect monitoring. Furthermore, the system can be integrated with the internet of things (IoT) or smart city concept in the future [21]. The methodology will be discussed after this section, including the employed traveling salesman problem algorithm, ant colony algorithm, and the combination of both algorithms. Then, the results and discussion provided a description of the built model for the optimization process and the proposed method performance.

2. Research Method

The research steps are shown in Figure 1. The first step is to observe the actual conditions of the journey of the waste vehicles, starting from the first point around the housing and then returning to the starting point. Using a google map, the next step is to determine the coordinates of the roads that the waste vehicles pass. The next step is to create a program in the form of a *.m file* according to the Ant System algorithm, then run the program that has been made to find the shortest path from the coordinates of the specified point data. The last step compares the results obtained from the program run with the real condition of the length of the path carried out by the waste vehicles. The results are in the form of advice to pass the short track so that oil diesel as material fuel waste vehicles becomes more efficient.

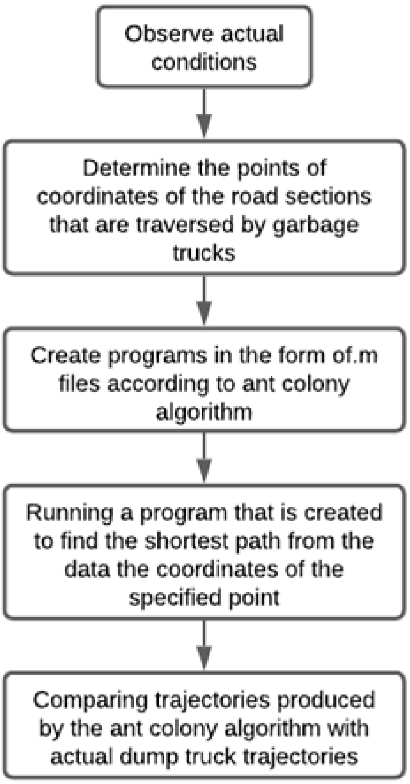

Figure 1. Research Diagram

2.1 Travelling Salesperson Problem (TSP)

TSP algorithm is a problem that initially is faced by a salesman who departed from the city of origin, trying to find the path most short that can be taken to all the cities of customers and then returned to the city of origin, with the proviso all city subscribers only be visited once in each tour.

In TSP, the expected result is to find the shortest path connected from n cities. Each city can only be visited once. The distance between city i and city j is defined by the equation Eucledian dij, $d_{ij} = \left[(x_i - x_j)^2 + (y_i - y_j)^2\right]^{1/2}$, x_i and x_j are the coordinates of the city [22][23].

TSP can be represented in the problems of the graph consisting of city coordinates. A node in Cartesian coordinates represents each city. Each node has a coordinate (x, y), and all the nodes are mutually connected one to the other. The distance of each node can be calculated from the coordinates of the node here. If there are nodes that are not connected, then the nodes are connected and given a value range that will not be used as a solution optimal.

2.2 Ant Colony Optimization (ACO)

The principle of the ACO is based on ant's behavior that always leaves a substance chemical specialty (pheromones) on a track that passed for making the trip. Pheromones are left in place, which passed by ants have become guides for the ants' others in making the trip. Increasingly ants that pass through the path that the amount of pheromone also be getting much, so the possibility of ants, others follow the path that will be increasingly large. Furthermore, pheromones are abandoned by ants on a track that will undergo evaporation along over time. At the time of the ant must choose the path which will be followed at point A, some ants choose the path down, and others chose the path above is random. The ants had been running with the speed of the same. The ants who choose the path down would be up at point B more quickly when compared with the ants who choose the path on which more long. The ants who choose the path below will be used until the source of food. If ants are already up on the sources of food are returned to the nest, the ants were going to follow the path that there are pheromones that were abandoned previously. It is causing the amount of pheromone on the path below to increase, and the number of ants that pass through the path will also be more. Artificial ants adopt real ant behavior when looking for solutions to optimization problems. Pheromones are the basic key for ants when making decisions [24][25].

2.3 Application of Ant Colony Optimization in TSP Algorithm

ACO is employed to test the settlement of cases TSP. The ACO uses several ants who work together to find the shortest path in several cities. The ants in the US in search of the shortest path solution on the TSP work as follows:

At the beginning of the search for the shortest path, each ant put itself in each town randomly. Then each ant visits other cities which he has never visited until all cities have been visited. Each ant will have a list of visits from cities that have passed. This list of visits is called the taboo list.

Selection of the cities that have not been visited based on a rule called the rule of the transition state (state transition rule). Rules have to consider the visibility (inverse distance of the town to town the other) and the amount of pheromone in each segment that connects the city with the city other. Ants in the ACO will tend to choose a town next to most close to the city of origin (having visibility large) and the amount of pheromone majority on a segment. The taboo list owned by each ant serves to prohibit the ants from visiting cities they have already visited. When a tour is completed, the taboo list in this function will calculate the length of the path that has been traversed by an ant on tour.

After the ants complete the tour, the taboo list will be full. The length of the tour was done by each ant is calculated based on the taboo list. A step further is doing the process of renewal of pheromones on each segment which is traversed by an ant. A rule of renewal of pheromone globally (global pheromone updating rule) is applied in each segment. The shorter a tour produced by the ants, the more pheromones abandoned in segments that pass will be increasingly large. It will cause the segments that were given pheromone more lots to be increasingly in demand ants on tour next.

In contrast to the segments with pheromone little more and less desirable by ants, the tour next will increasingly rarely passed, until the final segment that does not ever pass again. On the renewal of pheromone globally, the next sequence is the process of evaporation of pheromones. Evaporation pheromones aim that does not occur stagnation, which is when all the ants end up doing the tour are the same.

The process is repeated until the tour who do reach the maximum amount, or the system is generating behavior of stagnation, i.e., the behavior when the system is stopped looking for solutions alternative. The next tour shortest were found by the ants stored, and the taboo list is emptied back.

2.4 States Transition Rules

A rule transition is the probability of ant for the visit of the town beginning i towards the town next j during build a solution to-t. The rule is called a random proportional rule. The probability of transition from city i to city j by ant in the US is defined as Expressed in Equation 1 [26][27].

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}}{\sum_{l\, \in N_i^k}[\tau_{il}(t)]^{\alpha}[\eta_{il}]^{\beta}}, if\ j \in N_i^k \\ 0, \qquad\qquad\qquad otherwise \end{cases} \quad (1)$$

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τ_{ij} is the amount of pheromone that exist in each segment between node i and node j, η_{ij} is the inverse of the distance between nodes i and node j $(1/d_{ij})$, the value of $1/d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$. α is a parameter that controls the weight of pheromones, β is a parameter controlling the distance, and is the set of nodes N_i^k that have not been visited by the ant.

2.5 Update Pheromone Trail

After all, ants go through the route, trail pheromones value, which exists in every segment, will be updated. Updates the value of pheromones have done with more first reducing (vaporize) pheromones that exist in the segment with a value of evaporation is constant, then add it to the pheromone new. Pheromone updates are carried out as shown in Equation 2, Equation 3, and Equation 4 [26][27].

$$\tau_{ij} \leftarrow (1-\rho)\tau_{ij} + \Delta\tau_{ij} \tag{2}$$

$$\Delta\tau_{ij} = \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{3}$$

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{Q}{L_k}, if\ (i,j) \in\ tour\ described\ by\ taboo_k \\ 0, \qquad\qquad otherwise \end{cases} \tag{4}$$

ρ is the parameter evaporation of pheromones, m is the number of all the ants, tour Described by taboo is the tour that made ant k based taboo, and L_k is the tour length that made ant k, Q is a constant amount of pheromone to be stored.

There are three variations of the experiment that were performed that ant-cycle, ant-density, and ant-quantity. Differences three algorithms are situated on the way updates pheromones. Ant-cycle produces the best solution compared to the other two algorithms. Update pheromones do after ants visiting all the cities that exist.

In the ant-density and ant-quantity, the pheromone update is carried out every time the ants visit the next city without waiting for the ants to visit all the cities on the TSP. Every time the ants visiting the town next, pheromones on roads that bypassed the ants are updated. In the addition of ant-density pheromones using Equation 5 [26][27].

$$\Delta\tau_{ij}^{k} = \begin{cases} Q, if\ k_{th}\ ants\ goes\ from\ i,j \\ 0, \qquad\qquad otherwise \end{cases} \tag{5}$$

Whereas for the ant-quantity addition of pheromones using the following Equation 6.

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{Q}{d_{ij}}, if\ k_{th}\ ants\ goes\ from\ i,j \\ 0, \qquad\qquad otherwise \end{cases} \tag{6}$$

2.6 ACO Parameters

ACO uses several parameters which aim to be the solution to the problem. TSP gets results close to optimal. parameters are [26][27]:

1. For controlling pheromone weight for each α segment, the best α value
2. For β visibility controller, the best β value according is between 2 and 5
3. The constant of pheromone evaporation for each segment of ρ, the best value of ρ is 0.5
4. The number of pheromones to store Q
5. τ_0 is given a small value of $0 < \tau_0 < 1$, it can also be obtained from the equation is a long tour of the best derived from the method of the nearest neighborhood, m is the number of ants. In ACO, the number of ants is the same as the number of cities.
6. Q is of 1, 100, and 1000. The previous research has concluded that constant Q does not affect the solution that is generated.

3. Results and Discussion

3.1 Observation Results

From the observation, the track is covered by waste vehicles in the neighborhood of Housing Lecturer UGM Sekip, shown in Figure 2. The first point of starting the journey can be from anywhere because the TSP will connect each coordinate point then return to the first point.

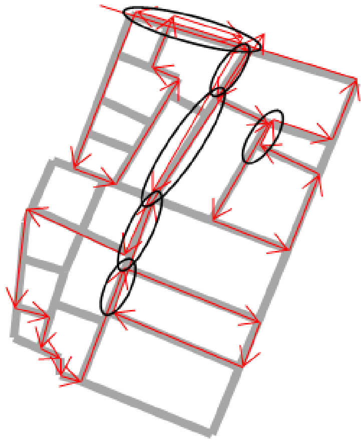

Figure 2. The Track of the Waste Vehicles

The coordinates on some road sections are shown as a segment marked with a circle in Figure 2. The length of the entire path that traversed waste vehicles is 1192 units of length. Then, based on Figure 2 is made of points coordinates of each assembly segment of road that passed by the truck. The coordinates of each of these points are shown in Figure 3.

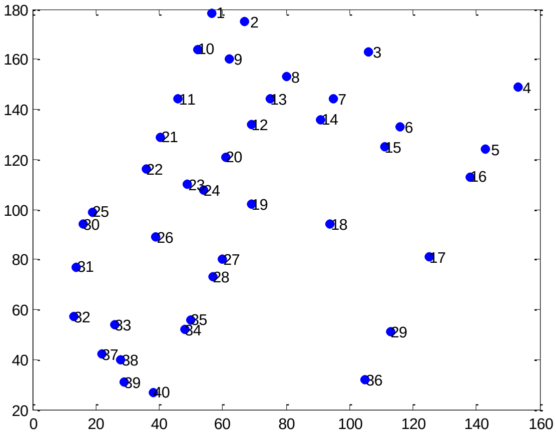

Figure 3. Dots Coordinate Joint Road

The coordinates of each point are the data needed to find the shortest path using ACO. In addition, it is also necessary other parameters to run the ACO so that obtained results are optimal. These parameters are shown in Table 1 below [26][27].

Table 1. Parameters in ACO

Parameter	Score	Information
$\boldsymbol{\alpha}$	1	weight parameter for pheromone per path
$\boldsymbol{\beta}$	4	weight parameter for the visibility of each track
$\boldsymbol{\rho}$	0.5	pheromone evaporation parameters
$\boldsymbol{Q}$	1	a constant of the quantity of traces the ants put on
$\boldsymbol{NCmax}$	3500	maximum number of iterations

3.2 The results After Running the Program

The program is run as many as ten times by using the parameters in Figure 4. Of the ten times the experiment, the results are obtained trajectory shortest, namely 752 meters.

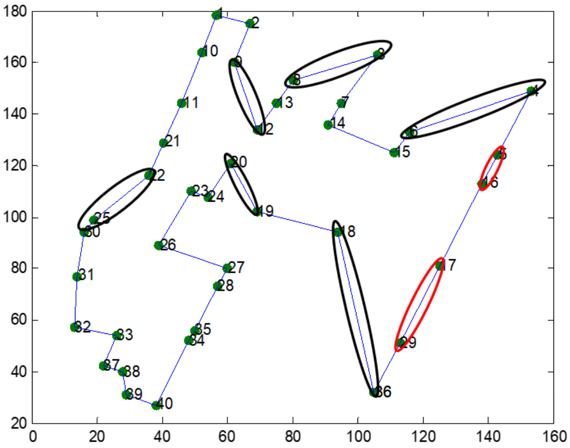

Figure 4. The Shortest Path from the Running Program (Unit is Meter)

The chosen order of the shortest path visits is:

1 → 10 → 11 → 21 → 22 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 26→ 23 → 24 → 20 → 19 → 18 → 36 → 29 → 17 → 16 → 5 → 4 → 6 → 15 → 14 → 7 → 3 → 8 → 13 → 12 → 9 → 2

The carried-out results of more trials are shown in Table 2.

3.3 Discussion

Of the ten times the experiments were carried out when compared with the length of the track passed by waste vehicles, long-track results of experiments are always more. It is happening because the trajectory of the experiment results is not the road that passed more than once. The weakness of the experiment results is the trajectory that is not there is a segment of the road but passable by ants in the search path of the shortest visits to all points. These results are indicated by a black circle in Figure 3. In addition, some sections can't be passed because there is a barrier wall, but they are crossed by ants in searching for the shortest route to visit all points. This condition is indicated by a red circle in Figure 3. This research is the same as other research that has been carried out, which produces the shortest path without looking at the trajectories that are traversed. There are disturbances, or the trajectory in real conditions cannot be passed [20].

Table 2. Results of the Experiment

No.	The order of visits	Long
1	1 → 10 → 11 → 21 → 22 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 26 → 23 → 24 → 20 → 12 → 19 → 18 → 36 → 29 → 17 → 16 → 5 → 4 → 6 → 15 → 14 → 7 → 3 → 8 → 13 → 9 → 2	760.4
2	1 → 10 → 11 → 21 → 22 → 23 → 24 → 20 → 19 → 27 → 28 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 36 → 29 → 17 → 18 → 15 → 6 → 5 → 16 → 4 → 3 → 7 → 14 → 12 → 13 → 8 → 9 → 2	766.0
3	1 → 10 → 9 → 11 → 21 → 22 → 23 → 24 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 36 → 29 → 17 → 18 → 19 → 20 → 12 → 13 → 8 → 7 → 14 → 15 → 6 → 16 → 5 → 4 → 3 → 2	760.8
4	1 → 10 → 11 → 21 → 22 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 26 → 23 → 24 → 20 → 19 → 18 → 36 → 29 → 17 → 16 → 5 → 4 → 6 → 15 → 14 → 7 → 3 → 8 → 13 → 12 → 9 → 2	751.7
5	1 → 10 → 11 → 21 → 22 → 23 → 24 → 20 → 19 → 18 → 28 → 27 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 36 → 29 → 17 → 16 → 5 → 4 → 6 → 15 → 14 → 7 → 3 → 8 → 13 → 12 → 9 → 2	762.3
6	1 → 10 → 11 → 21 → 22 → 23 → 24 → 20 → 19 → 18 → 28 → 27 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 36 → 29 → 17 → 16 → 5 → 4 → 6 → 15 → 14 → 7 → 3 → 8 → 13 → 12 → 9 → 2	762.3
7	1 → 10 → 9 → 11 → 21 → 22 → 23 → 24 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 36 → 29 → 17 → 18 → 19 → 20 → 12 → 13 → 8 → 7 → 14 → 15 → 6 → 16 → 5 → 4 → 3 → 2	760.8

8	1 → 10 → 11 → 21 → 22 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 26 → 23 → 24 → 20 → 19 → 18 → 36 → 29 → 17 → 16 → 5 → 4 → 15 → 6 → 3 → 7 → 14 → 12 → 13 → 8 → 9 → 2	755.2
9	1 → 10 → 9 → 11 → 21 → 22 → 23 → 24 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 36 → 29 → 17 → 18 → 19 → 20 → 12 → 13 → 8 → 7 → 14 → 15 → 6 → 16 → 5 → 4 → 3 → 2	760.8
10	1 → 10 → 9 → 11 → 21 → 22 → 23 → 26 → 25 → 30 → 31 → 32 → 33 → 37 → 38 → 39 → 40 → 34 → 35 → 28 → 27 → 36 → 29 → 17 → 18 → 19 → 24 → 20 → 12 → 13 → 8 → 7 → 14 → 15 → 6 → 16 → 5 → 4 → 3 → 2	765.2

4. Conclusion

The platform to determine the possible short path is built, especially to determine the shortest path of the waste collection process. The route position model is built based on the measurement of the path. The optimization program is built based on the algorithm of the traveling salesman problem and ant colony optimization. Based on the conducted experiment and comparison with the real conditions, it can be concluded that the proposed program can determine the shortest route for a waste vehicle visit to the Sekip UGM Lecturer Residence with the shortest path length is 751.7 length units representing the baseline for the waste collection process. If the vehicle does not follow the recommended path, the fuel consumption will be higher. The algorithm should be designed to accommodate several road segments that should not be skipped but still be passable for future works. Subsequent research is carried out so that ants from the program cannot pass the roads that should be impassable.

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