A novel hybrid jellyfish algorithm for minimizing fuel consumption capacitated vehicle routing problem

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Article Info

ABSTRACT

Distribution is a critical activity that must be carefully planned in order to minimize the company's fuel costs. The hybrid jellyfish (HJF) algorithm is proposed in this study to solve the fuel consumption capacity vehicle routing problem (FCCVRP). This problem's objective function is to minimize fuel consumption costs. The proposed HJF algorithm is used in this study to generate optimal fuel consumption through a population and iteration parameter experiment. The experiment results indicate that the HJF increasing parameter has an effect on reducing the total cost of fuel. Additionally, this study presents an algorithm comparison that demonstrates how effectively the proposed HJF algorithm solves FCCVRP.

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1. INTRODUCTION

Distribution route planning is an important activity in the supply chain sector [1], [2], and it can help a company's operational costs [3]. However, inadequate distribution route planning leads to high distribution costs [4], [5]. Transportation activities have contributed to an increase in pollution [6]. Thus, logistics policies in the supply chain sector must consider environmental effects [7]-[9] and economic aspects [10]. According to Fameli and Assimakopoulos [11], fuel consumption in transportation activities is critical for pollution control. The weight of the load is one of the factors that influence fuel consumption [11]. On the other hand, vehicle capacity affects route completion, a condition referred to as the capacitated vehicle routing problem (CVRP) by experts [12]. One of the CVRP variants to minimize fuel consumption is called the fuel consumption capacitated vehicle routing problem (FCCVRP) [6].

In recent years, several FCCVRP studies have been published. Kuo [13] was the first to propose the simulated annealing (SA) algorithm to solve the FCCVRP problem. The constant speed of each node was considered in his research as a factor affecting fuel consumption. Suzuki [14] provided a tabu search (TS) algorithm that took vehicle distance and speed into account when calculating fuel consumption. Poonthalir and Nadarajan [15] used the particle swarm optimization (PSO) algorithm to develop a fuel consumption model with varying vehicle speeds. In [16]-[18] proposed the SA algorithm, ant colony optimization (ACO) algorithm, and genetic algorithm (GA). Gaur *et al.* [19] proposed a simple procedure for estimating fuel consumption that takes distance into account. Unfortunately, their studies do not consider inter-node load when calculating fuel consumption.

Several FCCVRP studies have emphasized the importance of taking load into account when calculating fuel consumption. Ali and Farida [20] used the hybrid PSO (HPSO) algorithm, which resulted in increased fuel consumption due to increased load. Niu *et al.* [21] investigated this factor using novel hybrid tabu search (hybrid TS). Furthermore, Zhang *et al.* [22] conducted a similar study in which they proposed an evolutionary local search (ELS) algorithm to solve FCCVRP. Xiao *et al.* [23] proposed the SA algorithm to develop the FCCVRP model while considering vehicle load. Unfortunately, by taking into account the vehicle load, the FCCVRP study assumes that the vehicle speed remains constant between nodes. In fact, the vehicle speed between nodes differs. As a result, this study attempts to solve the FCCVRP while considering the variable vehicle load and vehicle speed between nodes.

Based on the previous research's description, FCCVRP research that focuses on load weight and vehicle speed is still insufficient. Furthermore, this study attempts to solve the FCCVRP problem using the Jellyfish algorithm. This algorithm is a new algorithm proposed by Chou and Truong [24] in 2021 that was inspired by jellyfish in the ocean. The Jellyfish algorithm has been used in a variety of fields, including parameter identification [25] and automated distribution system optimization [26]. However, jellyfish are never used to solve the FCCVRP problem. The jellyfish algorithm is combined with the neighborhood exchange procedure in this study to optimize the FCCVRP solution. As a result, we call this algorithm a hybrid jellyfish (HJF) algorithm. This research aims to propose the HJF algorithm to solve the FCCVRP problem. This research contributes to (1) the advancement of knowledge in the field of FCCVRP by proposing the HJF algorithm to solve this problem. The second contribution (2) is to develop a new mathematical model to solve FCCVRP by incorporating the weight of the load and varying vehicle speed between nodes.

2.   PROPOSED ALGORITHM

To reduce fuel consumption costs, this study proposes the HJF algorithm, which combines the Jellyfish method and the neighborhood exchange strategy. Chou and Truong [24] proposed a jellyfish algorithm that mimics the behavior of jellyfish swarms in search of food. There are three rules to jellyfish optimization. The first rule is that jellyfish move in swarms by following the ocean currents, and this change in movement mode is governed by a "time control mechanism." Jellyfish move in the ocean to find food, which is the second rule. They are drawn to areas with more food. The third rule is that the amount of food found is determined by the location and function of the destination.

This study proposes five major stages of HJF: 1) initializing the position of the jellyfish swarm and ocean currents; 2) update position based on jellyfish movement; 3) time control mechanism; 4) applying the rules of large rank value; and 5) improved solutions based on neighborhood exchange procedures. Algorithm 1 shows the proposed algorithm's pseudocode. The proposed HJF algorithm procedure is detailed in the following subsection.

2.1. Initialize the position of the jellyfish swarm and ocean currents

This section describes the initialization procedure for the position of the jellyfish shoal and ocean currents. As depicted in (1), the initial population is generated based on the logistics map. Where, X_i is the $i-th$ jellyfish location, and it is the chaotic logistic value. The initial population of jellyfish was generated using X_0 which has parameters (0, 1) and not elements (0, 0.25, 0.5, 0.75, 1). η is a parameter value that has a value of 4.

$$X_{i+1} = \eta X_i(1 - X_i), 0 \leq X_0 \leq 1 \tag{1}$$

Ocean currents are formulated in (2), where β is the distribution coefficient greater than 0. X^* is the current best jellyfish location. The average location of all jellyfish is denoted as μ.

$$X_i(t + 1) = X_i(t) + rand(0,1)x\ X^* - \beta\ x\ rand(0,1)x\ \mu \tag{2}$$

2.2. Update position based on jellyfish movement

This section describes position updates based on the movement of the jellyfish. The movement of jellyfish in the swarm is controlled by passive and active movements. As an illustration, passive motion indicates that the jellyfish simply moves in place. The new location of jellyfish based on passive motion is shown by the (3). Where a search space is limited by the upper bound by Ub and the lower bound by Lb. The length of motion around the jellyfish location has a coefficient of motion denoted as γ with a value greater than zero.

Algorithm 1: Pseudocode Hybrid Jellyfish (HJF) Algorithm

```
1.    Begin
2.    Define the objective function f(X),X = (x₁,…,x_d)ᵀ
3.    Set search space, population size (n_Pop) and maximum iteration (Max_iter)
4.    Initialize jellyfish population X_i(i = 1,2,…,n_Pop) based on (1)
5.    Calculate fitness in each jellyfish X_i,f(X_i)
6.    Find the best jellyfish based on best fitness (X*)
7.    Initialize iteration t = 1
8.    Repeat
9.    For= i=1 : n_pop do
10.  Calculate Time control based on (6)
11.             If c(t) ≥ 0.5: Jellyfish follow the ocean currents
             Update New location of jellyfish based on (2)
12.           Else: Jellyfish move in swarms
13.           If rand(0,1) > (1 − c(t)): jellyfish do passive movements
             Update New location of jellyfish based on (3)
14.           Else: Jellyfish do an active movement
             Update New location of jellyfish based on s (4) and (5)
15.           End if
16.           End if
17.          Update best jellyfish based on best fitness (X*)
18.          for i = 0:0.25 × node
           Perform flip on X*_flip position
19.                 if (evaluate (X*_flip) < evaluate X*))
             X* = X*_flip
20.                 end if
21.          end for
22.          for i = 0:0.25 × node
           Perform flip on X*_swap position
23.                 if (evaluate (X*_swap) < evaluate X*))
             X* = X*_swap
24.                 end if
25.          end for
26.  End for i
27.  Update iteration: t = t + 1
29.  Until stop criteria met (t > (Max_iter))
30.  Output results based on the best jellyfish (X*)
31.  End
```

On the other hand, active movement is considered effective exploitation of local search space. It is defined according to the formula shown in (4). Where, $\overrightarrow{Direction}$ is the behavior of each jellyfish swimming in the best direction to find food. This behavior is denoted in (5), where f is the objective function of location X.

$$X_i(t + 1) = X_i(t) + \gamma \; x \; rand(0,1)x \; (U_b − L_b) \tag{3}$$

$$X_i(t + 1) = X_i(t) + rand(0,1)x \; \overrightarrow{Direction} \tag{4}$$

$$\overrightarrow{Direction} = \begin{cases} X_j(t) − X_i(t) \; if \; f(X_i) \geq f(X_j) \\ X_i(t) − X_j(t) \; if \; f(X_i) < f(X_j) \end{cases} \tag{5}$$

2.3. Time control mechanism

The time control mechanism is used to model the movement of jellyfish due to changes in sea current temperature, passive and active movements. This movement is modeled in (6). Swarms of jellyfish are formed over time (iteration). Each jellyfish migrates within the swarm to get a better position by using active and passive movements. This activity is referred to as exploitation. $c(t)$ keeps changing every iteration. in the proposed algorithm, the number of swarm and Max_{iter} are the two parameters that must be used in this algorithm. Where Max_{iter} is the maximum allowable iteration.

$$c(t) = (1 − \frac{t}{Max_{iter}})x \; (2 \; x \; rand(0,1) − 1) \tag{6}$$

2.4. Apply large rank value

The travel sequence is the decision variable in the FCCVRP problem, which is a discrete problem. FCCVRP is classified as a non-polynomial deterministic (NP) hard problem, indicating that optimizing the problem's solution is difficult. To change the position of the jellyfish vector in the travel sequence, this study proposes a large rank value (LRV) approach. LRV procedures are easy to apply to combinatorial problems such as scheduling [27]-[30] and routing problems [7]-[9]. This procedure is depicted in Figure 1, where the jellyfish's position changes to a travel sequence. It is used to compute the total distribution cost, which is shown in (7).
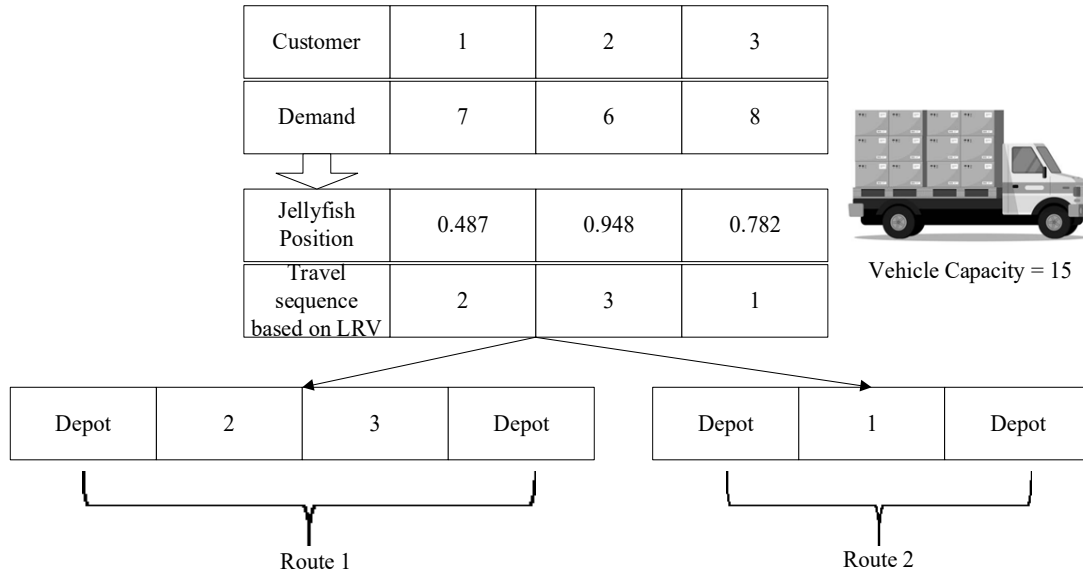
Figure 1. Overview Jellyfish position changed to travel sequence

2.5. Apply neighborhood exchange

In each iteration, neighborhood exchange is used to improve the performance of the jellyfish algorithm. This study proposes two exchange rules: Neighborhood flip and swap. The flip rule is a rule that reverses the positions of two randomly chosen jellyfish position vectors, as shown in Figure 2. Two randomly selected jellyfish position vectors are swapped to demonstrate the swap rule. The swap rule is depicted in Figure 3. Every iteration of the neighborhood exchange procedure must be repeated 0.25 times. In each iteration, the LRV procedure is used to convert a set of jellyfish positions into a travel sequence. The previous solution is compared with the new Neighborhood exchange result to determine the best solution in the current iteration.
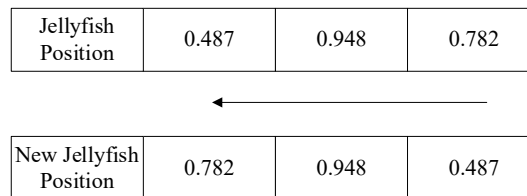

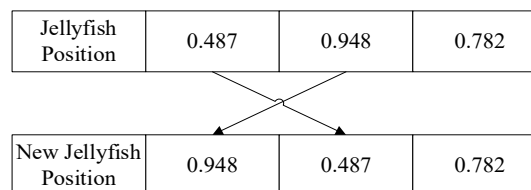Figure 2. Illustration of the flip rule

Figure 3. Illustration of the swap rule

3. RESEARCH METHOD

3.1. Assumptions, notations, and problem descriptions

The following are the problem assumptions for the FCCVRP problem: (1) A single vehicle serves each customer; (2) The vehicle used for the trip leaves and returns to the depot; (3) Fuel consumption is influenced by the weight of the load, liters per hour (LPH), increase in fuel consumption (p), and distance; (4) Vehicles for distribution are all the same.; (4) The demand for each customer is fixed; and (5) Only one distribution center is considered in this problem. Therefore, to describe the FCCVRP problem, this study uses the notation described as:

p	: increase in fuel consumption
R_r	: number of routes/vehicles
Q	: vehicle capacity
G_r^i	: vehicle travel to node i on route r
$FC_{(G_r^i)(G_r^{i+1})}$	: Total fuel consumption from node i to $i+1$ in route r
$L_{(G_r^i)(G_r^{i+1})}$	: Vehicle load between node i to $i+1$ on route r
$d_{(G_r^i)(G_r^{i+1})}$	: The travel distance of node i to $i+1$ on route r
$KPL_{(G_r^i)(G_r^{i+1})}$	: the fuel consumption per kilometer from node i to $i+1$ on route r
$LPH_{(G_r^i)(G_r^{i+1})}$	: the fuel consumption per unit time from node i to $i+1$ in route r
$v_{(G_r^i)(G_r^{i+1})}$	: Vehicle speed from node i to i+1 on route r
M	: When an additional load weight M is added to the vehicle, the fuel consumption increases.
V_r	: Number of travel routes
$q_{G_r^i}$	: Demand node i on route r
fc	: fuel price per liter

The mathematical formulation of the FCCVRP model was developed by Kuo [13]. The FCCVRP mathematical formula for this problem is presented as:

$$\text{Min} \sum_{r=1}^{R_r} \sum_{s=1}^{V_r-1} LPH_{(G_r^i)(G_r^{i+1})} \frac{d_{(G_r^i)(G_r^{i+1})}}{v_{(G_r^i)(G_r^{i+1})}} \times (1 + p \times \frac{L_{(G_r^i)(G_r^{i+1})}}{M}) \times fc \tag{7}$$

$$LPH_{(G_r^i)(G_r^{i+1})} = \frac{v_{(G_r^i)(G_r^{i+1})}}{KPL} \tag{8}$$

subject to

$$\sum_{r=2}^{V_r-1} q_{G_r^i} \le Q, \qquad \forall r = 1, 2, \cdots, V_r \tag{9}$$

$$L_{(G_r^i)(G_r^{i+1})} = \sum_{i'=i+1}^{V_r-1} q_{G_r^{i'}}, \qquad \forall r = 1, 2, \cdots, V_r \tag{10}$$

$$R_r^1 = R_r^{V_r} = 0, \qquad \forall r = 1, 2, \cdots, V_r \tag{11}$$

$$R_r \ge 0, V_r \ge 0, R_r^i \subset V, \forall r = 1, 2, \cdots, V_r, \qquad \forall i = 1, 2, \cdots, V_r \tag{12}$$

The objective function of this problem is to minimize the cost of fuel consumption, as presented in (7). The value of $LPH_{(G_r^i)(G_r^{i+1})}$ is generated based on (8). There are four constraints of this FCCVRP problem. Constraints to keep the load from exceeding the vehicle's capacity (9) and (10). The constraint that ensures that the start and end trips are at the distribution center is (11). The last constraint is (12) which ensures that the number of vehicles and routes is > 0.

3.2. Data and experiment

This study used several numerical experiments. The data used was KPL which refers to Kuo's research [14]. The value of ρ was 2% for every 46 kg increase in weight. The value of M is 46 kg, and the fuel price (fc) was 5,500 IDR. The distance matrix for problems had a range of 0.3 to 17 kilometers. Vehicle speed data between nodes had a range of 40 to 60 kilometers per hour. Furthermore, customer demand data had a range of 18.75 to 490 kilograms.

An experiment was carried out to assess the effect of the iteration parameter and the HJF population on the cost of vehicle fuel consumption. The experiment was conducted at 20 nodes, with the number of populations and iterations varying. The population parameter ranges used were 10, 20, 50, 100, 200, 500, and

1000. Meanwhile, the experiment's iteration parameters were varied across a range of 10, 50, 100, 200, 500, and 1000 iterations. As a result of the cost of fuel consumption, each calculation result was archived. The experimental results were examined to determine the effect of population variations and iterations on numerical experiments with varying nodes.

In addition, the proposed algorithm was compared to the previous algorithm in this study. Some of the comparison algorithms used were HPSO [20], Hybrid TS [21], dan ELS [22]. Algorithm comparisons were performed on 10, 20, 50, 60, 90, and 100 nodes. In addition, the algorithm was run on the population and iterations 1000. Matlab 2014a software was used to perform all experiment on a Windows 10 AMD A8 with x64-64 4GB RAM.

4. RESULTS AND DISCUSSION

Table 1 shows the experimental results for the effect of HJF parameters on fuel costs in the case of 20 nodes. These results indicate that the cost of fuel consumption is optimal in experiments with large populations and iterations when 20 nodes are used. As a result, the larger the population and iteration parameters, the less fuel is consumed. Hence, this study recommends using a large iteration and population parameter to minimize the cost of fuel consumption in this FCCVRP problem. In addition, population parameters and large iterations can result in the lowest possible fuel consumption costs.

Table 1. The HJF parameter experiment on fuel cost (IDR)

Population	Iteration					
	10	50	100	200	500	1000
10	144,230	126,286	117,622	111,455	93,626	85,649
20	134,327	110,609	98,933	87,893	86,634	84,344
50	133,393	106,780	95,765	81,571	80,457	77,771
100	130,046	104,156	94,033	83,168	78,813	76,554
200	128,009	108,749	93,490	89,671	77,682	76,517
500	111,972	96,295	92,864	79,145	75,706	73,418
1000	111,167	89,972	92,143	77,461	73,418	73,418

The results of the comparison of the proposed algorithm against the HPSO [20], Hybrid TS [21], and ELS [22] algorithms are presented in Table 2. In the case of 10 nodes, the proposed algorithm produces the same solution as the comparison algorithm. However, in the case of 20 nodes, the proposed algorithm produces a solution similar to HPSO and better than the hybrid TS and ELS algorithms. These results indicate that the proposed HJF algorithm produces a smaller total fuel cost for cases 50, 60, 90, and 100 nodes.

Table 2. Algorithms comparison (IDR)

Node	HJF	HPSO	Hybrid TS	ELS
10	**36,825**	**36,825**	**36,825**	**36,825**
20	**73,418**	**73,418**	73,651	73,651
50	**183,545**	184,127	189,265	188,184
60	**220,255**	220,952	227,119	225,821
90	**330,382**	331,428	338,731	340,678
100	**367,091**	368,253	376,368	378,531

5. CONCLUSION

This study discusses the problem of FCCVRP to minimize fuel costs. The HJF algorithm is proposed to minimize fuel costs. The experimental results show that the population and iteration parameters affect the quality of the solution to the FCCVRP problem. In addition, the proposed algorithm can minimize FCCVRP problems compared to the HPSO, Hybrid TS, and ELS algorithms. One of the study's limitations is that it does not account for the pick-up load at each node. Further research ideas could include looking into CVRP issues while considering the pick-up load.

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