Optimization of municipal waste collection scheduling and routing using vehicle assignment problem (case study of Surabaya city waste collection)

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Abstract. Waste collection and disposal become a major problem for many metropolitan cities. Growing population, limited vehicles, and increased road traffic make the waste transportation become more complex. Waste collection involves some key considerations, such as vehicle assignment, vehicle routes, and vehicle scheduling. In the scheduling process, each vehicle has a scheduled departure that serve each route. Therefore, vehicle’s assignments should consider the time required to finish one assignment on that route. The objective of this study is to minimize the number of vehicles needed to serve all routes by developing a mathematical model which uses assignment problem approach. The first step is to generate possible routes from the existing routes, followed by vehicle assignments for those certain routes. The result of the model shows fewer vehicles required to perform waste collection as well as the number of journeys that the vehicle to collect the waste to the landfill. The comparison of existing conditions with the model result indicates that the latter’s has better condition than the existing condition because each vehicle with certain route has an equal workload, all the result’s model has the maximum of two journeys for each route.

1. Introduction

Population growth in a country can affect the rate of waste production. This waste problem must be handled properly, especially in urban areas. Municipal solid waste (MSW) is a multidisciplinary activity that includes several activities such as source separation, storage, collection, transfer and transport, processing and recovery and also disposal [1]. The complexity of this MSW problem will increase the importance of planning or policy-makers to find an effective and sustainable way for the collection and disposal of MSW [2] [3].

A municipal waste transfer and transportation activity covers the transportation process, determining vehicles route and scheduling vehicles departure process. This problem is specific for Stationary Container System (SCS) where the vehicle is traveling to several nodes and pick up the garbages until the container is full. The vehicles route is determined in the beginning of process by optimizing the
fastest travel time on the sequence of visits combination at each point of garbage collection. From the selected route then the vehicle move to serve to the other routes. This distribution problem involves some key considerations, from number of fleet and vehicle’s routes including their scheduling [4]. Waste transport system can be modeled as a variant of the vehicle routing problem (VRP) in the presence of the compound and facilities between intermediate facility [5].

The research of [6] aims to collect garbage using waste collection vehicle routing problem with time windows (WCVRPTW) model to minimize the cost route by considering all waste must be transported to the disposal site within each customer time window. In this planning process, each vehicle has a departure schedule to serve each route which is determined by the start opening hour of the depot and the cycle time for each route. Route Sequencing on each route is intended to minimize the number of vehicles needed to serve all existed routes. [7] designs the daily truck schedule with each truck has a fixed route and empty cargo in several recycling operations. [2] founds that a route scheduling garbage collection is influenced by several factors, including the number of stops, the number of accumulated trash, road access, workers’ schedules, and capacity of the container.

Surabaya is a the largest population city in East Java. This will affect the level of waste in Surabaya which triggers problems related to garbage. Surabaya provides several places and its vehicles for garbage collection on any residential areas to final processing. Waste volume is significantly increased while the activity of transporting waste transfer and transport are not yet optimally applied, so that city officials need to conduct operational strategy to be able to optimize the use of the vehicle in the depot to all routes of transporting waste. Surabaya has 37 compactor trucks with a capacity of 40 garbage containers to be operated in 60 locations in transporting garbage collection points and one landfill. Each location has a deterministic garbage collection request.

In this research, transportation and scheduling problems in the municipal waste is modeled by developing a mathematical model in the form of Integer Linear Programming (ILP) with considering the cycle time for all existing routes. The objective of this research is to minimize the number of vehicles used to serve meeting the demand for garbage collection, to schedule departure time of the vehicles, and to determine the sequence route for vehicles used on each existing route.

2. Literature review

2.1 Municipal solid waste
Municipal Solid Waste is universally recognized and used to calculate the expenses of solid waste management [8]. Thus, planners or policymakers try to find an efficient and sustainable way for collection and disposal of municipal solid waste [3]. To reduce waste collection and transportation cost, the city government is motivated to develop new strategies for collection and transportation of waste, especially in downtown [1].

2.2 Assignment problem
Generally, assignment problem is one of the fundamental combinatorial optimization problems in optimization which tries to match all supplies and demands equal to one [9]. Thus, the assignment problem is characterized by how to assign each point of supply for each point of demand. Assignment Problem becomes more complicated if the incidence varies in duration, and each event must occupy only one task for the entire duration of the assignment [10]. One of the implementation of this method is to determine the class into classroom by proposing a simple heuristic procedure [11].

2.3 Route sequencing
Route Sequencing determines the vehicle assignment on a route considering the time takes for a vehicle on one route. [12] develops a model that vehicle routes is designed from existing route and scheduling methods. It is assumed that the existing service is assigned to a particular vehicle. If the service has a short duration of time, the use of vehicle is not optimal, based on existing time horizon. It is intended
that a route starts after the first service is completed, the vehicle then is available to be assigned to the second route, and so on until specified time horizon is completed. The example of route sequencing in vehicle routing problem is shown in figure 1. Therefore, the number of vehicle needed could be determined by sequencing these placements. Sequencing the route with this method has an objective to minimize the number of vehicle needed to serve all existed routes. Although these procedures are manually sorted, the computer program can be used to integrate routing and vehicle scheduling to provide a plan for the entire vehicle.

**Figure 1.** Route sequencing.

### 3. Model of Vehicle Assignment Problem

This study develops a model based integer linear programming. The model starts from existing condition which a route consists of multi trips. The route sequencing is calculated based on the calculation of operational travel time (cycle time), composed of the vehicle’s travel time and service time at each temporary disposal site and the number of demand transported by truck compactor. The objective of this research is to minimize the number of vehicles used to serve all temporary disposal site and to schedule the vehicles departure times for each destination route.

The formulation used for this study can be defined as ($i$) for vehicle destination route and ($j$) for vehicle departure time per hours. This parameters and decision variables of this model are as follow:

**Parameters:**

- $D_i$ = Number of demand on route $i$.
- $TS_{ij}$ = Time slot for every destination route $i$ in departure time $j$.
- $n$ = Minimal number of cycle from departure vehicles every hour.
- $m_i$ = Maximum number of cycle on destination route $i$.
- $CT_i$ = Cycle time for every destination route $i$.

**Decision variables:**

- $Y$ = Number of vehicles used.
- $Rit_i$ = Number of cycle for every destination route $i$.
- $X_{ij}$ = The cycle for destination route $i$ in departure time $j$.

The mathematical model of this vehicle assignment problem is as follow:

\[
\text{Minimize} : Y
\]

\[
\text{Subject to:}
\]

\[
\sum_{j=1}^{J} TS_{ij} \times X_{ij} = Rit_i \quad \forall i \in I
\]

\[
\sum_{j=1}^{J} Rit_i \times CT_i \leq Y \times J \quad \forall i \in I
\]

\[
\sum_{j=1}^{J} TS_{ij} \times X_{ij} \geq D_i \quad \forall i \in I
\]

\[
\sum_{i=1}^{I} TS_{ij} \times X_{ij} \leq n \quad \forall j \in J
\]
\[ T_{S_{ij}} \times X_{ij} \leq m_i \quad \forall i \in I, \forall j \in J \]  
\[ \sum_{i=1}^{I} \sum_{j=1}^{J} T_{S_{ij}} \times X_{ij} \leq n \times J \]  
\[ X_{ij} = \text{Integer} \]  
\[ Y = \text{Integer} \]

The objective function (1) is to minimize the number of vehicles to meet the waste transportation demands. Constraint (2) is to find the total cycles for each destination route. Constraint (3) is to ensure that number of vehicles are enough to serve the system. Moreover, constraint (4) ensures that all destination routes must meet the demand. Constraint (5) ensures that every vehicle in one hour on the transport cycle must in the minimum number of vehicle dispatched. Constraint (6) explains that every destination route and every departure time should be less or equal than the maximum number of cycle on destination route. Constraint (7) ensures that transport cycle in one day should not exceed the total cycle. Constraint (8) and (9) enforce decision variables are integer.

4. Discussion
This existing routes defined by Surabaya City Council become the input in calculating cycle time in every route to determine the route sequencing. The calculation of cycle time for each vehicle on the existing routes can be seen in table 1. Based on the data of table 1, the number of vehicle that can be used during waste collection process is calculated. The result shows that the minimum vehicle that need to be used are 19 compactors of which has 6 cycle. Maximum number of cycle in every route is 3 cycles.

Based on the existing route, a new route is generated by considering the truck compactor’s capacity and the number of containers in temporary disposal site. If a new destination is created when a container cannot be transported by the existing vehicle, it must be served by another vehicle by considering travel time between locations and by using with the nearest neighbour algorithm. The travel time is calculated based on the in real time from Google Maps. The cycle time of a new route can be seen in table 2. The new route shows that the optimal minimum number of vehicle is 13 truck compactors of which has 5 cycles for all routes and the maximum number of cycles in one route is two.

| Routes | Ritase | Cycle Time (Hours) | Routes | Ritase | Cycle Time (Hours) |
|--------|--------|-------------------|--------|--------|-------------------|
| Route 1 | 1      | 3.07              | Route 17 | 1      | 3.68              |
| Route 2 | 2      | 5.97              | Route 18 | 1      | 3.79              |
| Route 3 | 1      | 3.20              | Route 19 | 1      | 3.12              |
| Route 4 | 2      | 6.40              | Route 20 | 1      | 3.25              |
| Route 5 | 1      | 3.28              | Route 21 | 1      | 2.97              |
| Route 6 | 2      | 3.23              | Route 22 | 1      | 3.45              |
| Route 7 | 1      | 3.69              | Route 23 | 1      | 3.05              |
| Route 8 | 1      | 2.96              | Route 24 | 1      | 2.51              |
| Route 9 | 1      | 3.45              | Route 25 | 1      | 3.10              |
| Route 10 | 1     | 3.19              | Route 26 | 2      | 5.49              |
| Route 11 | 1     | 3.75              | Route 27 | 2      | 5.14              |
| Route 12 | 1     | 3.18              | Route 28 | 2      | 5.11              |
| Route 13 | 1     | 3.30              | Route 29 | 1      | 3.09              |
| Route 14 | 1     | 3.43              | Route 30 | 1      | 3.81              |
| Route 15 | 1     | 3.20              | Route 31 | 1      | 3.40              |
| Route 16 | 1     | 2.97              |        |        |                   |
Table 2. The cycle time on the new routes.

| Routes | Ritase | Cycle Time (Hours) | Routes | Ritase | Cycle Time (Hours) |
|--------|--------|--------------------|--------|--------|--------------------|
| Route 1 | 1      | 3.07               | Route 19| 1      | 2.51               |
| Route 2 | 1      | 2.63               | Route 20| 1      | 3.12               |
| Route 3 | 1      | 3.17               | Route 21| 1      | 3.25               |
| Route 4 | 1      | 3.02               | Route 22| 1      | 2.81               |
| Route 5 | 0      | 2.00               | Route 23| 2      | 4.97               |
| Route 6 | 2      | 5.21               | Route 24| 1      | 3.24               |
| Route 7 | 3      | 8.93               | Route 25| 1      | 3.71               |
| Route 8 | 2      | 5.26               | Route 26| 1      | 2.51               |
| Route 9 | 2      | 5.43               | Route 27| 2      | 5.41               |
| Route 10| 1      | 2.72               | Route 28| 1      | 2.50               |
| Route 11| 1      | 2.65               | Route 29| 2      | 5.62               |
| Route 12| 1      | 3.52               | Route 30| 1      | 3.77               |
| Route 13| 1      | 3.19               | Route 31| 0      | 1.77               |
| Route 14| 2      | 6.33               | Route 32| 1      | 2.53               |
| Route 15| 1      | 3.18               | Route 33| 1      | 3.07               |
| Route 16| 2      | 5.39               | Route 34| 1      | 2.63               |
| Route 17| 2      | 5.56               | Route 35| 2      | 4.41               |
| Route 18| 2      | 4.91               |         |        |                    |

Comparing the departure schedules between the existing data and the new route can be seen in table 3 and table 4 as seen in below:

Table 3. Vehicle Assignment Problem and Departure Schedule vehicles on existing routes.

| Vehicles | Departure Scheduled Time Routes | Vehicles | Departure Scheduled Time Routes | Vehicles | Departure Scheduled Time Routes |
|----------|---------------------------------|----------|---------------------------------|----------|---------------------------------|
| Vehicle 1| 5 Route 27 10 Route 22          | Vehicle 8| 7 Route 16 11 Route 3           | Vehicle 14| 9 Route 30                      |
| Vehicle 2| 5 Route 29 10 Route 24          | Vehicle 9| 7 Route 17 11 Route 4           | Vehicle 15| 9 Route 32 11 Route 13          |
| Vehicle 3| 5 Route 35 10 Route 25          | Vehicle 10| 8 Route 6                      | Vehicle 16| 9 Route 33 12 Route 15          |
| Vehicle 4| 6 Route 7                        | Vehicle 11| 8 Route 8                      | Vehicle 17| 9 Route 34 12 Route 2           |
| Vehicle 5| 6 Route 18 10 Route 26          | Vehicle 12| 8 Route 9                      | Vehicle 18| 10 Route 20 12 Route 10         |
| Vehicle 6| 6 Route 23 11 Route 1           | Vehicle 13| 9 Route 28 11 Route 12         | Vehicle 19| 10 Route 21 12 Route 11         |
| Vehicle 7| 7 Route 14 12 Route 19          |          |                                |          |                                 |

Table 4. Vehicle Assignment Problem and Departure Schedule Vehicles on a new routes.

| Vehicles | Departure Scheduled Time Routes | Vehicles | Departure Scheduled Time Routes | Vehicles | Departure Scheduled Time Routes |
|----------|---------------------------------|----------|---------------------------------|----------|---------------------------------|
| Vehicle 1| 5 9 11                           | Vehicle 6| 7 8 11                           | Vehicle 10| 7 10                            |


Both tables show the vehicle assignment problems on every route of which table 3 shows on each existing route while table 4 shows on each new route. Each vehicle can be assigned to transport on all routes due to homogeneous compactor vehicles. The differences in the number of route served by one vehicle are influenced by the cycle time on each route. If the cycle time on one route reaches the deadline of the specified departure time, then the vehicle can serve one or two routes more. This activity will form route sequencing.

Having the model for vehicle assignment problems, we perform a sensitivity analysis. The sensitivity analysis is done by changing the demand in destination route’s parameter (Di). The changes of demand value will affect the number of truck compactor used which consequently limit the number of vehicles depart from depot for each hour (n), the maximum number of cycle performed by vehicle on each destination route (m) and the total cycle time (CT) for each condition. The sensitivity result of changes in demand can be seen in table 5:

| Total Demand (Di) | Number of route | Objective function | Number of Ritase Vehicle Depart in every hour (n) | Maximum ritase (m) | Total Cycle Time (CT) per day |
|------------------|-----------------|--------------------|-----------------------------------------------|-------------------|--------------------------------|
| 1297 (Existing)  | 35 Route        | 19 Vehicle         | 6                                            | 3                 | 133.98                         |
| 1297 (New Route) | 31 Route        | 13 Vehicle         | 5                                            | 2                 | 113.25                         |
| 1427 (Increase 10%) | 32 Route      | 17 Vehicle         | 5                                            | 2                 | 124.51                         |
| 1556 (Increase 20%) | 32 Route      | 20 Vehicle         | 6                                            | 3                 | 136.59                         |
| 1816 (Increase 40%) | 30 Route      | 28 Vehicle         | 9                                            | 4                 | 154.77                         |

The increase demand in temporary disposal site will be directly proportional to the number of truck compactor needed, maximum number of cycle transported by vehicle and the total cycle time required to transport the demand to all destinations per day. As seen in table 5 above, the changes in demand has a significant influence to another parameter.

5. Conclusions

Based on the results using the model of vehicle assignment problems on generating a new route, it is obtained that the minimum number of vehicle required is 13 out of 37 truck compactors owned by Surabaya City Council. Also, the minimum number of cycle vehicle for each departure time is 5 cycle and maximum number of cycle is two for each destination route. Total number of truck compactor and its departure schedules are used for daily operations of transporting waste to all temporary disposal site served by the Surabaya City Council. Changes in demand affects the number of vehicle needed from existing destinations. The larger demand, the larger number of vehicle to transport the waste. Also, the larger the demand, the more frequency the truck serving in temporary disposal site. The increasing demand in temporary disposal site also affects the cycle time on each of destination route. The cycle time for this destination route is influenced by time to transport in each temporary disposal site and number of demand that must be transported by truck compactor on each destination route. In other words, the increasing demand will be directly proportional to the number of vehicle used, the number cycle of vehicle in every departed hour, and cycle time needed for a vehicle to serve every destination route by truck compactor.

For future research, the model of vehicle assignment problem can be developed to a heterogeneous vehicle with different capacity. Also, the model can be developed to area of decision support system, in
which the system will be integrated with Google Maps to generate solution directly when the rerouting of vehicle used is necessary.

6. References

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