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Article

Waste Collection Vehicle Routing Problem Model with Multiple Trips, Time Windows, Split Delivery, Heterogeneous Fleet and Intermediate Facility

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Abstract. Waste Collection Vehicle Routing Problem (WCVRP) is one of the developments of a Vehicle Routing Problem, which can solve the route determination of transporting waste. This study aims to develop a model from WCVRP by adding characteristics such as split delivery, multiple trips, time windows, heterogeneous fleet, and intermediate facilities alongside an objective function to minimize costs and travel distance. Our model determines the route for transporting waste especially in Cakung District, East Jakarta. The additional characteristics are obtained by analyzing the characteristics of waste transportation in the area. The models are tested using dummy data to analyze the required computational time and route suitability. The models contribute to determining the route of transporting waste afterward. The WCVRP model has been successfully developed, conducted the numerical testing, and implemented with the actual characteristics such as split delivery, multiple trips, time windows, heterogeneous fleets, and intermediate facilities. The output has reached the global optimal for both dummy and real data.

Keywords: Waste Collection Vehicle Routing Problem, split delivery, multiple trips, time windows, heterogeneous fleet, intermediate facility.

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1. Introduction

Municipal solid waste management is now a global concern and needs to be addressed [1]. The large increase in population along with consumer behavior change, including the overuse of packaging will have a positive correlation to the volume of waste produced every day [2]. The public waste collection points are usually extremely smelly, influence the hygiene, and damage the image of modern society [3]. Waste could cause toxic environmental pollutant which jeopardizes human, animals, plants, environment, and other living organisms [4]. The solid waste management system may be described as the management of all responsibilities, practices, procedures, processes, and resources establishing a system that manages waste and complies with environmental regulation [5].

The problem of municipal solid waste (MSW) can be solved by increasing the services for transportation waste. When the service exceeds the stakeholders' expectations, it can be rated excellent [6]. This paper discusses the transportation effectiveness from residential areas to a treatment facility through route optimization. Even more, route optimization plays an important role in the solid waste management process [7] due to cost, economic, and social impact [8].

Several studies were performed to tackle MSW in such ways. A previous study proposed the optimized paths for MSW collections using Geographical Information System (GIS) in India [9]. The previous study investigated the recyclable solid waste using Monte Carlo Simulation [10]. The utilization of the analytical hierarchy process (AHP), Group method of data handling (GMDH), and artificial neural network (ANN) simultaneously have also been conducted [1].

There are many studies have discussed the variety of optimization in waste transportation. There are three main components in a waste collection VRP: depot, treatment facility, and customers [11]. The traditional VRP problem has been tackled by its distinguishable characteristics such as multiple depots [12]. Basically in this paper, all drivers start their collections from a single depot [11]. The characteristics such as split delivery, multiple trips, and intermediate facilities are considered to minimize the cost of travel. The characteristics of split delivery and multiple trips comply with the typical transportation problem, which is the capacity of the transportation mode [13]. Another study discussed the route determination of waste transportation in Denmark by considering the time of transporting waste to minimize travel costs [14]. Besides, another study discussed the problem of transporting hazardous waste by considering lunch break, vehicle capacity, and different types of waste which requires special handling [8]. Research on VRP problems with time windows was also conducted in determining the distribution routes to minimize costs [14]. In that particular problem, a study proposed a neighborhood-based metaheuristic until all demand had been served, and routes were subject to a maximum duration constraint [15]. Another study discussed the determination of the waste transportation route which using the multiple neighborhood search method with heterogeneous fleet and flexible assignment of destination depots characteristics [16]. Also, another study discussed the determination of the waste transportation route with time windows and intermediate multiple depot facilities characteristics [14] and utilized the nearest neighbor algorithm [15].

The amount of waste produced per day will be directly proportional to the population in an area. Therefore, the increasing population growth surely means the increasing waste problem, especially in terms of transportation. This paper is based on the observation in Cakung District, which is the most populated and the largest waste-producing region compared to other districts in East Jakarta. Currently, Cakung District still has not been transported about 11.6 tons out of 262 tons of waste produced per day.

When it comes to the waste transportation route determination, the waste collection vehicle routing problem model is used. This problem may be started as the customer's order (waste waiting at the collection points to be transported) and ended by sending the final product to the customer (sending waste to the treatment facility) [17]. Our model is developed by analyzing the characteristics of waste transportation in the Cakung District. The characteristics of split delivery allow the collection point to be visited by more than one vehicle, while the characteristics of multiple trips allow vehicles to visit other collection points after unloading in the treatment facility. Also, the characteristic of time windows is used to limit the visiting hours of the vehicle and the characteristics of the intermediate facility require each vehicle to visit the treatment facility before returning to the depot. The last characteristic is a heterogeneous fleet which is used to determine the vehicle to be used to transport waste according to a certain rule. The rule assigns the largest vehicle capacity to transport waste from the collection point with the largest waste volume. These mentioned characteristics above are considered in determining the applicable route in a particular area.

According to the explanation above, it is known that this study develops a model for determining waste transportation routes with the characteristics of multiple trips, time windows, split delivery, heterogeneous fleet, and intermediate facilities. This paper aim is to minimize the distance and traveling costs of the vehicles. Later, the developed model proceeds to the numerical test in 7 different villages.

2. Literature Review

Transportation is the activity of moving goods and passengers from one place to another place [18]. The most important element in transportation is the endless effort to keep costs as low as possible [19]. Waste is unwanted leftover goods or materials from the result of a particular process and is usually managed through landfilling. Landfilling is a common option due to its simplicity and economic advantages [20]. In this context, the land must be maintained in good physical structure [21]. Besides, the transportation issue is an interesting discussion in minimizing costs. The vehicle routing problem was originally proposed by Danzig and Ramses in 1950, which discussed the routing of vehicles to serve a given number of customers. The traditional vehicle routing aims at reducing the total operating costs of the vehicles. A reduction in cost partly comes from the use of better routes, which leads to a reduction in the total distance traveled [22]. Another paper minimize the total cost, that is, the conventional vehicle cost, plus the occasional drivers' compensation [23]. Another investigation included the buying cost into the cost of transportation [10]. A penalty cost is also added when the delivery is tardy [24]. A study defined the transportation cost as stochastic travel time [25]. In this paper, the traveling cost per km is approximated by the travel distance.

The Waste Collection Vehicle Routing Problem (WCVRP) is the waste collection problem consists of routing vehicles to collect waste while minimizing the cost of travel. WCVRP differs from the traditional VRP due to the waste-collecting vehicles must empty their load at disposal sites. The vehicles must have been emptied when returning to the depot. WCVRP also carries the number of characteristics and constraints that complicate the routing and require special handling [8].

Waste transportation is an operational activity that starts from the collection points to the treatment facility [9]. The systems of the waste collection are known as [26]:

- Hauled Container System
  The hauled container has 2 systems that the systems known as conventional hauled container systems and modified hauled container systems. In conventional hauled container system, the collection truck picks up the filled container of waste from the source point and moves straight to the disposal site, and then returns the emptied container to its original point of collection. In a modified hauled container system, the collection crew sets out of the station with an empty bin and at the first station, the bin is dropped off while the filled bin at the site is collected and taken to the disposal point. The filled waste bin whose content has been disposed of from the previous site is then taken to the next source and dropped off as the new empty bin for that source. Then, the filled bin on site is taken for disposal and then dropped off at the next source. This loop continues for as many sources as there are in the collection plan.
- Stationary Container System
  This system is characterized by a continuous collection of waste from source to source until all the sources for which waste is to be collected from have been exhausted and the waste vehicle is ready to return to the disposal site. The vehicle is limited by the capacity constraints it may have to go to the disposal site when it is full.

The general structure of the problem involves a single depot, a set of fixed location satellites where transshipment activities take place, a set of heterogeneous vehicles which are responsible for delivering goods to customers [27]. Even though this paper does not point out closely the reason behind the depot location selection, it is necessary to understand the logic of a single depot. The choice of having a single depot is motivated by a variety of taxes and infrastructural costs [27]. This area is characterized by a sufficiently large parking area [27] to accommodate the fleet when they are not used.

A detailed model takes into account the presence of intermediate facilities and multiple trips in the service network [23]. A study proposed a Branch-and-Cut-and-Price algorithm while considering intermediate facilities and time windows simultaneously to coordinate the arrivals of the vehicles [28]. This study allows both customers and facilities to have time windows in which they can be visited [28]. Furthermore, a recent study examined multiple waste types, pickup and delivery constraints [29]. While another paper discussed the characteristics of multiple trips with time windows under a fleet of identical vehicles [24], this paper discusses the heterogeneous fleet. The previous research discussed the heterogeneous fleet and some intermediate facilities using a memetic algorithm with a local search procedure [27].

Another paper used a variable neighborhood search heuristic [23] while this paper utilizes the nearest neighbor algorithm. The nearest neighbor algorithm was introduced in 1983 and is a very simple and greedy algorithm because of every subsequent iteration. The heuristic searches for the closest customer to the last added customer into the route and adds it at the end of the route.

3. Model Development

This research was conducted in Cakung District, the data in this study was officially obtained from the Jakarta Environment Agency. This study discusses the waste transportation route where the collection points are the only place to load the waste. The data in this study are the location of collection points, the volume of waste from each collection point, the number and capacity of the used vehicles, loading and unloading time, and the velocity of the vehicle. After the data is completed, the next step is to develop the model.

Figure 1 shows the stages of the model development for determining the route of waste transportation. Our model development is performed by adding characteristics of waste transportation problems. The basic model of model development is the model of waste collection VRP with characteristics of multiple trips, split delivery, and intermediate facilities (WCVRPMTSDIF). The next stage of model development is adding the characteristics of time windows to the WCVRPMTSDIF model. The addition of time windows characteristics in the WCVRPMTSDIF model is known as WCVRPTWMTSDIF. After adding the characteristics of time windows, the model is not developed the correct route so the additional models are needed. The WCVRPTWMTSDIF requires 3 additional constraints to complement the model development. The first additional constraint avoids paths from the collection point to the depot (the treatment facility is visited before coming back to the depot). The second additional constraint is used to determine the duration of travel time by the vehicle. The last additional constraint required to non-negative of travel time. The function of the last additional constraint is to ensure travel time with a positive number. The final stage of model development is adding the heterogeneous fleet characteristics to the previous model. The additional characteristics of the heterogeneous fleet to the model are finally turning the model to WCVRPMTTWSDHFIF.

After the model development stage is completed, the next step is performing numerical testing. At this stage, the developed model is tested using dummy data. After the numerical test, the next step is analyzing the results of the numerical tests. The focus of analysis are computational time while satisfying constraints. The next step is the stage of data processing. The data processing used the collection points data in Cakung District. After the data processing, the next step is analyzing the formed route using Lingo 17.0 software. The last stage is to determine the conclusions and recommendations from the research.

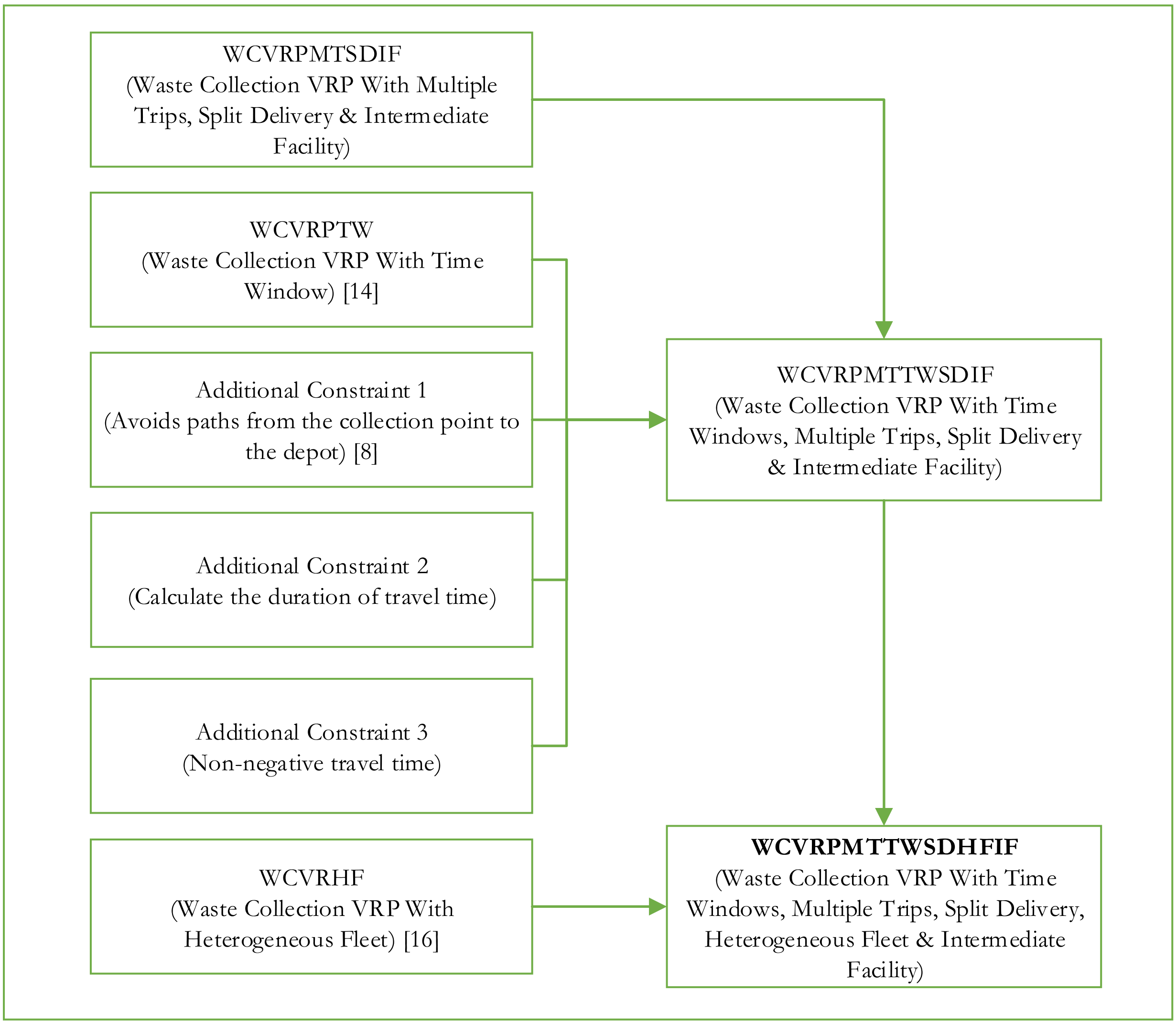

Fig 1. The Stage of Model Development.

4. Mathematical Model

Determination of waste transportation routes can be solved using the Mixed Integer Linear Programming (MILP) method. The following is a notation used in mathematical model development for determining the waste transportation route:

Sets:

N = sets of collection point that the volume of waste less then vehicle capacity $\{2, 3, ..., n\}$

M = sets of collection point that the volume of waste greater then vehicle capacity $\{n+1, n+2, ..., n+m\}$

V = sets of nodes $\{1, 2, ..., n, n+1, n+2, ..., n+m, n+m+1\}$, which node 1 is depot and $n+m+1$ is treatment facility

K = sets of vehicles $\{1,2, ..., k\}$

Index:

- i, j, p = index of nodes
- k = index of vehicles

Parameters:

- S_i = volume of waste in node i
- w_k = capacity of vehicle k
- c_k = unit-distance running cost of vehicle k
- d_{ij} = distance from node i to node j
- $BigM$ = positive constants
- v_k = velocity of vehicle (km/minute)
- L = loading and unloading
- $[twa, twb]_i$ = lower and upper of time window bound at point i
- Dur_{ijk} = duration time from node i to node j using vehicle k

Decision Variables:

- f_{ik} = the cumulative volume of waste at node i transported by vehicle k.
- Q_{ik} = the cumulative volume of waste on vehicle k at the point i
- R_k = the cumulative route of vehicle k.
- M_{ik} = start of service time of vehicle k at the point i
- x_{ijk} = 1 if i and j are, respectively, the origin and destination of vehicle k, 0 otherwise (binary variable)
- y_k = 1 if vehicle k is used, 0 otherwise (binary variable)

The mathematical model is used to construct the algorithm in determining the waste transportation route and the objective function is to minimize the distance and cost [8], [16]. The following is a mathematical model in the study.

Objective function:

$$Min\ Z = \sum_{k\in K}\sum_{j\in V}\sum_{i\in V} c_k d_{ij} x_{ijk} \quad (1)$$

Subject to:

$$\sum_{j\in N\cup M} x_{1jk} \le 1, \forall k \in K \quad (2)$$

$$\sum_{j\in N\cup M} x_{1jk} \le y_k, \forall k \in K \quad (3)$$

$$x_{ijk} \le y_k, \forall i,j \in V, \forall k \in K \quad (4)$$

$$\sum_{\substack{i\in V\\ i\neq p}} x_{ipk} - \sum_{\substack{j\in V\\ p\neq j}} x_{pjk} = 0, \forall p \in V, \forall k \in K \quad (5)$$

$$\sum_{k\in K}\sum_{\substack{i\in V\\ i\neq j}} x_{ijk} = 1, \forall j \in N \quad (6)$$

$$\sum_{k\in K} f_{ik} = 1, \forall i \in M, \quad (7)$$

$$\sum_{j\in V} x_{jik} \ge f_{ik}, \forall i \in M, \forall k \in K \quad (8)$$

$$Q_{ik} + S_j - Q_{jk} \le (1 - x_{ijk})\, BigM, \forall j \in N, \forall i \in V, \forall k \in K, \quad (9)$$

$$Q_{ik} + f_{jk}S_j - Q_{jk} \le (1 - x_{ijk})\, BigM, \forall j \in M, \forall i \in V, \forall k \in K \quad (10)$$

$$\sum_{i\in N\cup M} x_{i(n+m+1)k} \ge y_k, \forall k \in K \quad (11)$$

$$\sum_{i\in N\cup M} x_{i(n+m+1)k} = R_k, \forall k \in K \quad (12)$$

$$x_{(n+m+1)1k} = y_k, \forall k \in K \quad (13)$$

$$Q_{ik} \le w_k, \forall k \in V, \forall i \in V \quad (14)$$

$$Q_{1k} = 0, \forall k \in K \quad (15)$$

$$Q_{(n+m+1)k} = 0, \forall k \in K \quad (16)$$

$$x_{ii} = 0, \forall i \in S, \forall k \in K \quad (17)$$

$$Q_{ik} \ge 0, \forall i \in V, \forall k \in K, \quad (18)$$

$$0 \le f_{ik} \le 1, \forall i \in M, \forall k \in K \quad (19)$$

$$x_{ijk} = \{0,1\}, \forall k \in V, \forall i,j \in V, \quad (20)$$

$$y_k = \{0,1\}, \forall k \in K \quad (21)$$

$$Dur_{ijk} = \frac{d_{ij}}{v_k}, \forall i,j,k, i \neq j \quad (22)$$

$$M_{ik} \ge 0, \forall i,k, i \neq 1 \quad (23)$$

$$\sum_{i\in N\cup M} x_{i,1,k} = 0, \forall k \in K \quad (24)$$

$$twa_i \le M_{ik} \le twb_i, \forall i \in V, \forall k \in K \quad (25)$$

$$M_{ik} + L_i + Dur_{ijk} \le M_{jk} + (1 - x_{ijk}).BigM, \forall (i,j) \in V, \forall k \in K \quad (26)$$

$$\sum_{i\in N\cup M}\sum_{\substack{j\in N\cup M\\ i\neq j}} f_{ik}.x_{ijk} \ge \sum_{i\in N\cup M}\sum_{\substack{j\in N\cup M\\ i\neq j}} f_{ik}.x_{ijk}, \forall k \in K \quad (27)$$

Constraint (1) minimizes the distance traveled and traveling costs. Constraint (2) states not all of the vehicles will leave the depot. Constraint (3) ensures that the vehicles leaving the depot will be used to transport waste and constraint (4) guarantees that no node is visited by unused vehicles. Constraint (5) stipulates that the vehicle must leave the visited node. Constraint (6) and (7) correspond that collection point with the volume of waste less than equal to the maximum capacity of the vehicle will be visited exactly once ($S_i \leq \max \{w_k\}$ while constraint (8) states that collection point with the volume of waste greater than equal to the maximum capacity of the vehicle will be visited more than once ($S_i \geq \max \{w_k\}$). Constraint (9) and (10) ensure the amount of waste transported by vehicles will increase when the vehicle leaving the collection point. Constraint (11) enforces that each used vehicle must visit the treatment facility. Constraint (12) shows the number of trips, in other words, it is the frequency of each vehicle visiting the treatment facility. Constraint (13) imposes the vehicle has been used must return to the depot. Constraint (14) and (15) keep the amount of waste collected at each stop within the vehicle capacity constraint. Constraint (16) guarantees that the collected waste volume is reset to zero once the vehicle has visited a treatment facility, as well as in the particular instance when the vehicle leaves the depot. Constraint (17) and (18) stipulate that there is no trip on the same node while constraint (19) and (20) are a non-negative constraint. Constraint (21) imposes the binary condition. Constraint (22) states the correlation between travel time, distance, and speed. Constraint (23) ensures the start of service time is positive. Constraint (24) avoids paths from the collection point to the depot (the treatment facility is visited before coming back to the depot). Constraint (25) is a time window constraint for each collection point. Constraint (26) is service time from each collection point and constraint (27) states heterogeneous fleet constraint which the vehicle with the largest capacity will transport waste from the collection point with the largest volume of waste and so on.

4.1. Route Determination Algorithm

The mathematical model is used to build the algorithm to determine the waste transportation route, the route determination uses the nearest neighbor algorithm approach. Following is the steps to determine the waste transportation route using the nearest neighbor algorithm approach:

- Determine the number of vehicles and the capacity of the vehicle that will be used (Set $K = \{1,\ldots,k\}$) and the location of the depot.
- Determine the collection point to visit with the largest volume of waste (S_i) and with the closest location from the depot by considering the time windows from each collection point (*twa, twb*).
- For the collection point with the largest volume of waste (S_i) will visit by vehicles with the largest capacity (k) and vehicles will immediately visit the treatment facility to unloading the waste if $Wk \leq S_i$ while if $Wk \geq S_i$ then the vehicle will visit the next collection point.
- Calculate the residual at the collection point after the transportation process ($S_{i\ residual} = S_{i\ initial} - W_k$) or calculate the remaining capacity of the vehicle after picking process ($W_{k\ residual} = W_{k\ initial} - S_i$).
- For collection point with the closest distance from the depot will visit by vehicle with the smallest costs and must satisfy the existing time windows (*twa, twb*).
- Calculate the remaining capacity of the vehicle after transporting waste from the collection point ($W_{k\ residual} = W_{k\ initial} - S_i$) if $W_k \geq S_i$, while calculating the remaining volume of waste in the collection point ($S_{i\ residual} = S_{i\ initial} - W_k$) if $W_k \leq S_i$.
- If $W_k \geq S_i$ then the vehicle will go to the next collection point by considering the minimum distance and availability of time ($M_{ik} \leq twb$), if the time doesn't satisfy ($M_{ik} \geq twb$) then the vehicle will go to the treatment facility to unload the waste and return to the depot. Then if $W_k \leq S_i$ then the vehicle will go to the treatment facility to unload the waste.
- From the treatment facility, the vehicle will go to the closest collection point if the cost is minimum, compared to other vehicles and still satisfy the time limit ($M_{ik} \leq twb$). Otherwise, the vehicle will return to the depot.
- From the next collection point, the vehicle will go to the remaining collection point by considering the closest distance and minimum cost, compared to other vehicles and still satisfy the time limit ($M_{ik} \leq twb$). Otherwise, the vehicle will return to the depot.
- If all of the collection points still haven't visited and the collection point still has the remaining volume of waste then go back to step 1.

5. Computational Experiments

5.1. The Numerical Test

A numerical test is performed to verify the mathematical models that have been developed. The mathematical model test is using Lingo 17.0 software. The mathematical model test from model development is using dummy data, testing of dummy data is take 6 trials with different amounts of data i.e. 5 nodes, 6 nodes, 7 nodes, 8 nodes, 9 nodes, and 10 nodes. The function of testing data with a different number of nodes is to compare the running time from each amount of data.

Figure 2 shows the running time of dummy data will increase if the number of nodes to be visited increases. In addition to the running time, the results of numerical tests show that the constraints have been fulfilled and the status of the solutions for each dummy data test reaches global optimal.

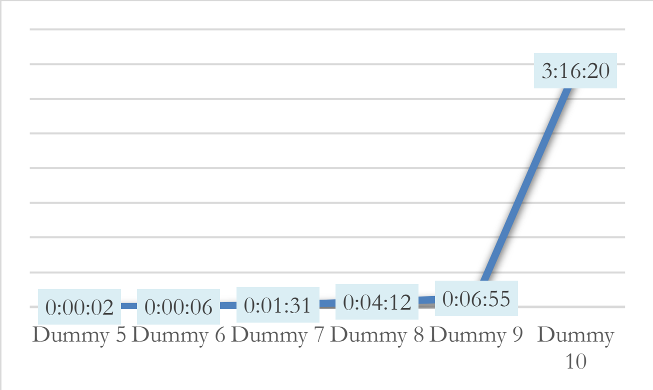

Fig. 2. Running Time of Lingo 17.0 Software on Dummy Data.

5.2. The Real Case Study

The waste transportation model that has been developed will be implemented in Cakung District, East Jakarta. Cakung District has 25 different collection points that are used in this research, the collection points are spread over 7 villages i.e. Rawa Terate Village, Pulo Gebang Village, Cakung Barat Village, Cakung Timur Village, Ujung Menteng Village, Jatinegara Village, and Penggilingan Village. The vehicle was officially obtained from the Jakarta Environment Agency. The following are the assumptions in the study:

- Only have 1 depot.
- Only have 1 treatment facility.
- The cost of travel per km is approximated by the travel distance.
- Loading and unloading time are 45 minutes.
- The number of time windows [0.480] indicates the driver works for 480 minutes or 8 hours.
- All vehicles have the same velocity (30 km/hour)
- Node 1 declares depot and the last node declares treatment facility (TF).
- BigM = 100000.
- All of the vehicles are in good condition.

Table 1, 2 and 3 show the data in Rawa Terate Village for example. Table 1 shows the waste volume and time windows. Depot and TF do not have anything to be picked, and the whole trip must be performed within 480 minutes or 8 hours.

Table 2 indicates the distance between nodes. There is no distance between the same nodes. Rawa Terate Village is nearer to the Depot rather than to the TF. The

Table 3 reveals the number and capacity of vehicles and travel costs per km. There are six vehicles with three farthest node from the TF is Node 2, which is 28.6 km away.

different capacity, dedicated to this particular village. The various capacity also means the variety of travel cost, which is ranging from IDR 12000 to 30000 per km.

Table 1. Location, Waste Volume and Time Windows for Rawa Terate Village.

Location	Volume (m^3)	Time Windows	
		twa	twb
Depot	0	0	480
Node 1	42	0	480
Node 2	12	0	480
Node 3	6	0	480
TF	0	0	480

Table 2. Distance Matrix in Rawa Terate Village. (km)

	Depot	Node 1	Node 2	Node 3	TF
Depot	0	5.4	5.6	4.5	30.1
Node 1	7	0	1.5	0.85	27
Node 2	7.4	1.5	0	1	27.7
Node 3	6.4	0.85	1	0	26.4
TF	32.7	26.8	28.6	28.4	0

Table 3. Capacity, Travel Costs and Number of Vehicles in Rawa Terate Village.

Code	Vehicle Capacity (m^3)	Travel Cost (IDR/km)
1	15	30000
2	15	30000
3	10	20000
4	10	20000
5	6	12000
6	6	12000

Table 4 shows the generated routes based on the available data in 7 different villages in Cakung District. This problem is solved using both Lingo 17.0 and the developed heuristics algorithm. This model successfully reduces the amount of waste that is not transported to zero in all villages. Even more, the global optimal solution has been reached with different computational time ranging from 0.11 seconds to 3 minutes 47 seconds.

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Table 4. Generated Route in Cakung District

Vehicle	Route	Transported Waste (m^3)	Completion Time (Minute)
	Rawa Terate Village (60 m^3)		
Vehicle 1 (15m^3)	Depot – Node 1 – Node 2 – Treatment Facility – Depot	15	268,6
Vehicle 2 (15m^3)	Depot – Node 2 – Treatment Facility – Depot	15	220,2
Vehicle 3 (10m^3)	Depot – Node 2 – Treatment Facility – Depot	10	220,2
Vehicle 4 (10m^3)	Depot – Node 2 – Treatment Facility – Depot	10	220,2
Vehicle 5 (6m^3)	Depot – Node 2 – Treatment Facility – Depot	4	220,2
Vehicle 6 (6m^3)	Depot – Node 3 – Treatment Facility – Depot	6	217,2
	Cakung Barat Village (29 m^3)		
Vehicle 1 (15m^3)	Depot – Node 4 – Node 5 – Node 6 – Treatment Facility – Depot	15	319
Vehicle 2 (15m^3)	Depot – Node 7 – Node 8 – Treatment Facility – Depot	14	267,6
	Cakung Timur Village (12 m^3)		
Vehicle 1 (6m^3)	Depot – Node 9 – Treatment Facility – Depot	6	236
Vehicle 2 (6m^3)	Depot – Node 9 – Treatment Facility – Depot	6	236
	Pulo Gebang Village (29 m^3)		
Vehicle 1 (12m^3)	Depot – Node 10 – Node 11 – Node 12 – Treatment Facility – Depot	12	309,8
Vehicle 2 (12m^3)	Depot – Node 13 – Node 14 – Node 15 – Treatment Facility – Depot	11	312,4
Vehicle 3 (6m^3)	Depot – Node 16 – Treatment Facility – Depot	6	224,2
	Jatinegara Village (37 m^3)		
Vehicle 1 (16m^3)	Depot – Node 17 – Treatment Facility – Depot	16	218
Vehicle 2 (10m^3)	Depot – Node 18 – Node 2 – Treatment Facility – Depot	10	266,8
Vehicle 3 (10m^3)	Depot – Node 2 – Treatment Facility – Depot	9	221,6
Vehicle 4 (2m^3)	Depot – Node 2 – Treatment Facility – Depot	2	221,6
	Penggilingan Village (24 m^3)		
Vehicle 1 (12m^3)	Depot – Node 19 – Node 20 – Treatment Facility – Depot	12	265,2
Vehicle 2 (12m^3)	Depot – Node 21 – Node 22 – Treatment Facility – Depot	12	264,2
	Ujung Menteng Village Route (22 m^3)		
Vehicle 1 (16m^3)	Depot – Node 23 – Node 24 – Treatment Facility – Depot	16	272,2
Vehicle 2 (6m^3)	Depot – Node 25 – Treatment Facility – Depot	6	222,4

Annotation:

Node 1; Swadaya Street	Node 13: Pulo Gebang Flat
Node 2: KRT Radjiman Street	Node 14: PTUN
Node 3: Damri	Node 15: PLN
Node 4: Palad Street	Node 16: Rawa Bebek Flat
Node 5: Albo Flat	Node 17: Arion
Node 6: Komarudin Street	Node 18: Polo Jahe Flat
Node 7: Cakung Market	Node 19: Penggilingan Street
Node 8: Tipar Cakung Flat	Node 20: Komarudin Flat
Node 9: Mahakam Street	Node 21: Pinus Elok Flat
Node 10: Soemarno Street	Node 22: Dr. Soemarno Street
Node 11: Terminal	Node 23: Raya Bekasi Street
Node 12: Post Office	Node 24: Metland Housing
	Node 25: Rawa Bebek Street

6. Conclusion

The WCVRPMTTWSDHFIF model for determining the waste transportation route in Cakung District using the nearest neighbor algorithm approach has successfully reduced the amount of waste that is not transported from each village to zero. Reduced waste always means a good impact on the process as a whole [30]. The determined route reaches the global optimal solution. The running time is exponentially and positively related to the number of nodes.

From the managerial point of view, this paper shows the importance of minimizing the transported waste in a particular area. This ensures the fleet management in optimizing fleet usage and effectiveness. When the fleet is used appropriately under the right assignment, there is no need to purchase an additional fleet, unless for replacement. When the condition leads to replacing the fleet, replacement analysis may be conducted in the future.

This paper assumes that the waste is ready to be picked at time zero. Therefore, this model needs to assume the waste arrival time at the collection points. Further research can also develop the model by considering the driver break time, the refueling location, and by using other heuristic methods such as sequential insertion or using metaheuristic methods such as simulated annealing, tabu search, ant colony, and particle swarm optimization. When the vehicles are waiting at customers and facilities, a cost or penalty may be given [28]. This condition could ensure the vehicle will be coming back to the depot as soon as the job has been done. It is also interesting to compare the fleet preventive maintenance policy where both periodic maintenance and routine maintenance [31]. This action may contribute to the availability of the fleet, which is still assumed ready every time in this paper.

References

[1] D. Purkayastha, M. Majumder, and S. Chakrabarti, "Municipal solid waste collection time optimization using AHP, GMDH and ANN," in *Advances in Waste Management*, A. S. Kalamdhad, J. Singh, and K. Dhamodharan, Eds. Singapore: Springer Singapore, 2019, pp. 43–57.

[2] H. Warnphen, N. Supakata, and V. Kanokkantapong, "The reuse of waste glass as aggregate replacement for producing concrete bricks as an alternative for waste glass management on Koh Sichang," *Eng. J.*, vol. 23, no. 5, pp. 43–58, 2019.

[3] S. H. Huang and P. C. Lin, "Vehicle routing-scheduling for municipal waste collection system under the 'keep trash off the ground' policy," *Omega*, vol. 55, pp. 24–37, 2015.

[4] J. Tancharoen and M. Rachakornkij, "Hazardous waste management in the Department of Environmental Engineering, Faculty of Engineering, Chulalongkorn University," *Eng. J.*, vol. 22, no. 2, pp. 39–46, 2018.

[5] S. Elsaid and E. H. Aghezzaf, "A framework for sustainable waste management: Challenges and opportunities," *Manag. Res. Rev.*, vol. 38, no. 10, pp. 1086–1097, 2015.

[6] H. Tannady, F. Nurprihatin, and H. Hartono, "Service quality analysis of two of the largest retail chains with minimart concept in Indonesia," *Bus. Theory Pract.*, vol. 19, pp. 177–185, 2018.

[7] H. Han and E. Ponce-Cueto, "Waste collection vehicle routing problem: literature review," *Promet - Trafffic Transp.*, vol. 27, no. 4, pp. 345–358, 2015.

[8] M. Dotoli and N. Epicoco, "A vehicle routing technique for hazardous waste collection," in *IFAC-PapersOnLine*, 2017, vol. 50, no. 1, pp. 9694–9699.

[9] S. Singh and S. N. Behera, "Development of GIS-based optimization method for selection of transportation routes in municipal solid waste management," in *Advances in Waste Management*, A. S. Kalamdhad, J. Singh, and K. Dhamodharan, Eds. Singapore: Springer Singapore, 2019, pp. 319–331.

[10] T. Chua, P. Sachakamol, and K. Phusavat, "A commercial feasibility study on recycled concrete aggregate (RCA) in Bangkok dealing with random parameters," *Eng. J.*, vol. 21, no. 3, pp. 133–155, 2017.

[11] A. M. Benjamin, K. R. Ku-Mahamud, and Z. Idrus, "Truck queuing analysis at landfill sites in a waste collection vehicle routing problem," in *Proceedings of the 6th International Conference on Computing and Informatics, Kuala Lumpur. Universiti Utara Malaysia*, 2017, pp. 132–138.

[12] P. Sanghatawatana, P. Pornchaiwiseskul, and M. Lohatepanont, "Redesign of three-echelon multi-commodity distribution network," *Eng. J.*, vol. 23, no. 1, pp. 49–74, 2019.

[13] F. Nurprihatin, A. Octa, T. Regina, T. Wijaya, J. Luin, and H. Tannady, "The extension analysis of natural gas network location-routing design through the feasibility study," *J. Appl. Res. Ind. Eng.*, vol. 6, no. 2, pp. 108–124, 2019.

[14] K. Buhrkal, A. Larsen, and S. Ropke, "The waste collection vehicle routing problem with time windows in a city logistics context," in *Procedia - Social and Behavioral Sciences*, 2012, vol. 39, pp. 241–254.

[15] R. Aringhieri, M. Bruglieri, F. Malucelli, and M. Nonato, "A special vehicle routing problem arising in the optimization of waste disposal: A real case," *Transp. Sci.*, vol. 52, no. 2, 2018.

[16] I. Markov, S. Varone, and M. Bierlaire, "Integrating a heterogeneous fixed fleet and a flexible assignment of destination depots in the waste collection VRP with intermediate facilities," *Transp. Res. Part B Methodol.*, vol. 84, pp. 256–273, 2016.

[17] J. F. Andry, H. Tannady, and F. Nurprihatin, "Eliciting requirements of order fulfilment in a company," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 771, no. 1, pp. 1–6.

[18] F. Nurprihatin and H. Tannady, "An integrated transportation models and savings algorithm to minimize distribution costs," in *Proceeding of the 1st*

Asia Pacific Conference on Research in Industrial and Systems Engineering, 2018, pp. 216–221.
[19] N. Asgari, M. Rajabi, M. Jamshidi, M. Khatami, and R. Z. Faharani, "A memetic algorithm for a multi-objective obnoxious waste location-routing problem: a case study," *Ann. Oper. Res.*, vol. 250, no. 2, pp. 279–308, 2016.
[20] T. Tesseme and S. Chakma, "Trend analysis of long-term MSW leachate characteristics," in *Advances in Waste Management*, A. S. Kalamdhad, J. Singh, and K. Dhamodharan, Eds. Singapore: Springer Singapore, 2019, pp. 143–153.
[21] P. Chaudhuri, "Earthworm technology-a promising tool for second green revolution," in *Advances in Waste Management*, A. S. Kalamdhad, J. Singh, and K. Dhamodharan, Eds. Singapore: Springer Nature Singapore, 2019.
[22] C. H. Glock and T. Kim, "Coordinating a supply chain with a heterogeneous vehicle fleet under greenhouse gas emissions," *Int. J. Logist. Manag.*, vol. 26, no. 3, pp. 494–516, 2015.
[23] G. Macrina, D. P. L. Pugliese, F. Guerriero, and G. Laporte, "Crowd-shipping with time windows and transshipment nodes," *Comput. Oper. Res.*, vol. 113, pp. 1–15, 2020.
[24] D. Wang, J. Zhu, X. Wei, T. C. E. Cheng, Y. Yin, and Y. Wang, "Integrated production and multiple trips vehicle routing with time windows and uncertain travel times," *Comput. Oper. Res.*, vol. 103, pp. 1–12, 2019.
[25] F. Nurprihatin, R. Elnathan, R. E. Rumawan, and T. Regina, "A distribution strategy using a two-step optimization to maximize blood services considering stochastic travel times," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 650, no. 1.
[26] D. O. Olukanni, T. S. Iroko, and A. S. Aremu, "Cost appraisal of municipal solid waste transfer to disposal site using visual basic program," *Pollution*, vol. 1, no. 4, pp. 427–439, 2015.
[27] A. Bevilaqua, D. Bevilaqua, and K. Yamanaka, "Parallel island based memetic algorithm with Lin–Kernighan local search for a real-life two-echelon heterogeneous vehicle routing problem based on Brazilian wholesale companies," *Appl. Soft Comput. J.*, vol. 76, pp. 697–711, 2019.
[28] A. Bettinelli, V. Cacchiani, T. G. Crainic, and D. Vigo, "A Branch-and-cut-and-price algorithm for the multi-trip separate pickup and delivery problem with time windows at customers and facilities," *Eur. J. Oper. Res.*, vol. 279, no. 3, pp. 824–839, 2019.
[29] J. Raucq, K. Sörensen, and D. Cattrysse, "Solving a real-life roll-on–roll-off waste collection problem with column generation," *J. Veh. Routing Algorithms*, vol. 2, pp. 41–54, 2019.
[30] H. Tannady, E. Gunawan, F. Nurprihatin, and F. R. Wilujeng, "Process improvement to reduce waste in the biggest instant noodle manufacturing company," *J. Appl. Eng. Sci.*, vol. 17, no. 2, pp. 203–212, 2019.
[31] F. Nurprihatin, M. Angely, and H. Tannady, "Total productive maintenance policy to increase effectiveness and maintenance performance using overall equipment effectiveness," *J. Appl. Res. Ind. Eng.*, vol. 6, no. 3, pp. 184–199, 2019.

Filscha Nurprihatin, photograph and biography not available at the time of publication.

Anggun Lestari, photograph and biography not available at the time of publication.