Metaheuristic Optimization for Vehicle Routing Problem with Time Windows (VRPTW)

Triani Aulya Fitri, Dendi P Ishak
Industrial Engineering Department,
Faculty of Engineering University of Indonesia Depok,
West Java, Indonesia
triani.aulya@ui.ac.id, dendi@ie.ui.ac.id

Abstract

The problem of determining vehicle routes in logistics has a role Which on pIt isnting bagi company to reduce transportation costs and late fees. Time window constraints are very common in current distribution processes. This research focuses on optimizing fuel costs and penalties. In this study the authors used the Vehicle Routing Problem with Time Windows (VRPTW). VRPTW is one of the most tackled transportation problems in real world situations. Artificial Bee Colony Algorithm (ABC) and Camel Algorithm (CA) will be used in the research. Study This is Focused on optimizing fuel costs and penalties. Furthermore, the two algorithms will be compared which of the two algorithms is the most optimal for solving the route determination problem in VRPTW. Numerical testing will be carried out for the proposed algorithm, as well as conducting experiments on several parameters to determine the effect of parameters for fuel costs and penalties.

Keywords
Algorithm Artificial Bee Colony, Algoritma Camel, Vehicle Routing Problems with Time Windows, Vehicle Routing Problems and Optimasi.

1. Introduction
The problem of determining vehicle routes in logistics has meaning It is important for logistics companies to reduce transportation costs and late fees. This route determination problem is known as the Vehicle Routing Problem, abbreviated as VRP. VRP can be defined as a Goods distribution management that pays attention to service, for a certain period, a group of consumers with a number of vehicles conveniently located at one or more depots run by a group of motorists using the road network *(road network)* appropriately. VRP includes determining a number of routes, where each route is passed by one vehicle that starts and ends at the depot of origin, so that the demands of all customers are met while still meeting existing operational constraints and also minimizing global transportation costs. There are various types of VRP, one of which is VRPTWcan be defined as the problem of finding a cost-minimizing route for a number of homogeneous vehicles stationed at a depot, whose task is to deliver goods to a number of customers (Ursani et al. 2011).

In this study, the VRPTW problem is found in CV. Harapan Indah which is one of the industries that produce ice for consumption which is in the city of Padang. The resulting product is in the form of ice crystals. The company currently delivers ice to 30 places across the city of Padang. The delivery process uses 5 Colt Diesel cars with a capacity of 250 bags of ice per car. Figure 1 represents the map of delivery locations.

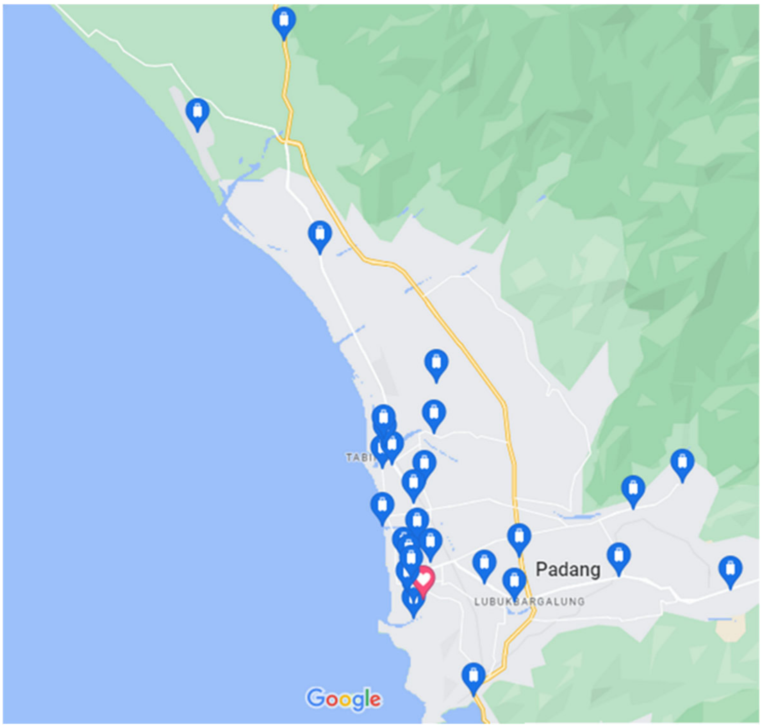

Figure 1. Map of Delivery Locations

For now, existing routes are only based on one-way routes without any study on route determination, so there are still customers who often miss visits because they have exceeded the operating hours set by the customer. So, the company needs a good route so that these goods can arrive at their destination according to the request and the opening and closing time of the shop, also so that shipping does not cost a lot (Figure 2).

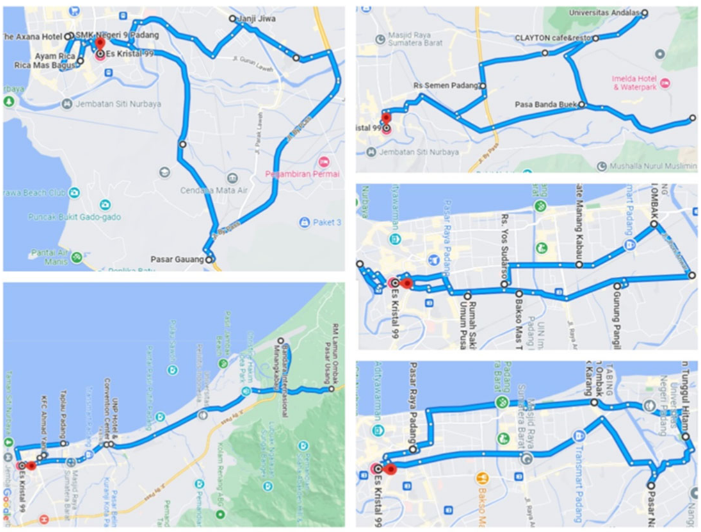

Figure 2. Existing Pathways

1.1 Purpose

Based on the problems that have been So the purpose of this study is divided into two, the first is to determine vehicle routes in the company using metaheuristic optimization and the second is to compare the total distribution costs of the routes obtained from the artificial bee colony algorithm and the Camel algorithm.

2. Library Review

VRPTW is one of the most widely handled transportation problems in real world situations (Harzi and Krichen 2017). In VRPTW, each vehicle must arrive in a certain time window with each customer and also each vehicle must return to the depot ahead of time (Pérez-Rodríguez and Hernández-Aguirre 2019). The function of the VRPTW itself is in various ways, one of which is reducing the number of vehicles and minimizing wastage of time during the delivery process caused by earlier arrivals according to Zhang et al. (2020). Zhang et al. (2020) used a hybrid multi-objective evolution algorithm (HMOEA-GL) approach to achieve this goal. Another goal of VRPTW is to minimize the total duration of the vehicle, energy consumption, customer satisfaction, total service time and minimize mileage, which has been discussed by Qi et al. (2022), Wang et al. (2019), Pérez-Rodríguez and Hernández-Aguirre (2019), Semiz and Polat (2020), Ben Hassen et al. (2019), Dhahri et al. (2016), Li et al. (2020), Schneider (2016), Androutsopoulos and Zografos (2017), Pan et al. (2021), Ongcunaruk et al. (2021), Ali et al. (2021), Erdelić et al. (2019), Pan et al., (2021) Ghannadpour and Zarrabi (2019) and Zuo et al. (2019).

In previous research, other goals were also discussed, such as improving the performance of the algorithm proposed by Dong et al. (2018), proving the effectiveness of the solution method and stochastic models, mathematical proposals for new models, and developing new models have been discussed by Errico et al., (2018), Truden et al. (2022), Srivastava et al., (2021), Ticha et al. (2019), Nguyen et al. (2016), and Baños et al. (2016).

For the algorithm modeling approach used mostly from previous journals, namely the branch-and-price algorithm by Ticha et al. (2019), Errico et al., (2018), and Errico et al. (2016), artificial bee colony improvisation algorithm Li et al. (2020), the Mallow distribution algorithm Pérez-Rodríguez & Hernández-Aguirre (2019)

3. Methods

a. VRP

Vehicle Routing Problem (VRP) is a goods distribution management that pays attention to services, a certain period of time, a group of consumers with a number of vehicles located at one or more depots run by a group of drivers using the appropriate road network. Vehicle Routing Problem (VRP) was discovered by Dantzig and Ramser in 1959. The Vehicle Routing Problem (VRP) was the first non-linear program to search for a solution in solving a problem (VRP). According to Rahmi & Murti (2013): Vehicle Routing Problem (VRP) is a problem in a distribution system that aims to create an optimal route, with a group of vehicles whose capacity is known, in order to meet consumer demand with a known location and number of requests.
There are four general purposes of VRP (Toth and Vigo 2002):

4. Minimize global transportation costs, related to distance and fixed costs associated with vehicles
5. Minimizing the number of vehicles (drivers) needed to serve all customers
6. Balancing route, for travel time and vehicle payload
7. Minimizing penalties due to unsatisfactory service from consumers

b. VRPTW

VRPTW is a scheduling problem for a certain number of vehicles with a certain capacity and travel time from a depot to a set of geographically dispersed consumers. Each consumer has certain requests and can only be served during the time (*time windows*) certain. VRPTW is divided into two cases, namely cases *Hard time windows* and*Soft time windows*. In the case of hard *time windows* delivery will be rejected if it is not in accordance with the specified service time, meanwhile soft *time windows* consumers will receive delivery even though it does not match the specified time but delivers penalty or fees extra for the delay. The mathematical formulation for the VRPTW problem which aims to minimize or travel costs with a number of outlets is formulated as a model mixed-integer *programming* by Thangiah (1995).The goal of this model is to minimize the total*travel cost* (which is proportional to the distance). Here is the formulation
objective function:
With :

$$Z_{vrptw} = minimum \sum_{i=0}^{n} \sum_{j=0}^{N} \sum_{k=1}^{K} C_{ijk} X_{ijk} + \sum_{i=n}^{N} P_i$$

- c_{iq} as transportation costs between consumers *i* and *j* by vehicle *k*
- P_i as a consumer penalty fee*i* (Kallehauge, Larsen, & Madsen, 2006)

The decision variable in this problem is *and* $_I$ and x_{iq} which are respectively 0 or 1. If*and*$_I$ value of 1, means the consumer i serviced by vehicles k, and if the value is 0, then vice versa. Ifx_{iq} has a value of 1, means the vehicle k from consumers i will go directly to the consumer j, and if it is 0, then vice versa. formulation mixed-integer *programming are* as follows (Thhangiah 1995) with constraints:

$$\sum_{i=0}^{N} q_{ik} y_{ik} \le v_k , k = 1,\ldots, K \quad \text{…(1)}$$

$$y_{ik} = 0 \text{ atau 1; i = 1, 2, …, N; k = 1, 2, …, K} \quad \text{…(2)}$$

$$x_{ijk} = 0 \text{ atau 1; i = 1, 2, …, N; k =1 , 2, …, K} \quad \text{…(3)}$$

$$\sum_{k}^{K} y_{ik} = \begin{cases} K, jika\ i = 0 \\ 1\ jika\ i = 1, \ldots, N \end{cases} \quad \text{…(4)} \quad \pi = r^2$$

$$\sum_{i=0}^{N} x_{ijk} = y_{jk} \text{ , j = 0, …, N; k = 1, …, K} \quad \text{…(5)}$$

$$\sum_{j=0}^{N} x_{ijk} = y_{ik} \text{ , i = 1, …, N; k =1, …, K} \quad \text{…(6)}$$

$$\sum_{i=0}^{N} \sum_{i=0}^{N} y_{ik} \left(t_{ij} + f_i + w_i\right) \le R_k \text{ ; k = 1,…, K} \quad \text{…(7)}$$

$$t_j \ge t_i + w_i + f_i + t_{ij} - M\left(1 - x_{ijk}\right) \text{; i, j = 1, …, N; k = 1, …, K} \quad \text{…(8)}$$

$$e_i \le t_i < l_i \text{; i = 1, …, N} \quad \text{…(9)}$$

$$t_i \ge 0 \text{; i = 1, N} \quad \text{…(10)}$$

With :

- K as a vehicle index
- N as consumer index (0 indicates depot)
- C_i show consumers i, C_O show depots
- IN_k shows the route of the vehicle k
- q_I is the total demand for vehicles k to consumers i
- in_k Specifies the maximum capacity of the vehicle k
- R_k is the total route time for the vehicle k
- t_{ij} is the travel time between consumers i and j (proportional to distance)
- t_i is the arrival time at the consumer i
- f_i shows the customer service time i
- In_i as the waiting time before serving the consumer i, with
- *It is*$_i$ as the earliest time to serve consumers i
- l_i is the last time for customer service i

The goal of this model is to minimize the total *travel cost* (which is proportional to the distance). Constraint (1) is used to limit that total number of requests carried by the vehicle k must not exceed the capacity of the vehicle. Constraint (4) states that each customer can only be served by one vehicle. Constraints (5) and (6) ensure that each customer is visited by the same vehicle that was scheduled for that customer. Constraint (7) states that each vehicle serves all customers scheduled for that vehicle, without exceeding the travel time of that vehicle. Constraint (8) is used to ensure that the arrival times of the two consumers are the same compatible, with M is a very large real number. Constraint (9) ensures that the vehicle will arrive at each consumer during the limit time *windows* from the consumer. Constraint (10) ensures that the arrival time of the vehicle to each customer is always positive.

c. Algorithm *Artificial Bee Colony*

The ABC algorithm is an algorithm that can be used to solve optimization problems inspired by the behavior of a group of honey bees in searching for food sources and exploiting these food sources. ABC Algorithm Divided into 3 groups viz Employed bee, Onlooker bee dan Scout bee. Each group of bees has a different role in finding food sources. Role *Employed bee* exploit food source, *Onlooker bee* waiting at the nest to share information about the food source it is being exploited by *Employed bee* and *Scout bee* play a role in searching for new food sources randomly. This food source will be a modeling solution or set of routes, by comparing food sources others will obtain the quality of honey in the form of modeling the fitness value of the solution (set of routes) (Mingyong & Erbao, 2010).

d. Algorithm Camel

Algorithm *Camel* (CA) is a proposed metaheuristic algorithm that systematically simulates the behavior of camel travel in the field and in search of food. In this algorithm it is assumed that the variable involved is the camel herd (*camel caravan*) Which Traveling. There are 4 phases of CA namely the first phase, camels that are looking for food scattered randomly in the desert. The second phase, the location of each camel affects the function fitness (make span) to find the best location. Phase third, The environmental temperature directly affects the camel's journey, and that affects the camel's endurance significantly. Because camels move in different directions, they feel different temperatures and produce different endurance in each camel. and the fourth phase, two scenarios to update each camel's location. Where available *two scenarios to update each camel's location*. When the visibility of the camel is greater than a certain visibility threshold, the second scenario of the location updating process occurs when the visibility of the camel is less than the visibility threshold, whereby the camel randomly updates its location based on the result of the equation

4. Data Collection

There are nine data needed in this study, namely:

1. Customer data
   Customer data provides information regarding the name and address of the customer.
2. Request data
   Request Data is order data from customers
3. Vehicle data
   Vehicle data provide information about the type of vehicle, vehicle capacity and type of fuel
4. Cost Fuel consumption
   Cost Fuel consumption Obtained from observing the price of fuel per liter. For now in Indonesia the cost of fuel is Rp. 6,800.-
5. Initial Route Data
   The initial route is the route that is currently passed by vehicles in carrying out distribution activities
6. Customer Distance Data
   Customer distance data is the distance between the depot and the customer and the distance between the customer and other customers. Distance data is obtained with the helpGoogle maps
7. Vehicle Speed Data
   In practice, speed vehicles different from one node to another. This is affected by traffic density conditions and the customer area covered
8. Data Time Windows
9. Data time windows are given by customer to the company where this becomes pretend to be a messenger days

5. Results and Discussion

a. VRPTW solutions use Artificial Bee Colony

Solving VRPTW using ABC is solving cases with datareal obtained from the company through direct observation. The data is processed using MATLAB software assistance R2014a with the Artificial Bee Colony (ABC) algorithm. Data processing is done on the amount food 1000. and the results are as shown in Figure 3.

```
Total_Biaya =

   6.5335e+05


TC_Terlambat =

   4.5378e+05


TFC =

   1.9957e+05


NumberOfRoutes =

     5
```

Figure 3. Best Total Cost Results from VRPTW Using the ABC Algorithm

It can be seen from the picture that the total cost is Rp. 65,335.- with a total cost penalty is IDR 45,378.- and a total fuel cost of IDR 19,957.-.

b. The VRPTW solution uses the Camel Algorithm

Solving VRPTW using CA is solving cases with real data obtained from companies through direct observation. The data was processed using the help of MATLAB R2014a software with the camel algorithm. Data processing is carried out on the amount of food 1000. and the results are as shown in Figure 4.

```
Total_Biaya =

   3.5865e+05


TC_Terlambat =

   2.0734e+05


TFC =

   1.5132e+05


NumberOfRoutes =

     3
```

Figure 4. Best Total Cost Result from VRPTW Using CA Algorithm

It can be seen from the picture that the total cost is Rp. 35,865.- with a total penalty fee of IDR 20,734.- and a total fuel fee of IDR 15,132,-.

6. Conclusion

After processing the data and analyzing the results, it can be concluded that the transportation route using the Camel Algorithm (CA) is more optimal. There are 5 routes formed from this algorithm with a total cost of Rpp.s. 35,865. - with a total penalty fee of IDR 20,734. - and a total fuel fee of IDR 15,132, -. This proposed route produces a better total transportation cost than the initial route. Where the existing initial route has a total cost of Rp. 312,205. In Research Metaheuristic Optimization for Vehicle Routing Problem with Time Windows (VRPTW)this is a lot it's the number of trials too little so that there is less comparison that allows you to get a smaller total cost.

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