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Optimization of Vehicle Routing Problem Using Particle Swarm Optimization: A Case Study Watering Plants in Yogyakarta City

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Abstract. *Dinas Lingkungan Hidup (DLH) Yogyakarta City always tries to carry out monitoring, controlling and controlling activities regarding all aspects of the environment, one of which is watering plants. Selection of the right path must be done so as not to exceed the time limit set. This study aims to determine the path of watering plants in Sector 3 for Vehicle Route Problem (VRP) using the Particle Swarm Optimization (PSO) and compare the performance results of the PSO method with the Genetic Algorithm (GA) in previous studies. The VRP criteria is heterogeneous fleet, intermediated facility, multi trip, split delivery and times window (VRPHFIFMTSDTW). The results of the comparison between the two methods, namely, in terms of computational time efficiency and fitness value, the GA method is better than the PSO method. The total travel time for the GA method is 22 minutes or 2.1% faster than the PSO method. While the total distance traveled by the PSO method is 345 meters shorter than the GA method. The results of these two methods are also very good when compared to the current watering route. The difference in total mileage is about 20.4% and total travel time is about 11.7% from the two methods.*

Keywords: *Comparison; DLH; Genetic Algorithm; Particle Swarm Optimization; VRP*

I. INTRODUCTION

Dinas Lingkungan Hidup (DLH) is a government agency engaged in the regional environment with activities to supervise, control and control all aspects of the environment in the area. Yogyakarta area. The activity that is routinely carried out by DLH to control the environment is watering plants. In general, the process of watering plants in Indonesia is almost the same as that carried out by DLH Yogyakarta.

Optimal route planning and considering the travel time of watering are problems that must be overcome in the process of watering plants. So that the problem of watering plants, especially in the city of Yogyakarta, is included in the Vehicle Routing Problem (VRP) model. Vehicle Routing Problem (VRP) is a way to find efficient use of a number of vehicles traveling to visit a number of locations to deliver goods to customers by minimizing the distance traveled (Lukman et al., 2019; Slamet et al., 2014).

The VRP model in this problem is very complex because of various types of problems such as taking into account the existence of intermediate facilities, different vehicle capacities and shapes (heterogeneous fleet), vehicles having more than one route (multiple trips), watering time limits (time windows), and serving the task of watering to one location more than once (split delivery). The VRP problem in this research study has a high complexity. Problems with high complexity, especially the combinatorial problem of determining location or routing, require an appropriate method. Solving using analytic optimization alone cannot be solved. One approach that can be applied to problems with high complexity is the metaheuristic approach.

According to Talbi (2009), the metaheuristic approach is an optimization method to find the best solution by repeatedly solving it according to its objective function. The metaheuristic method aims to find solutions faster and can solve complex problems (Talbi, 2009) . However, metaheuristics do not guarantee that the resulting solution is the best. Methods developed in metaheuristics to solve combinatorial optimization problems such as the Vehicle Routing Problem include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony

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Optimization (ACO), Cross Entropy (CE) and others (Talbi, 2009).

There are various kinds of algorithms in the problem of finding the shortest route making the selection of the most optimum algorithm has many considerations. Because each algorithm has its advantages and disadvantages. In the scope of route search, it is not certain which algorithm is the most optimum in all cases. An algorithm that has good optimization may not necessarily produce good optimization in other cases (Wiyanti, 2013).

According to Hendrawan (2007) Genetic Algorithm is a theory of natural selection and evolution which was first discovered by Charles Darwin. The basis of this theory is the concept of biological evaluation and produces alternative solutions to a problem to be solved. The advantage of the GA method is that it quickly and stably solves optimization problems on complex problems. The weakness of the GA method is that it requires many generations to produce optimal values (Paranduk et al., 2018).

According to Erdem et al. (2015), Particle Swarm Optimization (PSO) was inspired by natural phenomena that started from observing the behavior of a group of birds and fish. The behavior of a bird and fish in the group is called a swarm which is influenced by social behavior. Each individual behavior uses its own intelligence and is affected by the behavior of the herd (Erdem et al., 2015). The advantages of using the Particle Swarm Optimization are that there is no evolution in the operator, it is easy to implement and provides the best information so that the group's movements are followed (Sathya & Kayalvizhi, 2010). Meanwhile, according to Setyawan (2017), the weakness of the PSO method is that in complex problems, particles can be trapped in a local minimum and are difficult to converge and require a long computation time.

The PSO method has been widely used in solving various types of VRP. In the study of Lukman et al. (2019), the PSO method related to the Heterogeneous Fleet Vehicle Routing Problem (HFVRP) has been carried out. The results of this study indicate that using PSO can minimize the total distance traveled and minimize the total cost of the vehicle route that is operated. Research conducted by Sombuntham & Kachitvichyanukul (2010) on the problem of Vehicle Routing Problem Time Windows (VRPTW) with the PSO algorithm gives the result that the PSO algorithm is able to provide effective solutions in route selection with sufficient time.

Research conducted by Rabbani et al. (2013) on Periodic VRP with Pickup and Delivery. Solution of Heterogeneous Fleet VRP with 2-Dimensional Loading Constraint conducted by (Sun et al., 2015), completion of the Multi Depot Heterogeneous Fleet with Time Windows by (Abdallah & Ennigrou, 2020). The solution Vehicle Routing Problem Heterogeneous Fleet with Mixed Back Smooth and Time Windows was carried out by (Belmecheri et al., 2010) and research conducted on the completion of the Capacitated Vehicle Routing Problem by (Alinezhad et al., 2018; Iswari & Asih, 2018).

Conducted a VRP comparison test (Abdallah & Ennigrou, 2020), using the Multi-depot Heterogeneous Fleet Vehicle Routing Problem with Time Windows (MDHFVRPTW) model.research compares the performance of computational performance and also solutions using three methods, namely the PSO Algorithm, GA and the Memetic Algorithm. The results showed that PSO had the best CPU times compared to GA and ME. In addition, the resulting solution is better for different problem sizes.

Conducted a VRP (Armandi et al., 2019) that was almost the same as this study in the process of transporting waste. However, there is no time limit for this study. The study conducted a comparative test between hybrid GA (GA-LS) and PSO and found that the PSO method has a very long computational time compared to hybrid GA.

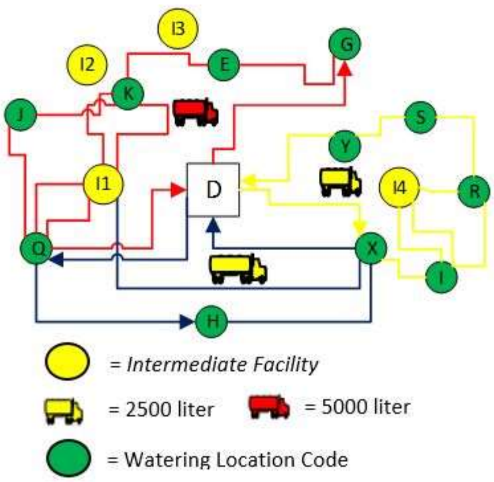
The problem in the VRPMTHFTWSDIF research (Vehicle Routing Problem Multiple Trips, Heterogeneous Fleet, Time Windows, Split Delivery and Intermediate Facility) has been carried out by Isdianto & Linarti (2021) using the GA method with Nearest Neighbor. The research also compares the performance of GA without Nearest Neighbor with GA using Nearest Neighbor. The results obtained are that GA by using Nearest Neighbor is better and the value obtained is stable.

This research basically aims to solve the problem of watering plants in the city of Yogyakarta. In addition, this study also analyzes and compares the PSO and GA algorithms used in the research of Isdianto & Linarti, (2021). The comparison and analysis is seen in terms of effectiveness, time efficiency and also fitness resulting it is hoped that by optimizing using the Particle Swarm Optimization , it can produce a better route than previous studies.

II. RESEARCH METHOD

System Characteristics

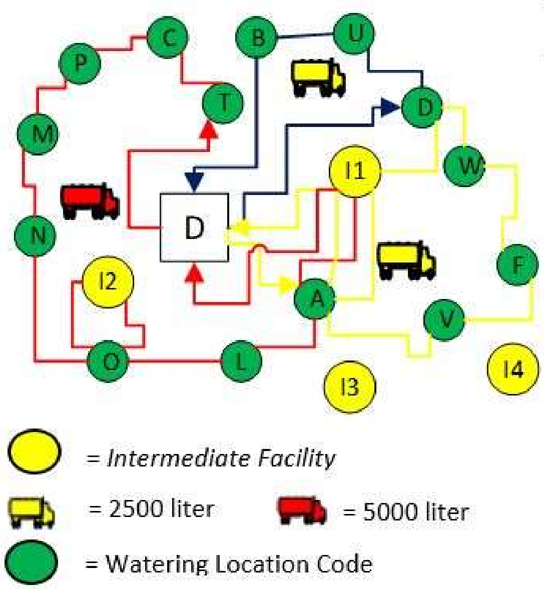
Study was conducted in area 3 of watering plants in the city of Yogyakarta. Region 3 is in Kapanewon Pakualaman, Kotagede and Umbulharjo. shift for region 3 has a watering



Location Code	Watering Location	Water Needs (liters)
E	Jl. Kusuma Negara (east) Park	5936
G	Jl. Kerto Park	8571
H	Muja-Muju Park	929
I	Jl. Veteran Park	10086
J	Jl. Gambiran Park	3036
K	Jl. Segitiga Veteran Park	1857
Q	Jl. Cendana Park	14214
R	Jl. Cendana II Park	1500
S	Jl. Kenari (in front SMK 6) Park	1286
X	Jl. Sukonandi Park	3771
Y	Jl. Sukonandi II Park	1429
I1	Kalimambu Bridge	-
I2	XT Square Rear River	-
I3	Ditch in front of the UST F. Agriculture	-
I4	Ditch Jl. Veteran	-

Source : (Isdianto & Linarti, 2021)

Figure 1. First Day Watering System



Location Code	Watering Location	Water Needs (liters)
A	Jl. Sultan Agung Park	5357
B	Pakualaman Park	900
C	Ki Mangun Sarkoro Park	71
D	Jl. Kusuma Negara (west) Park	5936
F	Jl. Soga Park	2500
L	Jl. Karang Park	4286
M	Jl. Tegalturi Park	857
N	Jl. Median Terminal Giwangan Park	929
O	Jl. Lowano Park	1071
P	Jl. Kapas Park	7714
T	Jl. Soka Park	5000
U	Jl. Tunjung Park	1786
V	Jl. Mawar Park	714
W	Jl. Cantel Park	571
I1	Kalimambu Bridge	-
I2	XT Square Rear River	-
I3	Ditch in front of the UST F. Agriculture	-
I4	Ditch Jl. Veteran	-

Source : (Isdianto & Linarti, 2021)

Figure 2. Second Day Watering System.

point and a water filling location with 25 and 4 location points, respectively. The watering truck starts from the DLH office with the truck's water tank fully filled and goes to the watering locations. If the water in the truck's tank is empty, the truck will refill it at the refilling point or intermediate facility. If the truck tank is full, the vehicle can resume assignment until all gardens have been watered without exceeding the watering time limit. Seen in Figures 1 and 2 are the first and second day plant watering systems for area 3 in the city of Yogyakarta.

VRP Models

The VRP model in this study adapted to conditions that occur in the field. The VRP model carried out in this study refers to the VRPHFIFMTSD model by (Armandi et al., 2019) and developed by Isdianto & Linarti (2021) by adding Time Windows, with the objective function of minimizing the total watering time and total distance traveled. The meaning of the VRP model used is as follows:

1. Multiple Trip (VRPMT), is a truck having more than one lane in one assignment, namely VRP multiple trips (MTVRP). Multiple trips means that each vehicle can enter and leave the depot more than once during the assignment period (Suprayogi, 2020).
2. Time Windows (VRPTW), according to (Atiqoh, 2020; Wardhana et al., 2019), Time windows is a type of VRP with deliveries that occur within a predetermined time frame and cannot be sent outside the specified time period. There is a grace period that must be considered when carrying out watering assignments. The time period used for watering activities is 05:00 – 10:00 WIB or within 300 minutes.
3. Intermediate Facility (VRPIF), there are intermediary facilities that carry out activities to fill water into the truck tank before making a trip if it does not exceed the time that has been set. determined. According to (Angelelli et al., 2002), states that the intermediate facility is a means that transportation vehicles need to go to to recover the freight when starting a new route.
4. Heterogeneous Fleet (VRPHF), is a type of VRP with the problem of having a different choice of vehicle type in each vehicle, usually in the form of vehicle capacity (Arvianto et al., 2014; Wardhana et al., 2019). The total plant watering vehicle has 3 trucks with 2 types with a capacity of 2500 liters and 5000 liters.
5. Split Delivery (VRPSD), is the possibility to serve more than once with the same type of vehicle or from different types of transportation. This is due to the need that exceeds the watering capacity.

Particle Swarm Optimization

Particle Swarm Optimization (PSO) was first discovered by Dr. Eberhart and Dr. Kennedy in 1995. The PSO method was inspired by natural phenomena that began with observing the behavior of a group of birds and fish (Shi Volume et al., 2004). According to Tuegeh & Purnomo (2009), the PSO method is a population-based random search computation technique called particle which is based on the behavior of individuals moving within the herd. Each individual particle spreads information in the form of its best position to other particles, the information received makes the other particles adjust their position and velocity according to the information received (Ariyati & Musthafa, 2018).

The flow diagram of the PSO Algorithm used can be seen in Figure 3. The PSO stage begins with determining the size by initializing the position (x_i) and particle velocity (v_i) on a swarm. Notation (i) is the size of the swarm. The term swarm is a collection of particles, each particle representing a potential solution to the problem being solved. The position of a particle is a representation of the current solution. In general swarm, the recommended swarm (El-Shorbagy & Hassanien, 2018; Prathama & Sulistyo, 2016; Talukder, 2011).

The next step is to evaluate the fitness (f_i). The fitness is the reliability of the particles to survive in a population (swarm). Then the next step is to determine the best, by getting it from the fitness for each particle. The next step is to determine the Gbest. Gbest value is obtained

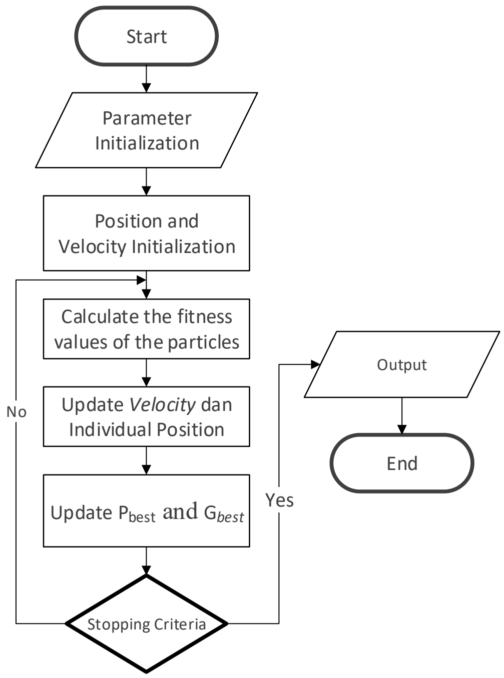


Figure 3. Flowchart Algorithm Particle Swarm Optimization (PSO)

Table 1. Input parameters for GA and PSO.

GA Parameter		PSO Parameter	
Population size	40	Swarm	50
Crossover Probability	0.9	Cognitive parameters (c_1)	1.49
Mutation Probability	0.2	Social parameters (c_2)	1.49
Maximum Iteration	15000	W_{max}	0.9
		W_{min}	0.2
		Maximum Iteration	5000

from one of the Pbest with the fitness in the overall swarm at a certain iteration.

The next step is to update the position (x_i) and particle velocity (v_i). Both will be updated in each iteration to change from the initial position to a better position. At this stage also add inertia weight, acceleration coefficient (c_1, c_2) and also r_1 and r_2 which is a random number in the interval [0,1]. The value of inertia weight varies in the range of 0.9 to 0.4. Meanwhile, according to Shi et al. (1999), the value of the acceleration coefficient (c_1, c_2) proved to be effective with a value range of 1.5 – 2.5. Acceleration coefficient c_1=c_2= 1.49 has also been done by (Wu et al., 2016), in the VRPTW research.

The next step is to check whether the iteration has converged or not. If it has not converged, it can be repeated at the stage of determining the Pbest and Gbest by updating iterations.

III. Result and Discussion

Parameter Comparison a Parameter

Study will be conducted before solving this research problem. This parameter study serves to obtain the best parameters and will be used to solve the problem of plant watering routes. The number of locations for watering plants on the second day was more than on the first day. So this makes watering plants on the second day will be used in conducting parameter studies.

Each method has tested the parameters and in Table 1 are the parameters that will be used in this study. In Table 1 there are differences in the number of populations/particles used. Research by Isdianto & Linarti (2021), the number of population used is 40 with a maximum iteration of 15000. While in this study the number swarms is 50 and the maximum number of iterations is 5000. The process of making the PSO program is carried out with software with a Lenovo ideapad 330 laptop with specifications AMD Ryzen 3 2200U 2.50 GHz, 8GB RAM and Windows 10 system (64-bit).

Comparison of Fitness and Computing Time

In the completion results there are fitness and also computational time in each watering day. The results of the fitness value and computation time are obtained after running the program again 5 times using the parameters in Table 1. Research conducted by Isdianto & Linarti (2021), not only uses the GA method but also uses the GA method with Nearest Neighbor in the formation of solutions. beginning. So that in the results of this settlement there are three methods to be compared, namely the GA method without Nearest Neighbor, GA with Nearest Neighbor and PSO. Comparison of the results of the settlement can be seen in Table 2.

Table 2. Comparison of Settlement Results

Method	Running	First Day Watering		Second Day Watering	
		Fitness value	Computing Time (sec.)	Fitness value	Computing Time (sec.)
GA without *Nearest Neighbor*	1	-	-	21810	26,67
	2	-	-	21519,5	24,60
	3	-	-	21519,5	24,39
	4	-	-	20818,5	25,16
	5	-	-	**20191,5**	24,32
GA with *Nearest Neighbor*	1	**20446,5**	27,85	20266,5	28,51
	2	21052,5	28,54	**20191,5**	26,73
	3	20446,5	27,93	20266,5	26,65
	4	20446,5	28,25	20266,5	26,53
	5	20446,5	27,64	20191,5	26,94
PSO	1	20961,5	94,47	22199,5	96,89
	2	21281,5	94,52	22450,5	97,54
	3	20721,5	94,63	21438,5	95,36
	4	**20696,5**	94,42	**20677,5**	95,85
	5	21015,5	94,87	21697,5	96,31

Based on the results of the settlement in Table 2, researchers Isdianto & Linarti (2021), the GA method without Nearest Neighbor on the first day was not tested and only tested on the second day with a fitness 20191.5 and the computation time is 24.32 seconds. The GA method with Nearest Neighbor, on the first day of watering using the results running with a fitness of 20446.5 and a computation time of 27.85 seconds. As for the second day of watering, the results are running of the 2nd fitness 20191.5 with a computation time of 26.73 seconds.

The PSO method has the fitness from the two watering days when PSO does running the 4thThe first fitness value of 20696.5 with a computation time of 94.42 seconds and the second day watering got a fitness 20677.5 with a computation time of 95.85 seconds.

Based on the results of the completion of the two watering days, the fitness resulting from the GA method using Nearest Neighbor is smaller than using the PSO method. Although the fitness generated in the PSO method is not too far away.

The computational time generated for each method on the two watering days is different. The PSO method takes a little longer than the GA method without Nearest Neighbor and GA uses Nearest Neighbor. The long computation time in the PSO method can be caused by the large number of particles in the process of finding the best space for the entire swarm (Efendi et al., 2017).

The long computation time in the PSO method is shown by (Armandi et al., 2019) on the problem of the waste transportation process. The parameters used by (Armandi et al., 2019) are 100 particles and 25,000 iterations using the PSO method with a very long computation time of 1,240.22 seconds (20.67 minutes). The large number of particles and iterations lead to long computational times. Sombuntham & Kachitvichyanukul (2010) state that the number of combinations that occur in a problem results in a long computation time.

The results of running and the fitness of the three methods also produce a graph of the objective function of each method. It can be seen in Figure 3 which is a graph of the objective function of the GA method without Nearest Neighbor, Figure 4 is the graph of the objective function of the GA method with Nearest Neighbor and Figure 5 is the graph of the objective function of the PSO method.

Based on the graph of the objective function of watering on the two days of the three methods, there are differences. In Figure 3 the graph of the objective function with the GA method without Nearest Neighbor reaches a

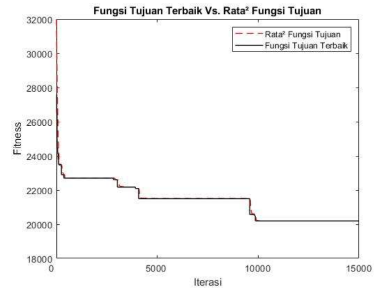


Figure 3. Graph of Objective Function of GA Method Without Nearest Neighbor Watering Second Day.

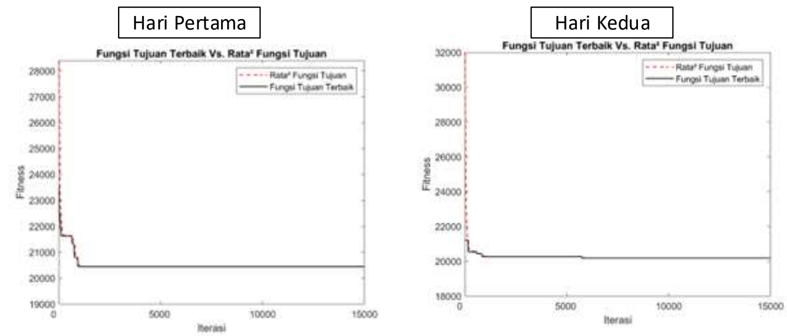


Figure 4. Graph of Objective Function of GA Method With Nearest Neighbor Watering on the First and Second Days.

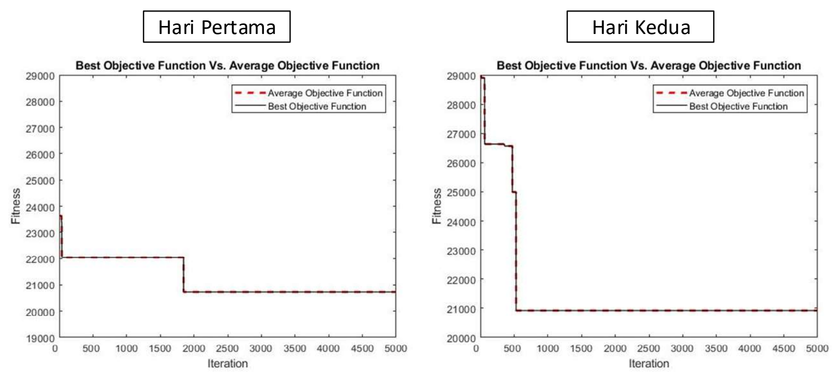


Figure 5. Graph of the Objective Function of the PSO Method of Watering the First and Second Days

convergent value when entering the 10000th iteration. The graph of the GA method without Nearest Neighbor in the research of Isdianto & Linarti (2021) only uses watering data on the second day as a comparison with the GA method using Nearest Neighbor.

In Figure 4 the graph of the objective function of the GA method with Nearest Neighbor, the first day of watering when entering the 1000th iteration has reached a convergent value. Meanwhile, on the second day of watering, it entered a convergent value at the 6000th iteration. The GA method using Nearest Neighbor was chosen because the resulting value is better and stable when compared to the GA method without Nearest Neighbor.

In Figure 5 the graph of the objective function of the PSO method, on the first day of watering when entering the 1800th iteration the objective function value has reached convergence and the second day of watering shows that when entering the 500th iteration the objective function value has reached convergence. The convergent value on the second day produced by the PSO method was faster than the two GA methods. Because according to (Sathya & Kayalvizhi, 2010),

Table 3. Proposed Plant Watering Route for Region 3 Yogyakarta City GA Method with Nearest Neighbor

Watering Day	Vehicle/ Volume	Route	Total Mileage (m)	Total Time Travel (minutes)
First Day (Monday, Wednesday, Friday)	AB 8003 UA (2500 liter)	Depot - R – I - I4 - I – I4 – I – I4 - I – I4 - I – K – J – I4 – J – I4 - J – I4 - Depot	15.600	182
	AB 8004 UA (2500 liter)	Depot – Q – I1 – Q – X – I1 – X – I1 - X – S – Y – I1 – Y - R – I1 - Depot	9.100	114
	AB 8236 UA (5000 liter)	Depot – H – G – I1 – G – E – I1 – E – I1 - E – Q – I1 – Q – I1 – Depot	15.590	277
Second Day (Tuesday, Thursday, Saturday)	AB 8003 UA (2500 liter)	Depot – V – U – I1 – F – I1 – P – I1 – P – I1 – Depot	7.400	115
	AB 8004 UA (2500 liter)	Depot – P – I1 – P – D – I1 – D – I1 – D – W – T – I1 - Depot	10.400	120
	AB 8236 UA (5000 liter)	Depot – T - C – B – I1 – B – A – I1 – A – O – M – N – L - I4 – L – I4 - Depot	22.130	218

Source : (Isdianto & Linarti, 2021)

Table 4. Proposed Plant Watering Route for Region 3 Yogyakarta City PSO Method.

Watering Day	Vehicle/ Volume	Route	Total Mileage (m)	Total Time Travel (minutes)
First Day (Monday, Wednesday, Friday)	AB 8236 UA (5000 liter)	Depot - H - G - I1 - G - E - I1 - E - I1 - E - Q - I1 - Q - R - I1 - Depot	15.640	278
	AB 8003 UA (2500 liter)	Depot - R - S - I1 - S - X - I1 - X - I1 - X - I1 - X - I1 - Depot	8.400	142
	AB 8004 UA (2500 liter)	Depot - X - Y - I - I4 - I - I4 - I - I4 - I - I4 - I - K - I2 - K - J - I4 - J - I4 - Depot	16.730	202
Second Day (Tuesday, Thursday, Saturday)	AB 8236 UA (5000 liter)	Depot - A - I1 - L - M - I4 - M - N - O - T - I1 - T - V - U - I1 - Depot	20.200	247
	AB 8003 UA (2500 liter)	Depot - W - B - C - F - I1 - F - P - I1 -P - I1 - P - I1 - Depot	8.700	91
	AB 8004 UA (2500 liter)	Depot - P - D - I1 - D - I1 - D - I1 - D - I1 -Depot	10.205	118

Table 5. Comparison of Total Mileage Results and Travel Time.

Watering Day	Current Line		GAs Proposal Path		PSO Proposed Path	
	Total Distance (m)	Total Time (minutes)	Total Distance (m)	Total Time (minutes)	Total Distance (m)	Total Time (minutes)
First Day	48.450	628	40.290	603	40.770	622
Second Day	51.880	597	39.930	453	39.105	456
Total	100.330	1.225	80.220	1.056	79.875	1.078

the space search process in the PSO method is wider than the GA method.

Comparison of Proposed Routes, Total Distance and Travel Time

Solving the problem to choose the path of watering plants in the city of Yogyakarta will use the solution from the results of the fitness of each method. The results of the proposed route in the research of Isdianto & Linarti (2021) using the GA method with Nearest Neighbors can be seen in Table 3. While the results of the proposed route in this study using the PSO method are shown in Table 4.

From the results of the proposed route for watering plants in the city of Yogyakarta region 3 has different route selection from the two methods. On the first day of watering, both methods showed that trucks with a capacity of 2500 liters became the trucks with the longest total distance traveled. The total distances are 15,600 and 16,730 meters respectively. The total travel time of the watering trucks from the two methods has similarities, namely trucks with a capacity of 5000 liters being the trucks with the longest travel time with each travel time of 277 and 278 minutes. The travel time resulting from the GA method with Nearest Neighbor is one minute faster than the PSO method.

The results of watering on the second day of each method showed that the truck with the license plate number AB 8236 UA with a capacity of 5000 liters was the longest truck in total travel time and also the farthest distance. The total travel time required for the watering truck from the GA method with Nearest Neighbor is 218 minutes. While in the PSO method the time required is 247 minutes. The total mileage on the watering truck in the GA method with Nearest Neighbor is 22,130 meters. While the total distance traveled by the PSO method is 20,200 meters.

The results of the total mileage and travel time in the research of Isdianto & Linarti (2021), using the GA method with Nearest Neighbor will be compared with the results obtained by this study using the PSO method. It can be seen in Table 5 which is a comparison of the results of the total travel time and distance of the current path, the proposed GA path with Nearest Neighbor and the proposed path using PSO.

Based on Table 5, it can be seen that the total travel time, the proposed GA method is 22 minutes faster or about 2.1% faster than the total PSO travel time. While the total mileage of the proposed route using PSO is shorter than the current route and the proposed route using GA with Nearest Neighbor. The difference between the PSO and GA methods with Nearest Neighbor is 345 meters or about 0.43%.

The results of these two methods are also very good when compared to the current watering route. The difference in total mileage is about 20.4% and total travel time is about 11.7% from the two methods.

IV. CONCLUSION

Comparison between genetic algorithm (GA) and Particle Swarm Optimization with (PSO) VRPMTHFTWSDIF (Vehicle Routing Problem Multiple Trips, Heterogeneous Fleet, Time Windows, Split Delivery and Intermediate Facility) problems in a case study of watering plants in the city of Yogyakarta was successfully carried out. Based on the results that have been obtained in terms of computational time efficiency and fitness and total travel time the GA method with Nearest Neighbor is better than the PSO method. Meanwhile, the total distance traveled by the PSO method is shorter than the GA method with Nearest Neighbor. The proposed route resulting from the two methods is more optimal than the current watering truck route.

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