Vehicle Routing Problem with Split Service, Time Window and Intermediate Facility for Municipal Solid Waste Collection in Surabaya City with Ant Colony Optimization Algorithm

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Abstract. The volume of waste production in the Surabaya City from 2013 to 2017 increase in line with the population growth in the Surabaya city. The number of vehicles owned by Dinas Kebersihan dan Ruang Terbuka Hijau is limited so that in satisfying the order from every LPS in Surabaya that must be collect by the compactor, the transportation needs optimization planning. The model for the case of MSW collection in Surabaya City is Vehicle Routing Problem with Split Service, Time Window and Intermediate Facility (VRPSSMTTWIF). The vehicles load from every LPS with deterministic demand and unload to LPA as an intermediate facility in this model. The vehicle will depart from the depot and return to the depot in a state of empty load during operating hours or with time window constraint. The vehicle will do the ritase more than once when not exceed the operational hours. In 1 LPS can be served more than once with the same vehicle or different according to the number of demand. In finding the optimal routes that have a minimum total distance value, this research using the approach methodology, metaheuristic with the ACO algorithm which is expected to be solved with faster computation time. The result is a new recommendation route with a total distance of 4256.7 km. The difference between the existing and recommendation route is 354.4 km by using 35 vehicles. The results of the sensitivity analysis show that with the current DKRTH vehicles, the number of 44 units of compactor is estimated to be able to handle the increasing demand until up to 20%.

1. Introduction
Surabaya City is a big city in Indonesia that has a high rate of population growth that supports the high rate of urban waste growth, so Municipal Solid Waste (MSW) management is very important to pay attention to creating good governance. MSW management is a multidisciplinary activity that includes several activities such as the separation of sources, storage, collection, transfer and transportation, management and recovery, and disposal [1]. With the limited number of truck compactor fleets that are believed to be the most efficient in processing garbage collection, Surabaya City needs to carry out the MSW Collection optimization process. This research focuses on developing the VRPSSMTTWIF model for MSW collection truck compactors in Surabaya City. To search optimal routes for minimum total distance, the approach used is Metaheuristic Method with ACO algorithm by considering 80 LPS and 1 LPA that should be visited also should refill fuel before returning to the depot. The ACO algorithm is expected to help search for optimal values well with faster computing time.
2. Literature Study

Naturally, the gathering process of trash is an aspect of Waste Management cycle that is the most important and costly, since the intensity of the work is very high and it requires a lot of truck in the gathering process [2]. In transportation case, the model that is the most common is VRP, which have been adjusted according to the needs of each problem cases. It also relates to this research in which MSW collection uses the basic model of VRP that have been adjusted to the needs.

Constraints time window is the limitation of the operational work time [3][4]. This constraints exist in this research. The vehicle that is used in MSW collection differs between each other depends on each its territory. But in general it uses a homogeny vehicle with a same capacity just like the one in this research. This kind of vehicle is different with the one that uses heterogenic vehicle in which the capacity of each vehicle differs between each other.

Time window and vehicle capacity fulfill the needs of all LPS which results in a lot of research to tried to find an optimal solution. One of them are to use a a model where one vehicle serve more than one route in a period of time [4]. The demand in a node could be divided so that one node could be visited by more than one vehicle [7]. Split service cant be avoided in MSW collection in surabaya city, because some deterministic demand on some LPS surpasses the capacity of the vehicle so there’s a need of recurring of activity on LPS with or without the same kind of vehicle.

Related to the last disposal place that is needed to be visited before the vehicle return to the depot, it is found that VRP need and additional support related to intermediate facility. Research use a multiple intermediate facility because it has more than one last disposal place after the vehicle is fully loaded. Intermediate facility that is chosen are the one that is closest according to its last loading of last disposal place before it reaches its maximum capacity [3][4][6][8]. This research uses the same one as in [9] which use one intermediate facility as its last disposal.

VRP and VRPTW are classified into NP-hard combinatorial problem. Using exact method on that problem may make it hard to be solved, long time in working for feasible solution and moreover it is very hard to find the optimal solution for minority cases. Heuristic model is a better method in giving solution compared to exact method since it gives a more reasonable amount of computation cost, but it doesn’t guarantee an optimal solution, it might only able to offer a near optimal and feasible solution. Heuristic model can only be used on specific problem, so the method that works on one cases cant be used on the other cases. Heuristic method in decision-making will yield a high quality solution for an important application in a lots of different kinds of problem in large scale. Metaheuristic are capable to solve some high difficulty level of combinatorial problems such as VRPTW [10].

Using the metaheuristic method in finding solutions and comparing with previous heuristic methods. The heuristic method used is taboo search, variable neighborhood search and variable neighborhood taboo search, the result with these three metaheuristic methods can reduce the total distance and total computing time used [3]. [11][12][13] uses ACO and [10] which adds 2 local searches in the ACO method is a search for solutions with different models, namely population based where solution improvements are made in populations not using single solution based, the result is a problem with size big ones can be done with less time. The addition of the heuristic local search method is needed to solve the effective multi compartment vehicle problem.

Ant Colony Optimization (ACO) is included in the swarm intelligence group, which is one type of development paradigm used to solve optimization problems where the inspiration used to solve the problem stems from the behavior of the collection of ants. Ant Based Techniques were first used by [14] by using ACO to solve TSP cases. ACO has been applied in various fields, including ACO for VRP [13] Capacities Vehicle Routing Problem (CVRP) [15] and in 2018 ACO is still used in developing VRP cases including research [16] which completes multi-trip capacities arc routing problem models for cases of urban waste disposal.

This research is an Np-hard problem, the size that must be solved is also not small so that the ACO method will be used in finding a solution in the hope that it can get a route solution with a total distance better than before and in fast computing time.
3. Methodology

3.1. Data Collecting

This study uses the historical data of DKRTH, direct observation and google maps application. The detail is:

1. Data of 80 LPS served by truck compactors in all points in Surabaya City.
2. The number of different demands for each LPS with container units.
3. Data on 44 vehicles with 35 container truck capacity.
4. Time windows for operating hours where new vehicles will be served on all LPS accordingly at 05.00 WIB and must return to the depot at 15.00 WIB.
5. Distance data are between LPS and depot, between each LPS, between LPS and LPA with Google Maps.
6. Travel time data are between LPS and depot, between each LPS, between LPS and LPA with Google Maps.
7. Service time is assumed to be constant for loading containers in 1 minute LPS per container, unloading truck compactors at LPA 60 minutes and refill fuel requires 30 minutes.

3.2. Data Processing

The conceptual model of system under discussion is given in Figure 1. Each vehicle will depart and return to the depot during operational hours \((a, b) = (a, 900)\). a flexible here according to the initial route to be addressed. The vehicle must return in the 900th minute. Vehicle 1 in gray takes garbage at LPS 1 followed by LPS 2. In Figure 1 it is assumed that at most vehicles can carry as many as 2 containers, therefore in vehicle 1 after transporting 1 container from LPS 1 and 2 will go to LPA to do the unloading process. Vehicle 1 transports 2 containers of LPS 2 and unloads again, fills fuel and returns to the depot before or during the 900th minute. This means that LPS 2 can be served twice with vehicles 1. The vehicle 2 which is green starts the journey by taking 1 container of garbage in LPS 2. This states that LPS 2 can be served in a split service, which means it can be served more than once with the same vehicle or with a different vehicle.

There are 2 main steps in the development of the ACO algorithm, namely: generation of TSP route and separate into several VRP sub routes that are adjusted to existing constraints, or in other words this research uses "route first cluster second", model flow diagram can be seen in Figure 2. In the development of the ACO algorithm requires several parameters that must be tested in several replications in order to get the optimal objective value. The testing of all algorithms in this study will be conducted with Matlab software with computer specifications: Intel® core™ i3-3110m CPU @ 2.40GHZ 6GB RAM. Each combination of parameter values will be tested for 10 replications. The evaporation value to be tested is \(\rho = (0.9)\) because the value is believed to be able to provide relatively optimal results for VRP cases \([10][11][14][13]\). There is no provision regarding the parameters of the number of ants and the maximum number of iterations, so in this study using the number of ants = \([5, 10, 15]\) and the maximum number of iterations = \([500, 1000, 1500]\).
where: first route
    second route

Figure 1. Conceptual Model

Table 1 is the best test results for each combination of the parameters tested for 10 replications. From the previous considerations, it was decided in this study to use the parameters of evaporation value ρ = 0.9, the number of ants N = 10 and iterations = 1500. The choice of this parameter is because iterations 1500 have a smaller standard deviation than the 1000 iterations, parameters will be used to test large sample data for MSW collection cases in Surabaya City. Table 2 Results that the minimum value of 10 replications carried out is in the 5th replication with the objective function value of 4265.7 km.

Table 1. System Parameters

| Description          | Min     | Mean   |
|----------------------|---------|--------|
| Total Distance       | 4252.2  | 4358.06|
| Parameter            | [0.9,10,1000] | [0.9,10,1500] |
| Number of Vehicle    | 35      | 35.2   |

Distance in km, the parameter is [ρ, N, iteration] and the vehicle in units

Table 2. Result 10 replications of ACO Model

| No | Objective Function | Number of Vehicle | Time   | No | Objective Function | Number of Vehicle | Time   |
|----|--------------------|-------------------|--------|----|--------------------|-------------------|--------|
| 1  | 4335.2             | 35                | 16.5781| 6  | 4314.6             | 36                | 17.4688|
| 2  | 4291.5             | 36                | 15.8281| 7  | 4343.2             | 36                | 15.8594|
| 3  | 4344.3             | 35                | 15.5469| 8  | 4333               | 36                | 16.0469|
| 4  | 4311.9             | 36                | 17.6094| 9  | 4393.2             | 35                | 16.3906|
| 5  | 4265.7             | 35                | 15.6563| 10 | 4408.5             | 35                | 16.4688|

Objective value (km), number of vehicles (units) and time (seconds)

From the results of the sensitivity analysis in Table 3, it is known that the algorithm model used in this study can well adapt to changes in the number of demand in each LPS. The result shows that if the number of vehicles in the Surabaya DKRTH
is 44 units, with an increase of around 20%, the vehicles owned, it is estimated that it is still able to take out garbage in each LPS with a note that all vehicles are not down. If up to 30% of the demand increases, using 44 units of vehicles is estimated not to be able to take all the garbage in one operational day.

Figure 2. Flowchart of Developing ACO Algorithm
Table 3. Sensitivity Analysis

| Scenario          | Total Demand | Objective Function | Number of Vehicle | Time comp. |
|-------------------|--------------|--------------------|-------------------|------------|
| Existing          | 2811         | 4611.1             | 44                | -          |
| Recommendation    | 2811         | 4256.7             | 35                | 15.6563    |
| Increase 10%      | 3119         | 4863               | 39                | 17.6094    |
| Increase 20%      | 3391         | 5223               | 43                | 18.2344    |
| Increase 30%      | 3675         | 5826.1             | 48                | 18.2656    |
| Increase 40%      | 3950         | 5965.6             | 52                | 18.7188    |
| Increase 50%      | 4228         | 6494.2             | 55                | 18.7813    |

Objective value (km), number of vehicles (units) and time (seconds)

4. Case Study

This study took a case study at the MSW collection in Surabaya City. Refer to Regulation of Minister of Public Works in Republic of Indonesia Number: 03/PRT/M /2013, that waste transportation activities should consider: transportation patterns, types of equipment or transportation facilities, transportation routes and financing aspects. The focus of this study is transportation system using mechanical Stationary Container System (SCS). SCS is a garbage collection system in which the collection container is not carried around (fixed), where the container is lifted or cannot be removed. This system is usually used for small containers with compactor truck conveyors.

In the existing routing Surabaya City Government requires 44 truck compactors to meet the needs of all demand in each LPS. But there are 2 vehicles that still have to return to the depot beyond the operating hours. This study calculates the minimum total number of vehicles needed which has a minimum total distance consider the research limitations and assumptions.

5. Result and Discussion

The parameters used in the ACO model test for the MSW collection in Surabaya City were obtained from testing several parameters with 10 replications in each combination. The result of the selected parameter is a parameter that has a small standard deviation can provide a minimum objective function value. The recommended route generated by the ACO algorithm model with 0.9 evaporation value parameters, 10 ants and a maximum iteration of 1500 for the MSW collection in Surabaya City produces an objective function value of 4265.7 km. The value of the objective function is obtained by using the number of vehicles of 35 units. The route is generated in a computing time of 17.04 seconds which is the 5th replication of 10 replications. The number of vehicles used is still below the number of vehicles currently owned by DKRTH. So that with every demand LPS will be able to be served all and also still have spare compactor trucks that will stay at the depot. One reason is the neglect of compaction ratios in compactor truck vehicles and several other policies that were not considered or perfectly included in this study. For example, time to refuel, travel time obtained from Google Maps and queues that exist on a node. The assignment of vehicles recommended in this study is to use 35 units of compactor truck vehicles according to the test results using the ACO model. Existing assignments do not violate existing constraints both in terms of capacity and time window with all demands on each LPS served by all.

The algorithm developed based on the results of sensitivity analysis shows that algorithms are able to properly adapt to changes in demand, this is needed by DKRTH because during certain events there is a frequent increase in demand. at that time, if not properly planned, the garbage in the city community cannot be taken by all and can disrupt the journey the next day or the city community becomes disturbed.
6. Conclusion
Conceptual models and ACO algorithms has been developed for decision making in determining route of truck compactor vehicles, number of vehicles needed and scheduled departure for each route in the case of the MSW collection in Surabaya City. Based on the test results of ACO algorithm model for the case, comparison between the existing route and the recommended route is obtained, the total distance traveled by recommended route is 4256.7 km using 35 vehicles. The results obtained are smaller than the existing route of the difference of 354.4 km and the difference in vehicle is 9 units. Assignment of vehicle recommendations is based on the test results of ACO algorithm model. The vehicles needed are 35 compactor trucks. Based on the results of sensitivity analysis, it was found that the algorithm model used in this study could well adapt to changes in number of demand in each LPS. The result is that up to a 20% increase in demand, it is still able to take all garbage demand in each existing LPS.

For future research, we suggest model integrates distance and travel time in real time and makes the user interface of ACO algorithm so that it can be easily used even by common people.

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