

An Improved Genetic Algorithm for Vehicle Routing Problem Pick-up and Delivery with Time Windows

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ABSTRACT

Vehicle Routing Problems (VRP) have many applications in real systems, especially in distribution and transportation. The optimal determination of vehicle routes impacts increasing economic interests. This research seeks to find the optimal solution in Vehicle Routing Problem Pick-up and Delivery with Time Windows (VRPPDTW). Targets in this problem including reducing distance travel and penalties. Three penalties that consider are a capacity penalty, opening time capacity, and closing time capacity. An improved genetic algorithm is developed and used to determine the vehicle route. There are one main depot and 42 customers. This research raises the problem of a shipping and logistics company. Analysis of the results shows that the proposed route obtained from improved genetic algorithms (GA) is better than the existing route and previous algorithm. Besides, this research carried out an analysis effect of the number of iterations on distance traveled, the number of penalties, and the fitness value. This algorithm can be applied in VRPPDTW and produces an optimal solution.



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1. Introduction

Vehicle routing problems (VRP) attempt to find routes to deliver goods from a central depot to various destinations. Many companies face these problems, which are crucial in distribution and logistics. The right route can find cost-effective routes providing high customer satisfaction [1]. Moreover, transportation plays a vital role in the success of the distribution process [2]. In this case, it is necessary to determine the path of visits to a set of customers by several vehicles [3]. The vehicles start and end at one depot. The depot's capacity and transport capacity affect the route designed to serve all customer requests [4]. Many more complex VRP problems have been developed from the classic VRP combination problems [5] [6]. One of some problem is Vehicle Routing Problem Pick-up and Delivery with Time Windows (VRPPDTW). VRPPDTW has the primary goal of determining vehicles and routes' allocation to minimize costs by considering pick-up and delivery, capacity, and time windows [7]. VRPPDTW is based on integrating vehicles that



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deliver and pick-up goods in the transport network affected by the time [8]. Pick-up and delivery systems refer to how the vehicle fulfills the destination node's demand. The time window refers to when the fleet reaches the customer's node [9]. Two types of time windows impose each vehicle delivers the goods to the customers within a specific time interval [10]. The vehicle may not arrive at the customer's node closing time and before node open time. The best route must be on time and disciplined capacity as well as minimum distance and cost.

The first Genetic Algorithm (GA) was developed by Holland and his colleagues at the University of Michigan in the 1960s. The main objective of developing GA is to design algorithms that can explore natural adaptation mechanisms' phenomenon into computer systems. GA adheres to biological evolution to transfer chromosome populations to other chromosomes through genetic crossover and mutation. GA necessarily are search algorithms based on selection and genetics mechanisms. The use of GA in solving engineering and industrial problems reduces the amount and time of calculations, simplifies the modeling of functions, and reduces modeling errors [11]. Genetic algorithm applications have been widely used to support decision-making in routing problems [12].

VRP has numerous applications in real life, especially in transportation and distribution. VRP effect of improving the economic interests and appropriateness of logistics planning [13]. Mohammed, et al. [14], Ho, et al. [15], and de Oliveira da Costa, et al. [16] have investigated VRP that was solved by an improved GA. The algorithm succeeded in solving the problem quickly and found a shorter distance for some routes. Good routing and scheduling can reduce delivery distance and travel that improve the level of efficiency and decrease delivery cost. Minimization of travel time and distance is essential to optimize costs. Several studies that utilize GA include Nazif and Lee [17], Saxena, et al. [18], and Visutarrom and Chiang [19] that solve capacitated vehicle routing problems. The proposed algorithm uses an optimized crossover operator. Computational results showed that the proposed algorithm is competitive in terms of the quality of the solutions found. Liu, et al. [20] and Escobar-Falcón, et al. [21] have utilized the GA to solve fleet size and mix vehicle routing problems. Even, Marinakis and Marinaki [22] combined GA and particle swarm optimization. Their research shows that combining GA and particle swarm optimization can increase the algorithm's effectiveness in solving a problem VRP.

Cheng and Wang [23] proposed solving the Vehicle Routing Problem With Time Windows (VRPTW) by a decomposition technique and GA. The results explained that GA provides a better solution if combined with the decomposition technique. Ghoseiri and Ghannadpour [24] solved VRPTW by goal programming and GA. Two famous local heuristics, namely one-interchange shortest path heuristic and elitism, are used to keep a few right individuals. Vidal [25] developed an efficient hybrid GA for problem VRPTW. The proposed algorithm outperforms all current state-of-the-art algorithms on classical benchmark instances. Furthermore, Ursani [26] introduced the localized GA. The result from this research is a proposed algorithm on VRPTW for can minimize the distance. Results show that the new algorithm provides the superior performance of the previous algorithm. The genetic algorithm is useful in solving challenging and complex issues for more substantial problems. Although it is used to solve the many kinds of VRP, GA should possibly solve the VRPPDTW. Almost all paper describes a GA developed for the VRP can be competitive with other modern heuristic techniques in terms of solution time and quality. Because of previous research, this paper solves VRPPDTW using Genetic Algorithms under some of the facts that have been explained previously and considers that GA has never been applied in the case of VRPPDTW. This paper improves the standard genetic algorithm for solving VRPPDTW.

This paper proposes an improved GA for solving VRPPDTW problems based. Genetic algorithms through previous research have indeed been proven to solve various VRP problems. VRPPDTW has a higher complexity level, and the GA must be improved to solve the VRPPDTW problem effectively. The goal is to achieve the solution that most closely approaches the optimal solution with several targets: (1) to reduce the total distance and (2) to reduce the penalty. The improved GA for solving VRPPDTW was adapted from the original genetic algorithm developed by Holland [27]. Nearest neighbors heuristic algorithms are used in the initial population formation to create a better parent than just random generation. Calculation of fitness value (value of how good the route) based on distance traveled and several penalties related to VRPPDTW, including time windows open/close penalties and capacity penalties.

This paper's organization is presented as follows: The notations, assumptions, and descriptions of vrppdtw problems, improved genetic algorithm, and case studies are presented in section 2. comparison improve ga and existing route and comparison improve GA with the standart GA are presented in the results and discussion section 3. Section 4 presents conclusions and further work.

2. Methods

2.1 The Notations, Assumptions, and Descriptions of VRPPDTW Problems

The notations used in this problem are presented as follows:

G_m	: vehicle capacity
d_{ij}	: the distance between customer i to customer j
d_i	: total demand on customers i
p_i	: quantity of pick-ups to customers i
K	: Set the number of vehicles
k	: Set of a vehicle used for distribution
N	: Set the number of customers
i, j	: customer index
n_k	: the number of vehicles
N	: customer index (0 indicates the depot)
C_i	: customer i , Co show depot
V_k	: vehicle route k
q_{ik}	: total demand for vehicle k to customer i
x_{ijk}	: has a value of 1, meaning that vehicle k from customer i go straight to customer j , and if it is worth 0, then vice versa.
R_k	: total route time for vehicles k
t_{ij}	: travel time between customer i and j (proportional to distance)
t_i	: time of arrival at the customer i
f_i	: customer service time i
w_i	: waiting time before customer service i
e_i	: earliest time to serve customers i
l_i	: due date for customer service i
L_i	: lateness of service in customers i
PO_i	: opening penalty on customer i
PC_i	: closing penalty at customer i
$PCap_i$: capacity penalty for the i th customer

VRPPDTW is an extension of Capacitated Vehicle Routing Problem. Every customer i (in this case, the branch office) is associated with demand and pick-up, representing the demand for homogeneous commodities to be sent and taken at each

customer [28]. Besides, each branch office i is also associated with a time interval which is called time windows.

The assumptions used in this problem are

- (i) Vehicles must arrive and carry out loading and unloading at each customer i within the available time windows span, and the vehicle stop at the customer i during service time.
- (ii) If the vehicle arrives earlier than the customer time windows i , vehicles can wait until service can be started.
- (iii) Each route visits the depot vertex
- (iv) Each customer vertex is visited precisely on one route
- (v) Current vehicle load along the route must not be negative and exceed the capacity of the vehicle C .
- (vi) Demand is deterministic
- (vii) Time window (open and close) customer is fixed
- (viii) Vehicle speed is considered constant

The mathematical model of the VRPPDTW problem is as follows:

Objective Function

$$\text{Min} = \sum_{i=1}^N (PO_i + PC_i + PCap_i) + \sum_{k=1}^K \sum_{i=0}^N \sum_{j=0}^N x_{ijk} \cdot d_{ij} \quad (1)$$

Constraint

$$\sum_{k \in K} \sum_{i \in V} x_{ijk} = 1, \forall j \in V \quad (2)$$

$$\sum_{i \in V} x_{ijk} - \sum_{i \in V} x_{jik} = 0, \forall j \in V, \forall k \in K \quad (3)$$

$$\sum_{i \in V} x_{ik} \leq 1, k \in K \quad (4)$$

$$\sum_{i \in V} q_{ijk} = \sum_{i \in V} \sum_{j \in V} x_{ijk} d_i, \forall k \in K \quad (5)$$

$$\sum_{k \in K} \sum_{i \in V} q_{ijk} - d_j = \sum_{k \in K} \sum_{i \in V} q_{ijk} - p_j, \forall j \in V \quad (6)$$

$$\sum_{i \in V} q_{ijk} = \sum_{i \in V} \sum_{j \in V} x_{ijk} - p_j, \forall k \in K \quad (7)$$

$$q_{ijk} + p_{jk} - d_{jk} \leq G_m \quad (8)$$

$$\sum_{i=0}^N \sum_{i=0}^N x_{ik} (t_{ij} + f_i + w_i) \leq R_k, . k = 1 \dots K \quad (9)$$

$$t_j \geq t_i + w_i + f_i + t_{ij} - M(1 - x_{ijk}); j, j = 1, \dots, N; k = 1, \dots, K \quad (10)$$

$$e_i \leq t_i < l_i, i = 1, \dots, N \quad (11)$$

$$t_i \geq 0; i = 1, N \quad (12)$$

$$w_i = \max\{0, (e_i - t_i)\} \quad (13)$$

$$PO_i = \begin{cases} 1, & w_i > 0 \\ 0, & \text{Otherwise} \end{cases} \quad (14)$$

$$L_i = \max\{0, (t_i - l_i)\} \quad (15)$$

$$PC_i = \begin{cases} 1, & L_i > 0 \\ 0, & \text{Otherwise} \end{cases} \quad (16)$$

$$PCap_i = \begin{cases} 0, & q_{ijk} + p_{jk} - d_{jk} \leq G_m \\ 1, & \text{Otherwise} \end{cases} \quad (17)$$

$$x_{ijk} = \begin{cases} 1, & \text{Vehicle access to } j \text{ after access } i \\ 0, & \text{Otherwise} \end{cases} \quad (18)$$

The optimization model in equation (1) indicates the minimization of the opening penalty, closing penalty, capacity penalty, and vehicle distance. Equation (2) to ensure that each customer must be visited by 1 vehicle. Equation (3) is used to guarantee that the same vehicle comes and goes from every customer who visits it. Equation (4) is used to define that each vehicle only serves once. Equation (5) is a formula to ensure that the depot load is equal to the demand of all customers to be served. Equation (6) is a formula that indicates the change in load after the vehicle serves customer *i* before going to customer *j*.

Meanwhile, equation (7) ensures that the vehicle's load is equal to the quantity of pick-up from all that is served by the vehicle *k*. Equation (8) ensure that the load carried by each vehicle does not exceed the maximum load capacity. Constraint (9) states that each vehicle serves all customers scheduled for that vehicle without exceeding the vehicle's travel time. Constraint (10) is used to ensure that the two consumers' arrival times are compatible, where *M* is a huge real number. Constraint (11) ensures that the vehicle arrives at each consumer during the consumer's time window. Constraint (12) ensures that the arrival time of the vehicle to each customer is always positive. Equation (13) shows the waiting time for the vehicle to the customer *i*. Equation (14) *PO_i* has a value of 1 when the vehicle experiences waiting time for the *i*-th customer. Constraint (15) shows the time of delay in service in the *i*th customer. Equation (16) has a value of 1 when the vehicle is delayed, and vice versa is 0. Equation (17) is 0 when the transported capacity does not exceed the delay load capacity. Equation (18) represents the characteristics and decision variables.

2.2 Improved Genetic Algorithm

This section is outlining the proposed improved GA. The GA is one of the most powerful metaheuristic methods in solving very complex problems. According to [Mohammed, et al. \[14\]](#), GA is an adaptive heuristic search system based on natural and genetic selection's evolutionary ideas. The basic concept of GA is following the natural evolutionary system. Natural selection occurs, which makes the best individuals survive.

In this paper, the GA utilized solving the VRPPDTW problem. The main problem is delivering and picking up goods at each customer with different time windows. The use

of genetic algorithms aims to explore the solution space. With GA, it is expected that this complex problem can be solved with near-optimal results.

GA was developed initially by Holland [27]. So far, GA has developed as a method of solving complex problems. GA is starting to be used to find suitable solutions to complex problems like in Whitley, et al. [29], Sponsler [30], and Marin, et al. [31], Liu and Jiang [32], and Sethanan and Jamrus [33], especially when the optimal solution fails to be found with other searches. GA can be a complex problem-solving solution that requires big-time in achieving optimal solutions. GA is efficient for solving problems with high complexity, such as VRP.

An improved genetic algorithm is proposed in solving the problem of determining the vehicle route in the VRPPDTW problem. The flow chart improved genetic algorithm used can be seen in Fig. 1.

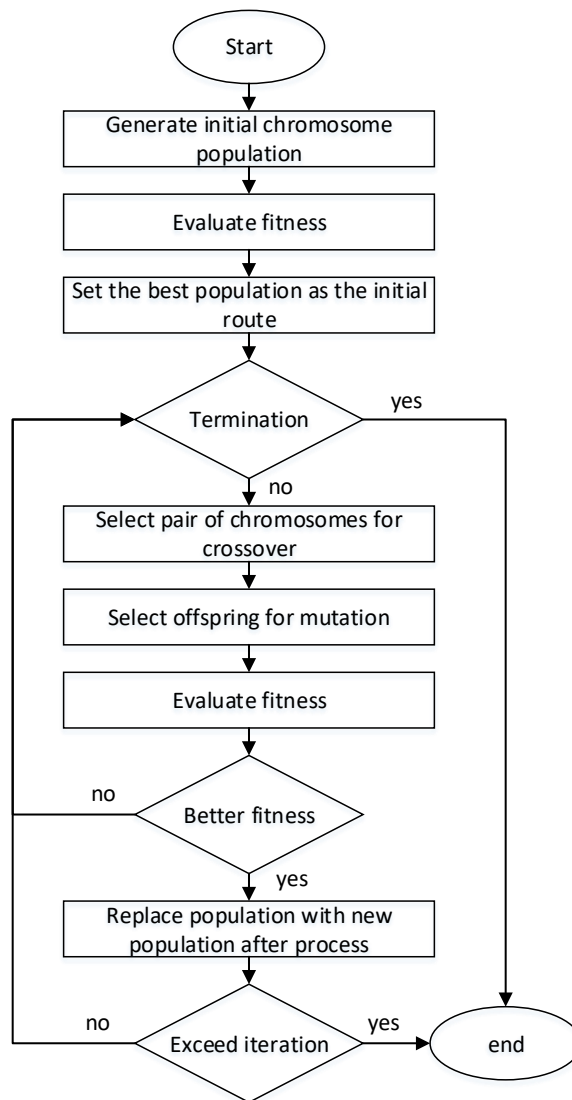


Fig. 1. The flow chart improved GA

The implementation of an improved genetic algorithm in VRPTW problems can be seen in Algorithm 1. The proposed GA improves stages such as establishing initial population, fitness calculations, selection, crossover, mutation, updating new population,

repetition number of iterations, and determining the best solution. Several stages of improved GA are presented as follows:

1. Establishment of Initial Population

The initial population formed using two methods, namely random and heuristic. One heuristic method that can use is the Nearest Neighbor. Each point is represented by one number, and then it can be called a gene. A valid single route is represented by each chromosome that contains a collection of numbers or genes. The use of heuristic methods in genetic algorithms to form initial populations is expected to minimize the time to find the best solution.

2. Fitness

In VRPPDTW, Route optimization is influenced by the suitability of arrival time with the customer time windows and the vehicle load discipline with its capacity. This research adopts the VRPPDTW conceptual model and represents it in the form of a penalty. In this study, the fitness value considers the penalties that occur. The penalty is worth one every time a violation occurs and can be accumulated with other abuses. Thus, the three components must consider in determining the fitness value. Fitness values formulated in equation (19).

$$fitness = \frac{1}{1 + total\ penalty} + \frac{1}{length\ of\ route} \quad (19)$$

3. Selection

In this stage, the selection process is carried out to select genes in the chromosomes formed before. One of the most commonly used selection methods is the Roulette Wheel Selection (RWS). In this method, the parents obtained the chromosome's fitness value proportion, meaning that the chromosome with the best fitness value has elected a higher likelihood than other chromosomes. Chromosome parents elected at the next selection process enter the crossover process to produce offspring chromosomes.

4. Crossover

In the crossover stage, not all chromosomes from parents are chosen for crossover. The crossover method used in this study is the heuristic crossover. The crossover step detail is explained in Algorithm 1. The distance between genes considered in the crossover stage to create a better new population.

5. Mutation

Like a crossover, whether or not a mutation process depends on the probability of mutation. In detail, the mutation process is explained in Algorithm 1. In this study's mutation process, the distance between genes is considered to create a better new population.

6. Establishment of a New Population

In this stage, a new population formed to replace the old population. Population replacement means that all chromosomes beginning in a generation replaced by chromosome results obtained after the crossover and mutation stages. The population becomes a new population and is repeated before selecting, crossover, and mutation back at the new population.

Algorithm 1: Proposed Improve GA for CVRPPDTW problem

1. start;
2. population (a set of the route) initialization, use randomized method and nearest neighbor algorithm to form chromosomes (routes) structure;
3. evaluate total length, total penalty, and fitness value of the initial population, $fitness = (1/(1 + total\ penalty)) + (1/length\ of\ route)$;
4. choose the population with the best fitness value as the initial route;
5. loop the following steps for the specified number of iterations (the more iterations, the better):
 - 5.1. copy chromosome structure of the best population to new population (route);
 - 5.2. generate random numbers (R_c) in the range 0.00 to 1.00, be compared to crossover probability (P_c);
 - 5.3. if $R_c > P_c$ proceed to stage 5.4; if $R_c \leq P_c$ do chromosome crossover; loop the following steps as much as the number of chromosomes:
 - 5.5.1. specify a random crossover point C_p by generating random numbers in range 1 to the value of the number of genes (node) in a chromosome;
 - 5.5.2. find the distance between the crossover point node from the previous node $C_d = distance\ gen\ C_p - 1\ to\ gen\ C_p$
 - 5.5.3. determine the chromosomes that be crossover by generating random numbers in the range of 1 to the value of the number of chromosomes except for the previously chosen chromosome;
 - 5.5.4. Find the distance between the crossover point node to all nodes on the chromosome selected for a crossover;
 - 5.5.5. Crossover the C_p genes with genes that have the closest distance;
 - 5.4. generate random numbers (R_m) in the range 0.00 to 1.00, compared to mutation probability (P_m);
 - 5.5. if $R_m > P_m$ proceed to stage 5.6; if $R_m \leq P_m$ do chromosome mutation; loop the following steps as much as the number of chromosomes:
 - 5.5.1. specify a random mutation point M_p by generating random numbers in range 1 to the value of the number of genes (node) in a chromosome;
 - 5.5.2. find the distance between the mutation point node from the previous node $M_d = distance\ gen\ M_p - 1\ to\ gen\ M_p$
 - 5.5.3. Find the distance between the node $M_p - 1$ to all other nodes on the same chromosome;
 - 5.5.4. Mutation the M_p genes with genes that have the closest distance;
 - 5.6. evaluate the fitness value of the result population;
 - 5.6.1 If the fitness value is better than the initial population;
 - 5.6.2.1 Replace population with population after the crossover and mutation process
 - 5.6.2 If the fitness value is not better than the initial population;
 - 5.6.2.2 Do not replace the population / Keep using the initial population
6. end of the loop;
7. write out the surviving population (best route);
- End.

7. Repetition Number of Iterations

At this stage, the selection process, evaluation of fitness, crossover, mutation, and new population formation repeated under the number of iterations determined with the

aim of achieving optimal results. That way, the chromosomes that survive are the chromosomes with the best fitness value, among other chromosomes. This process follows the principle of natural selection, "who is strong (has a better fitness value), it survives.

8. Determining the Best Solution

By comparing the fitness values obtained for each iteration, the best solution is the chromosome with the best fitness value that survives at the end of the iteration.

2.3 Case Study

A case study in shipping and logistics company serve shipping services throughout Surabaya, East Java, Indonesia. One main depot and 42 branch offices (customer) are scattered to help certain areas as a transit point for all packages before being sent to their destination. Each vehicle has a carrying capacity. Therefore, in the route's preparation, one must consider the load amount when loading and unloading. In this case, the branch office has various loading and unloading service time windows. The vehicle must wait if it arrives earlier than the branch office open time windows. If the vehicle comes more than close time windows, it disrupts the branch office's package delivery schedule. Couriers at the branch depart for the last mile delivery at specified times. Packages brought by vehicles arriving at times exceeding close time windows cannot be carried by the courier at that time and sent on the next shipment. Packages that are delivered late reduce customer satisfaction and buildup in the branch office warehouse, which is harmful. The case study data used are data on one day of delivery.

The company has four transport vehicles with a maximum capacity of 700 kilograms. Vehicles depart from the depot at eight in the morning to several branch offices. Each transport vehicle is assumed to have an average fuel consumption of eleven kilometers per liter of fuel. Data for each branch office related to the quantity of pick-up and delivery and time windows can be seen in [Table 1](#). The distance matrix data, which then be converted into the travel time matrix, can be seen in [Appendix A](#).

This study's experiments use the GA parameters as follows: crossover probability: 0.8, mutation probability: 0.8, chromosome: 4 (according to the number of vehicles), and 10,000 iterations. This experiment was performed using Matlab 14 running on an Intel (R) Core (TM) i5-3210M CPU @ 2.50GHz 8Gb RAM. This parameter is also used as a parameter for the comparison of the previous GA algorithm. This study also compares the Total cost comparison Actual Route. The total mileage of the problem is multiplied by the cost per kilometer. The cost per kilometer of this problem is IDR. 595.45.

3. Results and Discussion

3.1 Comparison Improve GA and Existing Route

The primary purpose of VRPPDTW is to minimize total penalty and distance. In VRPPDTW, the valid route is when it has a minimum distance and if the capacity and time windows constraints can be met. The VRPPDTW problem is very close to real system conditions where time windows and capacity also affect a distribution route's success. The improved genetic algorithm is proven to produce the best route with consideration of pick-up and delivery and time windows. This paper compares the actual route and the route that results from the improved genetic algorithm. The analysis has seen each route's advantages and disadvantages, especially the results of the developed algorithm. The total distance of each vehicle is obtained from the total distance between the nodes traversed. Each vehicle's total journey is added to get the total distance traveled by all vehicles on



that day. A penalty value of 1 is given every time there is excess capacity. The vehicle arrives before the time windows, and the vehicle arrives after the windows.

Table 1. Quantity of pick-up, quantity of delivery and time windows data

No.	Time Windows		Quantity		No.	Time Windows		Quantity	
	Open	Close	Pick-up	Delivery		Open	Close	Pick-up	Delivery
0	00:00	23:59	0	0	22	08:00	10:30	38.5	17.5
1	08:00	10:30	21	52.5	23	08:00	10:30	17.5	49
2	08:00	10:30	14	52.5	24	08:00	10:30	14	52.5
3	08:00	10:30	14	56	25	08:00	10:30	31.5	35
4	08:00	10:30	17.5	63	26	08:00	10:30	38.5	45.5
5	08:00	10:30	10.5	56	27	08:00	10:30	10.5	49
6	08:00	10:30	35	171.5	28	08:00	10:30	42	52.5
7	08:00	10:30	24.5	73.5	29	08:00	10:30	35	38.5
8	08:00	10:30	17.5	59.5	30	08:00	10:30	3.5	7
9	08:00	10:30	3.5	31.5	31	08:00	10:30	17.5	14
10	08:00	10:30	7	56	32	08:00	10:30	31.5	17.5
11	08:00	10:30	31.5	52.5	33	08:00	10:30	14	21
12	08:00	10:30	17.5	0	34	08:00	10:30	3.5	28
13	08:00	10:30	28	24.5	35	08:00	10:30	7	35
14	08:00	10:30	14	17.5	36	08:00	10:30	17.5	24.5
15	08:00	10:30	3.5	42	37	08:00	10:30	38.5	17.5
16	08:00	10:30	24.5	28	38	08:00	10:30	24.5	10.5
17	08:00	10:30	24.5	21	39	08:00	10:30	21	17.5
18	08:00	10:30	21	42	40	08:00	10:30	7	3.5
19	08:00	10:30	7	0	41	08:00	10:30	10.5	3.5
20	08:00	10:30	28	49	42	08:00	10:30	7	3.5
21	08:00	10:30	14	56					

Table 2. Distance comparison of the existing route and improved GA

Vehicle	Existing Route		Improved GA Route	
	Driving time (h:mm)	Distance Travelled (km)	Driving time (h:mm)	Distance Travelled (km)
1	1:53	94.1	1:32	76.90
2	1:57	97.1	1:49	90.90
3	2:13	111.1	1:52	93.40
4	2:16	113.6	1:22	69.00
Total	8:19	415.9	6:35	330.20

Table 2 describes distance comparison of the existing route and improved GA. From the total mileage value of all vehicles, it appears that the route from the improved GA results in shorter mileage compared to the company's existing routes. These results support the earlier research statement by Ibrahim, et al. [13] that genetic algorithms can

produce effective solutions to reduce total mileage in the case of VRP. On the proposed route, it appears that all vehicles have less mileage than the existing route. The proposed route resulted in a 20.6% cut in the distance. It can be concluded that the route resulting from the improved genetic algorithm succeeded in minimizing total mileage.

This research also compares the total cost of existing routes and proposed routes obtained with an improved genetic algorithm. Total cost comparison actual route and improved GA (In IDR.) can be seen in Table 3. Results found that the costs of the improved GA are more minimum, which is IDR. 196,619.09 compared to the company's existing routes with a total cost of IDR. 247,649.55. Therefore, the route formed by an improved GA is better than the company's existing route. The calculation of costs does not consider costs incurred due to vehicles arriving before or after the destination's time windows. The total cost is also not considered if there is excess capacity.

Table 3. Total cost comparison actual route and improved GA (In IDR.)

Vehicle	Existing Route	Improved Genetic Algorithm Route
1	56,032.27	45,790.45
2	57,818.64	54,126.82
3	66,155.00	55,615.45
4	67,643.64	41,086.36
Total	247,649.55	196,619.09

Table 4 shows the total penalty value comparison of the actual route and improved GA. The VRPPDTW problem in this paper uses the type of soft time windows. Penalties apply if the vehicle arrives outside the available time window (penalty time windows). Likewise, the capacity penalty applies if vehicles carry more than their capacity. The more penalties given on a route illustrate, the worse the route. We continue to analyze in-depth the penalties that occur on the proposed and existing routes.

Table 4. Penalty value comparison of actual route and Improved GA

Item	Existing Route	Improved GA Route
Penalty capacity	2	0
Penalty time windows (opening)	0	0
Penalty time windows (closing)	4	0
Total Penalty	6	0

The penalty capacity is worth two from the computational results, which means there are twice the vehicle's excess capacity events. Because the VRP problem in this paper is considering pick-up and delivery, routes that are not optimal can cause a vehicle's overcapacity. For example, a vehicle departs at full capacity and visits branch office A. Goods delivered are significantly less than those picked up from branch office A. There overcapacity in the vehicle. Therefore, the route formed must also consider the number of pick-ups and deliveries, not just the delivery order with the minimum distance. There have been four-time windows (closing) penalties, which means four vehicles are coming after the time windows limit. In this company's case, the vehicle must arrive before the time windows limit because the goods delivered immediately taken by the courier to be delivered to the customer's home. Delay in the vehicle's arrival will cause the package to be delivered late to the customer's home because they have to follow the next delivery time. Not only that, but the buildup of packages at the branch office also cause various new problems. On the route produced by an improved genetic algorithm, there are no

penalties or violations committed. That way, it can be concluded that all vehicles always arrived at the branch office time windows and all vehicles were never overcapacities.

3.2 Comparison improve GA with the standart GA

This article also analyzes the effect of the number of iterations on the value of fitness. GA is closely related to the concept of natural selection. Thus, the best generation survives while the weak be defeated and discarded. In this case, the intended generation is a set of routes. The higher the fitness value, the better the route (minimizing mileage and penalty). Logically the value of fitness increase with the increasing number of iterations. Thus, the more the number of iterations, the better the resulting route.

Based on Fig. 2, the experiment results show that the initial fitness value is 0.11 when the number of iterations increases to 1 when the number of iterations is 7700. The fitness value continues to grow when the iteration number is increased in proportion to the reduction in the value of the penalty and traveled distance but stops at a certain number of iterations. Even though the end of growing fitness value, even though the number of iterations continues added, illustrates no better solution. As seen in the results, the number of penalties during the iteration of 7700 has a value of 0. It means that no restrictions are violated.

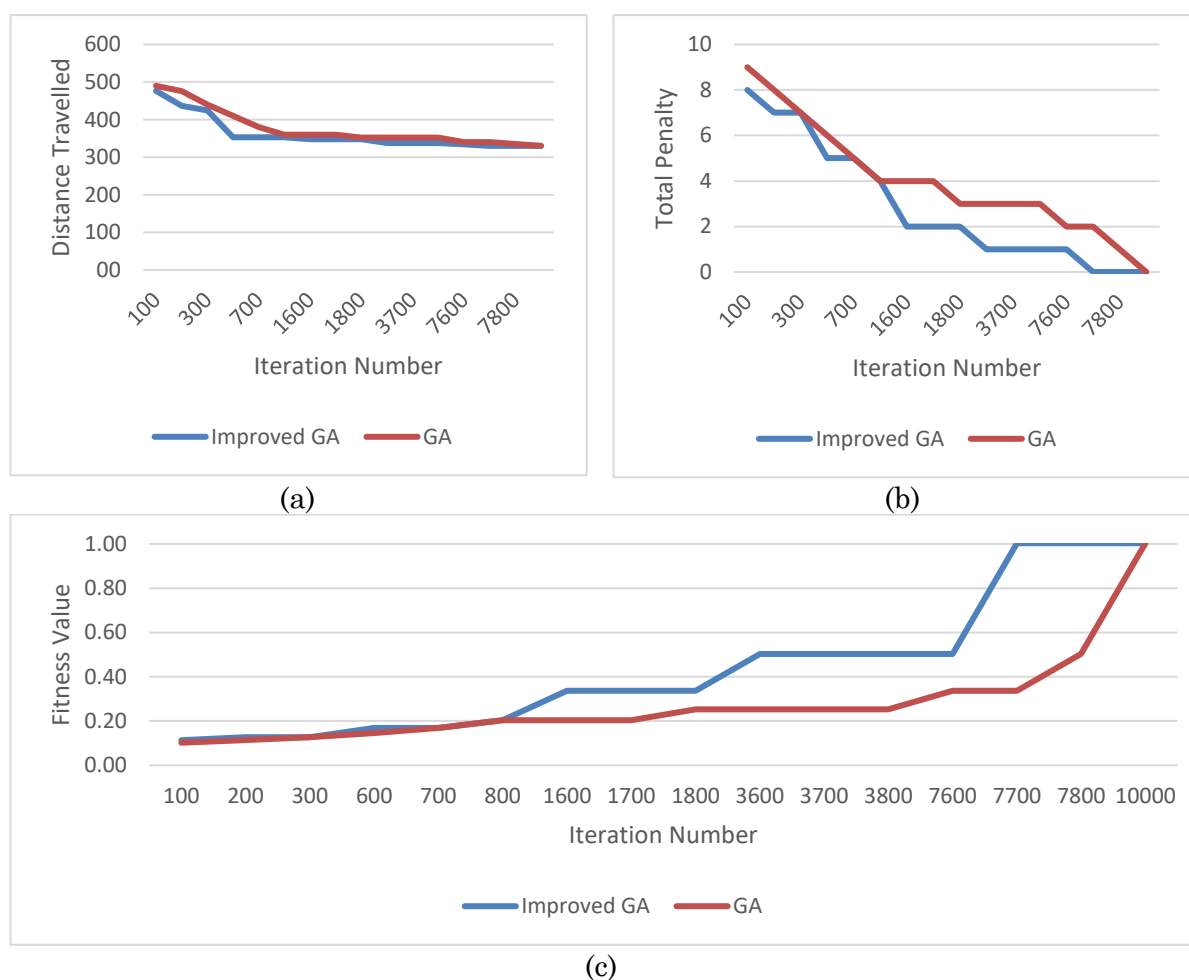


Fig. 2. (a) Affect iterations toward the distance, (b) Effect iterations toward Total Penalty, and (c) Effect iterations toward Fitness value

The cessation and insignificant increasing fitness value are among the stopping criteria in the Improved GA besides the specified number of iterations. Hence, if the research set the number of iterations to 20,000 iterations, but there has been no significant increase in fitness value when the number of iterations is 10,000, then the computation can be stopped. This study compared the performance of the Improved GA developed with the standard GA. From Fig. 2, it can be seen that the improved GA has succeeded in getting the best solution with a smaller number of iterations which certainly affects the computation time.

4. Conclusion

This study discussed the VRPPDTW model to optimize the route of a shipping and logistics company's vehicle. An Improved GA was developed and applied to solve the VRPPDTW problem. From the case study, it can be concluded that the improved GA that developed can be applied in determining the route. The resulting route is better than the existing company route, both in costs and customer service satisfaction. Improved GA results compared with the company's existing routes and routes generated by standard GA. The analysis is carried out in various aspects, including vehicle distance, total penalty, and total transportation costs. The total distance traveled on the proposed route is shorter than the existing route, affecting transportation's total cost. There are six violations related to time windows and capacity on the actual route. In contrast, on the proposed route, there are no violations at all. The best solution resulted in an improved GA with a shorter computation time than standard GA. Therefore, it can be concluded that the Improved GA developed successfully produces a better route in all aspects and resolves the VRPPDTW problems faced with relatively short computing time.

In future work, the exploration of various crossover and mutation methods can be done to provide recommendations for the most suitable crossover and mutation methods.

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Appendix A

Depot	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
0	7.8	11	11	17	14	20	20	23	31	25	23	24	13	18	16	16	17	11	9.4	7.5	9.6	17	16	11	24	19	19	25	39	38	20	9.4	17	19	8.9	8.4	22	17	5.3	4.7	13		
1	7.8	0	6.4	3.6	11	10	13	11	15	21	18	15	16	9.2	16	12	12	13	7.3	4.5	7.9	7.3	14	14	11	20	16	15	18	17	25	26	16	23	20	8.2	15	23	22	3.6	11	13	
2	11	6.4	0	9.3	11	13	13	11	15	22	21	16	20	14	16	15	17	17	7.3	9.8	14	13	19	17	17	12	18	23	21	30	31	31	16	27	24	14	19	29	28	6	15	8.5	
3	11	3.6	9.3	0	11	9.8	13	12	15	19	27	15	16	17	14	12	13	13	8.3	7.8	14	13	12	20	15	12	20	15	19	27	41	39	32	16	23	20	8.6	16	24	23	6	11	17
4	17	11	11	0	10	9.6	5.4	9.5	17	18	9.5	16	11	12	12	14	14	14	14	18	17	17	20	21	23	23	16	20	19	36	34	41	25	35	19	27	24	11	15	21	20		
5	14	10	13	9.8	10	0	5.4	7.2	11	9	9.8	11	7.6	2.2	4.5	2.5	5.7	5.2	6.5	9	12	7.6	8.6	11	12	15	14	7.2	11	13	27	25	35	19	27	24	12	19	27	26	11	15	21
6	20	13	13	13	9.6	5.4	0	5.4	5	10	9.6	5	8.2	6.8	3.5	4	8.6	6.5	11	14	16	12	13	15	17	18	19	12	16	14	28	26	30	41	25	32	29	18	25	33	32	14	20
7	20	11	11	12	5.4	7.2	5.4	0	4.8	13	13	4.8	13	8.2	7.1	7.6	11	11	13	14	17	17	13	15	17	18	21	20	13	18	21	32	31	41	25	32	29	18	25	33	32	12	20
8	23	15	15	15	9.5	11	5	4.8	0	13	14	0.7	13	12	7.5	9.3	14	11	16	18	21	18	22	23	23	24	17	21	18	32	30	45	29	36	33	22	29	37	36	17	25	24	
9	31	21	22	19	17	10	9	13	13	0	7.8	12	7.2	11	6.2	8.3	11	8.3	15	18	25	17	19	18	20	22	20	16	30	28	47	28	43	36	25	31	40	44	31	23	41		
10	25	18	21	27	18	9.8	9.6	13	14	7.8	0	12	3.2	9.8	5.7	8	7.5	6.2	13	17	20	15	14	19	20	16	20	11	15	12	26	24	43	31	39	31	21	27	36	40	26	37	
11	23	15	16	15	9.5	11	5	4.8	0.7	12	12	0	13	12	7.2	9	14	11	16	18	21	17	18	20	22	22	24	17	21	18	32	31	45	25	42	34	22	28	43	36	16	24	
12	24	16	20	16	7.6	8.2	13	13	7.2	3.2	13	0	8.2	4.1	6.4	4.8	4.5	17	15	20	17	14	18	20	16	19	10	14	11	23	21	42	31	38	31	20	27	35	39	26	36		
13	13	9.2	14	9.7	11	2.2	6.8	8.2	12	11	9.8	12	8.2	0	6.4	4	3.6	4.4	5.1	7.9	8.2	6.1	6.7	9.1	11	13	12	5.6	9.8	8.8	17	24	37	19	33	25	14	21	25	34	13	14	
14	18	16	16	14	12	4.5	3.5	7.1	7.5	6.2	5.7	7.2	4.1	6.4	0	3	7	4.6	10	13	15	12	13	15	17	15	23	13	14	12	25	24	46	24	42	34	23	23	38	43	17	19	
15	16	12	15	12	12	2.5	4	7.6	9.3	8.3	8	9	6.4	4	3	0	5.5	3.6	8	11	12	9.4	10	12	14	15	16	9.3	14	12	26	24	40	21	36	29	14	21	29	37	12	16	
16	16	12	17	13	14	5.7	8.6	11	14	11	7.5	14	4.8	3.6	7	5.5	0	2.3	8	11	16	9	7.7	12	14	9.8	12	4	8.3	7.3	23	21	39	27	35	27	16	23	32	36	22	16	
17	11	7.3	17	13	14	5.2	6.5	11	11	8.3	6.2	11	4.5	4.4	4.6	3.6	2.3	0	8.6	11	17	9.5	11	13	15	13	17	7.6	11	8.5	23	21	40	22	36	28	18	24	33	37	23	17	
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20	7.5	7.9	14	8.3	18	12	16	17	21	25	20	21	20	8.2	15	12	16	17	4.9	7.7	0	2.2	12	9	5.6	18	12	9.7	21	19	34	32	29	15	21	18	6.8	13	19	18	10	8.8	
21	9.6	7.3	13	18	17	7.6	12	17	18	17	15	17	17	6.1	12	9.4	9	9.5	3.5	7.2	2.2	0	8.8	6.2	7.7	15	9	7.9	19	17	31	29	32	16	28	20	8	15	23	24	10	11	
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24	11	11	17	12	21	12	17	18	23	24	20	22	20	11	17	14	14	15	8.3	11	5.6	7.7	9.9	8	0	17	11	12	22	19	33	31	29	16	25	17	8	10	16	15	11		
25	24	20	17	20	23	15	18	21	23	20	16	22	16	13	15	15	9.8	13	16	25	18	15	7.3	9.7	17	0	6.3	6.5	2.2	5.7	10	10	40	34	36	28	18	25	24	29	23	40	
26	19	16	22	15	23	14	19	20	24	24	20	24	19	12	13	16	12	17	9.6	15	12	9	5.8	3.9	11	6.3	0	8.1	7.4	12	15	15	36	24	32	24	13	18	21	26	19	29	
27	19	15	18	15	16	7.2	12	13	17	15	11	17	10	5.6	13	9.3	4	7.6	8.5	19	9.7	7.9	6.3	8.2	12	6.5	8.1	0	5	4.9	13	20	35	23	31	23	12	19	34	32	18	29	
28	25	18	23	19	20	11	16	18	21	19	15	21	14	9.8	14	14	8.3	11	12	18	21	19	8.1	10	22	2.2	7.4	5	0	4.2	9.7	10	42	30	38	30	20	26	26	39	25	36	
29	25	17	21	27	19	13	14	17	18	16	12	18	11	8.8	12	12	7.3	8.5	17	26	19	17	10	18	19	5.7	12	4.9	4.2	0	17	15	42	30	38	30	20	26	41	39	25	36	
30	39	25	30	41	36	27	28	32	32	30	26	32	23	17	25	26	23	23	31	40	34	31	17	18	33	10	15	13	9.7	17	0	2.2	4.9	4.8	45	38	27	38	25	31	44		
31	38	26	31	39	34	25	26	31	30	28	24	31	21	24	24	24	21	30	38	32	29	17	18	31	10	15	20	10	15	2.2	0	5.8	4.9	5.4	47	36	38	25	31	44			
32	20	26	31	32	41	35	40	41	45	47	43	45	42	37	46	40	39	40	32	31	29	32	33	34	29	40	36	35	42	42	49	58	0	16	5.8	12	30	20	27	21	36		
33																																											