Comparing genetic algorithm and particle swarm optimization for solving capacitated vehicle routing problem

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Abstract. In the logistics system, transportation plays an important role to connect every element in the supply chain, but it can produces the greatest cost. Therefore, it is important to make the transportation costs as minimum as possible. Reducing the transportation cost can be done in several ways. One of the ways to minimizing the transportation cost is by optimizing the routing of its vehicles. It refers to Vehicle Routing Problem (VRP). The most common type of VRP is Capacitated Vehicle Routing Problem (CVRP). In CVRP, the vehicles have their own capacity and the total demands from the customer should not exceed the capacity of the vehicle. CVRP belongs to the class of NP-hard problems. These NP-hard problems make it more complex to solve such that exact algorithms become highly time-consuming with the increases in problem sizes. Thus, for large-scale problem instances, as typically found in industrial applications, finding an optimal solution is not practicable. Therefore, this paper uses two kinds of metaheuristics approach to solving CVRP. Those are Genetic Algorithm and Particle Swarm Optimization. This paper compares the results of both algorithms and see the performance of each algorithm. The results show that both algorithms perform well in solving CVRP but still needs to be improved. From algorithm testing and numerical example, Genetic Algorithm yields a better solution than Particle Swarm Optimization in total distance travelled.

1. Introduction
Transportation planning, as one of the main areas of supply chain management, has become increasingly challenging for companies in terms of controlling cost because the fuel cost rises continuously [1]. Vehicle Routing Problem is a central issue in transportation planning. Since Dantzig and Ramser introduce VRP in 1959 [2], VRP has become one of the most important and widely studied topics in the area of combinatorial optimization [3][4]. VRP can be described as the process of determining optimal routes from one or several depots to a number of geographically scattered customers, subject to side constraints [5]. The most common VRP is CVRP ( Capacitated Vehicle Routing Problem). The implementation of VRP in real-life applications are blood pick-up routing, waste collection, street cleaning, school bus routing, food distribution, etc. Therefore, this topic has attracted the attention of numerous researchers.

The basic VRP and basically all of its variants like CVRP, VRPTW, VRPDP, and TDVRP belong to the class of NP-hard problems. These VRP extensions make it even more complex to solve with more additional variables such that exact algorithms become high time-consuming with the increases in
problem size. Thus, for large-scale problem instances typically found in industrial applications, finding an optimal solution is not practicable. Therefore, different types of heuristics, ranging from classical heuristics to sophisticated metaheuristics can produce solutions with good quality. This paper studies a comparison of two population-based metaheuristics: Genetic Algorithm and Particle Swarm Optimization to see which one is better to solve the Vehicle Routing Problem.

2. Literature Review

The well-known Vehicle Routing Problem was firstly introduced by Dantzig and Ramser in 1959 [2]. They tackled the optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal. They tried to find a way to assign stations to trucks in such a manner that the station demands are satisfied and the total mileage covered by the fleet is minimized.

Since its introduction by Dantzig and Ramser in 1959, VRP has been developed by many researchers. Lin et al [6] found that numerous types of traditional VRP were identified, including CVRP, time-dependent VRP, the pickup and delivery problem, multi-depot VRP, stochastic VRP, the location routing problem, periodic VRP (PVRP), dynamic VRP, inventory routing problem, fleet size and mix VRP, generalized VRP, multi-compartment VRP, site-dependent VRP, split delivery VRP, fuzzy VRP, OVRP, VRP with loading constraints, and multi-echelon VRP.

CVRP is the most common variant of VRP. Lin et al [7] define CVRP as a problem in which a set of routes for vehicles based at one or several depots have to be determined by the number of geographically dispersed customers. Each vehicle has the maximal loading capacity. The objective is to minimize the total cost (i.e. a weighted function of the number of vehicles and the distance traveled by the vehicles) to serve a set of customers. The customers have their known demands in which the route must be designed in such a way that each customer is visited at most once by one vehicle only.

Laporte [8] gave good overviews on solution methodologies for VRP. Those are exact algorithms, classical heuristics, and metaheuristics. From his research, given that VRP and its variants are NP-hard problems, classical heuristics and metaheuristics are considered more efficient and practical than the exact solution in solving large-scale problems. Example of classical heuristic methods is saving algorithm that developed by Clarke and Wright [9], while the metaheuristic are Ant Colony Optimization [10][11][12], Genetic Algorithm [13], Simulated Annealing [14], Particle Swarm Optimization [12][15] and Tabu Search [16].

Based on literature review, this research employs metaheuristic methods for solving the Vehicle Routing Problem. It is because VRP is a complex problem and it is not recommended to use exact method for real cases in large problems due to high computational time. This paper will compare two metaheuristic methods, those are Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). GA and PSO were chosen because both methods are population-based methods. In the population-based method, the solution will move from a population to another population with some evaluation processes. GA uses a genetic scheme such as selection, mutation, and crossover, while PSO uses swarm behavior such as updating position and velocity for the evaluation process.

3. Problem Description

Laporte [5] defines the classical VRP in graph-theoretic terms as follows: Let $G=(V,A)$ be a graph where $V=\{1,\ldots,n\}$ is a set of vertices representing clients with known and deterministic demands. $V_i$ represents the single depot [5]. $A$ is the set of arcs that interconnect all clients. The weight (i.e. cost) of each arc between node $i$ and $j$ is denoted by $c_{ij}$. The objective is to minimize the total distance traveled for each of $K$ vehicles available, subject to the following constraints:

1. Each customer is visited exactly once.
2. Each route starts and ends at the depot.
3. Other side constraints to be satisfied.

In CVRP, the vehicles have their own capacities and the total demands from the customer should not exceed the capacity of the vehicles. Below is the mathematical model of CVRP.
Notations:
\( N = \text{Set of nodes \{0,1,2,\ldots,|N|\}} \)
\( K = \text{Set of vehicles \{1,2,\ldots,|K|\}} \)
\( t_{ij} = \text{Travel time from node } i \text{ to node } j \)
\( C = \text{Vehicle capacity} \)
\( d_{ij} = \text{Distance from node } i \text{ to node } j \)
\( p_j = \text{Demand at node } j \)

Decision variable:
\( x_{ijk} = 1 \text{ if vehicle } k \text{ travels directly from node } i \text{ to node } j; 0 \text{ otherwise.} \)

Minimize
\[
\sum_{k \in K} \sum_{i \in N} \sum_{j \in N, j \neq i} d_{ij} x_{ijk}
\]  
(1)

Subject to:
\[
\sum_{k \in K} \sum_{i \in N} x_{ijk} = 1 \quad \forall j \in N
\]
(2)
\[
\sum_{i \in N} x_{0ik} \leq 1 \quad \forall k \in K
\]
(3)
\[
\sum_{i \in N} x_{ilk} = \sum_{j \in N, j \neq i} x_{ijk} \quad \forall l \in N, k \in K
\]
(4)
\[
\sum_{i \in N} \sum_{j \in N, j \neq i} p_j x_{ijk} \leq C \quad \forall k \in K
\]
(5)

The objective function (1) is for minimizing the total travel distance of vehicles. Each node can only be visited once defined by constraint (2), and each vehicle is used at most once as defined by constraints (3). Constraint (4) is a flow constraint. Constraint (5) guarantees that the demand picked up by a vehicle does not exceed the vehicle’s capacity.

4. Genetic Algorithm and Particle Swarm Optimization

4.1 Genetic Algorithm (GA)

The first method used for solving CVRP is Genetic Algorithm (GA). GA is a metaheuristic method based on the genetic scheme in living creatures. It uses some evolutionary scheme like selection, mutation, and crossover. The flowchart of GA is shown in Figure 1. The steps of Genetic Algorithm for solving the vehicle routing is written below:

1. Determine the parameter values that are used in GA, those are population size, mutation rate, crossover rate, and the maximum number of iteration.
2. Generate random initial population with the number of chromosomes appropriate with population size. The solution represented by a chromosome consisting a permutation of n customers denoted by the set \( \{1,2,\ldots,n\} \) and \( N_{dummy} \) zeros. Here, \( N_{dummy} \) is a variable that denotes the number of dummy depots for constructing a new route in addition to the route constraint. For example, the first chromosome is \( \{0,1,2,3,0\} \), meaning that the route is from depot to customer 1, then customer 1 to customer 2, then customer 2 to customer 3, and customer 3 will back to the depot.
3. Calculate the fitness value of each chromosome by calculating the total distance from each route and choose the chromosome with the minimum total distance as the best chromosome.
4. After calculate fitness value, then sort the population based on their fitness value. The sorting procedure is from chromosome that has best fitness value to the chromosome that has worst fitness value.

5. Then do selection process based on truncation method. In the truncation method, with the population that has been sorted, keep some of the best chromosomes so they can enter next iteration. This mechanism called elitism. Then, for other chromosomes, choose two chromosomes as a parent and do crossover and mutation.

6. After new population is obtained, repeat step 3 to 5 until the algorithm reaches the stopping criteria. In this research, the stopping criteria is maximum number of iteration.

4.2 Particle Swarm Optimization (PSO)

The second method used for solving CVRP is Particle Swarm Optimization (PSO). PSO is a metaheuristic method based on swarm behavior by updating the position and velocity of each individual. The flowchart of PSO is shown in Figure 2. The steps for solving VRP using PSO is written below:

1. Determine the first initialization as the number of particle, initial routes, c1, c2, maximum number of iteration, initial position and initial velocity

2. Evaluate the total distance of every particle

3. Choose the particle with the smallest total distance and use this particle into Gbest. For every particle, use the initial total distance as Pbest

4. Repeat the following steps until the stopping criteria is reached. In this research, the stopping criteria is maximum number of iteration.
   a. Use Pbest and Gbest for updating the velocity of every particle with Equation (6). With the new velocity then update the position of every particle use Equation (7).

\[
V_i(t) = V_i(t - 1) + c_1 r_1 (P_{best_i} - X_i(t - 1)) + c_2 r_2 (G_{best} - X_i(t - 1))
\]  
\[X_i(t) = V_i(t) + X_i(t - 1)
\]

Where,
- \(X\) = Particle position
- \(V\) = Particle velocity
- \(i\) = particle index
- \(t\) = \(t^{th}\) iteration
- \(P_{best_i}\) = local best from \(i^{th}\) particle
- \(G_{best}\) = global best from all swarm
- \(c_1, c_2\) = learning factor.
- \(r_1, r_2\) = random number

b. Evaluate the total distance of every particle

c. Choose the particle with the smallest total distance and make this particle into Gbest. For every particle, use the initial total distance as Pbest

d. Check the stopping criteria. If stopping criteria is reached then stop, otherwise go to step ‘a’ again.
5. Computational Results

5.1 Algorithm Testing
A computational study is conducted to evaluate the performance of Genetic Algorithm and Particle Swarm Optimization to solve the Capacitated Vehicle Routing Problem. The computational study is divided to algorithm testing and numerical example on a real case. First, this research evaluates solution quality of GA and PSO by test it on a small-medium data set from Augerat [17] to see the performance of both algorithms compare to the exact solution. The data sets that are used from Augerat et al are small-medium CVRP datasets that have 31-38 instance. Parameter used for Genetic Algorithm are as follows maximum number of iteration = 50000, population size = 80, mutation rate = 0.1, crossover rate = 0.8 and for PSO are maximum number of iteration = 50000, number of particle = 80, c1=2, c2=1. Table 1 shows the comparison of Genetic Algorithm and Particle Swarm Optimization results with the optimal solution from exact solution.
Table 1. Comparison Result for Small-Medium Instances

| No | Instance | Optimal Solution | GA  | PSO  | diff GA | diff PSO |
|----|----------|------------------|-----|------|---------|---------|
| 1  | 31       | 672              | 699 | 703  | 0,041   | 0,046   |
| 2  | 34       | 788              | 801 | 835  | 0,016   | 0,060   |
| 3  | 35       | 955              | 998 | 1,081| 0,045   | 0,132   |
| 4  | 38       | 805              | 829 | 891  | 0,030   | 0,107   |
|    | mean     | 805              | 831,70 | 877,55 | 0,033 | 0,086 |

The result in Table 1 shows that the average differences between these two method and the optimal solution are 0,033 and 0,086. It means that the performance of proposed algorithm is competitive because the differences with the optimal solution are relatively small. From the comparison results, we can see that GA obtain a better solution than PSO solution in total distance traveled.

5.2 Numerical Example in a Real Case

After conducting the algorithm testing, this research compares the performance of Genetic Algorithm and Particle Swarm Optimization in a real case of Vehicle Routing Problem that belongs to a medium-large case of Vehicle Routing Problem. The case used in this research is distribution routing of Chainstore A in Yogyakarta City, Indonesia. Chainstore A has 1 depot located in West Ringroad Yogyakarta and 62 retailers scattered within Yogyakarta City region. Each retailer has its own demand and the demand is fulfilled by the depot. The vehicle for distribution has its own capacity and the demand carried by the vehicle must not exceed its capacity. The algorithm has been generated ten times, then we calculate a minimum, mean and maximum value for each algorithm. This research compares GA results PSO results in terms of both solution quality and computational time. Table 2 shows the comparison between GA and PSO in the real case.

Table 2. Comparison Result for Real Case

| i  | TD    | Time  | TD    | Time  | diff   |
|----|-------|-------|-------|-------|--------|
| 1  | 401,54| 296,98| 452,64| 215,91| -0,127 |
| 2  | 402,43| 298,99| 451,69| 224,42| -0,122 |
| 3  | 418,89| 298,26| 437,45| 222,99| -0,044 |
| 4  | 412,65| 297,34| 452,14| 222,71| -0,096 |
| 5  | 404,54| 299,18| 408,59| 219,04| -0,010 |
| 6  | 407,25| 296,07| 447,44| 216,40| -0,099 |
| 7  | 413,89| 300,63| 452,10| 216,05| -0,092 |
| 8  | 407,64| 305,31| 475,20| 210,76| -0,166 |
| 9  | 414,05| 307,99| 448,25| 222,27| -0,083 |
| 10 | 402,20| 305,17| 451,54| 218,29| -0,123 |
| min| 401,54| 296,07| 408,59| 210,76| -0,166 |
| mean| 408,51| 300,59| 447,70| 218,89| -0,096 |
| max | 418,89| 307,99| 475,2 | 224,42| -0,010 |

Based on Table 2, GA provides a better solution than PSO in the average of total distance traveled. The average differences is -0,096, the negative sign means that GA produces smaller value than PSO. It also is shown by the minimum, mean and maximum value, the results fro GA is smaller than PSO results. It indicates that GA can produce better solutions than PSO. However, for the computational time, GA needs longer time to yields the optimal solution compared to PSO.
6. Conclusion
This study proposed two metaheuristics methods named Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) to solve the Capacitated Vehicle Routing Problem (CVRP). We tested the proposed algorithm on a small-medium data set from Augerat [17] to see the performance of both algorithms compare to the exact solution. The results indicate that the performance of proposed algorithm is competitive because the gaps with the optimal solution are relatively small, but it still has room for improvement. This research also compares the performance of Genetic Algorithm and Particle Swarm Optimization in a real case of Vehicle Routing Problem that is a distribution routing of Chainstore A in Yogyakarta City, Indonesia. From the results, we can know that GA can produce better solutions than PSO. However, in term of computational time, GA needs longer time to achieve the optimal solution compared to PSO. Researchers in the future may focus on developing more effective algorithms for solving medium and large CVRP instances.

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