A Novel Hybrid Yellow Saddle Goatfish Algorithm for Fuel Consumption Vehicle Routing Problem with Simultaneous Pick-up and Delivery Problem

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ABSTRACT

Currently, the issue of the fuel crisis has become a global concern. The distribution sector is one of the sectors that consume the most significant fuel. Therefore, an effective procedure for fuel energy efficiency is needed to resolve the routing problem. In addition, the vehicle load must be considered in delivery and pickup at each node. This research proposes the novel Hybrid Yellow Saddle Goatfish Algorithm (HYSGA) algorithm to solve the Fuel Consumption Vehicle Routing Problem Simultaneous Pickup and Delivery (FCVRPSPD) problem. The objective function to be achieved was to minimize fuel costs. This study conducted experiments with HYSGA parameters such as the number of Goatfish, iterations, and the number of goatfish clusters to optimize the FCVRPSPD problem. In addition, a sensitivity analysis was presented to examine the effect of the FCVRPSPD variable on fuel costs. This study also compared the proposed algorithm with several state-of-the-art procedures. The results showed that the parameters of the number of Goatfish and the HYSGA iteration affected fuel costs. Furthermore, based on experiments, the proposed algorithm provided a competitive fuel cost compared to other algorithms.

1. Introduction

Distribution and transportation are critical issues in supply chain management [1]. The vehicle routing problem generally improves economic performance in the supply chain [2, 3]. Some of the performances to be achieved include minimizing distance [4], reducing cost [5], maximizing profit [6], and minimizing delay [7, 8]. Recently, the supply chain sector significantly influenced environmental pollution [1] caused by logistics activities, especially routing problems [9]. Recent research reveals that route determination significantly influences distribution and environmental impact efficiency [10]. This problem is known as the Green Vehicle Routing Problem (GVRP) [11]. GVRP issues in recent years have attracted many researchers [12-14]. Fuel consumption produced in

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transportation activities is closely related to environmental problems [15]. This problem is triggered by the depletion of world fuel reserves [16]. A routing problem that considers fuel consumption is the Fuel Consumption Vehicle Routing Problem (FCVRP) [17, 18]. Distance influences fuel consumption in transportation activities, and fuel consumption also is influenced by vehicle speed and loads [19]. We call this problem a Fuel Consumption Vehicle Routing Problem Simultaneous Pickup and Delivery (FCVRPSPD), which harmonizes fuel efficiency in distribution activities.

Several studies on Vehicle Routing Problem Simultaneous Pickup and Delivery (VRPSPD) are dominated to improve economic performance [20]. The VRPSPD problem was first introduced by Min [21], which aimed to minimize distance. Several studies were also conducted to minimize distribution costs [20]. Moreover, the researchers were trying to propose an effective procedure for solving VRPSPD. Several VRPSPD procedures proposed to minimize costs include Simulated Annealing (SA) [22], Discrete firefly algorithm [23], variable neighborhood descent and local search [24], adaptive local search integrated with tabu search [25], iterated local search, and adaptive neighborhood selection [26], and branch and cut algorithm [27]. Several other algorithms were also developed to minimize the cost of VRPSPD distribution, such as Genetic Algorithm (GA) [28], particle swarm optimization (PSO) [29], hybrid chaotic quantum evolutionary algorithm [30], hybrid ant colony optimization (ACO) and tabu search [31], ACO [32], differential evolution algorithm [33], and improve ACO [34]. Several previous studies have a function and objective to minimize distribution costs. Unfortunately, the fuel costs involved only consider distance. In contrast, fuel consumption is affected by the vehicle load [35].

Other researchers have also suggested research on the FCVRP. Suzuki [35] was the first researcher to develop this problem. Xiao, et al. [36] proposed an SA procedure to solve the capacitated VRP problem. Environmental sustainability was studied by Rao, et al. [37], who used FCVRP mathematical modeling to evaluate its objective function sing hybrid local search. A novel hybrid Tabu search algorithm was used by Niu, et al. [38] to implement the concept of outsourcing logistics in FCVRP. Macrina, et al. [39] offered an iterative local search heuristic algorithm to minimize vehicle energy. The branch and bound procedure was proposed by Yu, et al. [40] on the heterogeneous fleet green vehicle routing problem with time windows. Zhang, et al. [41] developed an evolutionary local search procedure for capacitated VRP problems. Hybrid PSO was offered by Ali and Farida [42] to minimize fuel consumption. Based on the previous research, the study that addresses FCVRP has continued to increase over the last few years [11, 12].

Researchers have also published several FCVRPSPD papers. Majidi, et al. [43] proposed the Adaptive Large Neighborhood Search (ALNS) algorithm, which also considers time windows. Their model considers vehicle speed and load involving one vehicle. However, their research did not consider the load per unit of product transported. Huang, et al. [44] developed a GVRP model involving distance-dependent fuel costs. The ALNS procedure was also proposed by Majidi, et al. [45] that involves fuel consumption and emission costs. Gong, et al. [46] solved the GVRP problem by involving the cost of fuel consumption by proposing the bee Bee Evolutionary Algorithm. Unfortunately, their research does not consider the load of each product unit. One of the attractive FCVRP models that consider a load of each unit was proposed by Xiao, et al. [36]. Unfortunately, the study did not consider loads between nodes. Based on that weakness, Olgun, et al. [47] developed the model of Xiao, et al. [36] with pick-up and delivery to minimize fuel consumption costs with an iterative local search and variable neighborhood (ILSVN) algorithm. However, their study assumed using one vehicle. Based on the description above, FCVRPSPD studies are scarce. Therefore, this study tries to develop the

FCVRPSPD model from Olgun, et al. [48] to minimize the fuel consumption cost. Unfortunately, their model used one distribution vehicle. Companies sometimes have more than several homogeneous vehicles. Therefore, this study tries to consider homogeneous vehicles in routing problems.

This study aims to develop the Hybrid Yellow Saddle Goatfish Algorithm (HYSGA) to solve the FCVRPSPD problem. HYSGA is developed from the Yellow Saddle Goatfish Algorithm (YSGA) proposed by Zaldívar, et al. [49]. The motivation for this research is presented as follows: (1). No previous research has utilized HYSGA to solve the FCVRPSPD problem; (2) FCVRPSPD research is limited, especially involving homogeneous vehicles. Based on the research motivation, YSGA is a new metaheuristic algorithm proposed by Zaldívar, et al. [49] that was never implemented in the FCVRPSPD problem. The YSGA algorithm effectively solves energy savings in Wireless Sensor Networks [50] and controller design [51]. In this study, the YSGA algorithm is combined with the neighborhood exchange procedure to improve the quality solution of the FCVRPSPD. The neighborhood exchange procedure is a popular heuristic for solving route problems [48] [52]. Three neighborhood exchange rules applied are swap, flip, and slide. Therefore, we call this algorithm a Hybrid YSGA (HYSGA). Besides, this study tries to develop an FCVRPSPD model that considers the load unit transported from node i to node j and involves homogeneous vehicles. Therefore, this study's contribution is prominent, such as (1) proposing a new procedure for solving FCVRPSPD with HYSGA; and (2) developing a new model of the FCVRPSPD that considers loads unit between nodes and involving homogeneous vehicles.

The organizing of this paper is divided into several sections. Section 2 explains the assumptions, notations, and problem definitions. The HYSGA procedure for completing the FCVRPSPD is presented in section 3. Meanwhile, section 4 discusses data collection and experimental setup. The HYSGA optimization experiment results, FCVRPSPD sensitivity analysis, and algorithm comparisons are presented in section 5. The final section of this paper contains conclusions from the research results and future work.

2. Assumptions, Notations, and Problem Definitions

In this study, the assumptions used in the FCVRPSPD problem were as follows: (1) The vehicle departs and returns to the same depot; (2) The number of pick-ups is fixed; (3) Each customer is served by one vehicle; (4) Vehicles for the product distribution process are homogeneous; (5) Demand delivery for each regular customer is fixed; (6) Fuel consumption is affected by loading loads.

In solving the FCVRPSPD problem, the notations used in this paper are:

V : Set of customers

$V0$: Set of customers and agents: $V0 = V \cup \{0\}$

K : Set of vehicles

k : Number of vehicles

n : Number of customers: $n = |V|$

d_i : Number of deliveries to node (kg) i; $i = 1,2,3,\dots,n$

p_i : Number of pick up to node (kg) i; $i = 1,2,3,\dots,n$

q_{ijk} : The load carried from node i to node j using vehicle k

ρ_0 : Fuel Consumption Rate (FCR) when the vehicle is unloaded

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d_{ij} : The distance from node i to node j
ρ^* : Fuel Consumption Rate (FCR) when the vehicle is fully loaded
G_m : Maximum vehicle load capacity
c_0 : Fuel cost per liter
ρ_{ijk} : FCR from node i to node j using vehicle k
x_{ijk} : binary variables (0,1) from node i to node j using vehicle k

For the description of the FCVRPSPD problem, this study developed a mathematical model, which is presented as follows:

Objective function:

$$Min\ TC = \sum_{k=1}^{K} \sum_{i=0}^{n} \sum_{j=0}^{n} (c_0 \rho_{ijk} d_{ij} x_{ijk}) \quad (1)$$

$$\rho_{ijk} = \rho_0 + \frac{\rho^* - \rho_0}{G_m} q_{ijk} \quad (2)$$

Subject to :

$$\sum_{k \in K} \sum_{i \in V} x_{ijk} = 1, \ \forall j \in V \quad (3)$$

$$\sum_{i \in V} x_{ijk} - \sum_{i \in V} x_{jik} = 0, \ \forall j \in V, \forall k \in K \quad (4)$$

$$\sum_{i \in V} x_{ijk} \leq 1, \ j \in V, k \in K \quad (5)$$

$$\sum_{j \in V} q_{ijk} = \sum_{i \in V} \sum_{j \in V} x_{ijk}\, d_i, \ \forall j \in V \quad (6)$$

$$\sum_{k \in K} \sum_{i \in V} q_{ijk} - d_j = \sum_{k \in K} \sum_{m \in V: m \neq j} q_{jmk-}\, p_j, \ \forall j \in V \quad (7)$$

$$\sum_{i \in V} q_{ijk} = \sum_{i \in V} \sum_{j \in V} x_{ijk-}\, p_j, \forall k \in K \quad (8)$$

$$q_{ijk} + p_j - d_j \leq G_m, \ \forall j \in V, \forall i \in V, \forall k \in K \quad (9)$$

$$d_i \geq 0 \qquad i = 0,1, \dots, n \quad (10)$$

$$p_i \geq 0, \qquad i = 0,1, \dots, n \quad (11)$$

$$x_{ijk} = \begin{cases} 1, & \text{visit node i to node j using vehicle k} \\ 0, & \text{otherwise} \end{cases} \quad (12)$$

The objective function in Equation (1) aims to minimize the cost of fuel consumption that is influenced by the fuel cost per unit, distance and fuel consumption at each displacement presented in Equation (2). Constraint Equation (3) ensures that each customer has to be visited by 1 vehicle. Constraint Equation (4) is implemented to guarantee that the same vehicle will come and go from every customer who visits it. Constraint Equation (5) defines that each vehicle will only serve once. Constraint Equation (6) is a formula to ensure that the load at the depot is equal to the demand of all customers to be served customer. Constraint Equation (7) is a formula that indicates the change in load after the vehicle has served customer i before going to customer j. Meanwhile, Constraint Equation (8) ensures that the vehicle's loads are equal to the quantity of pick-up from all that is served by the vehicle k. Constraint Equation (9) is exemplified to ensure that the cargo carried by each vehicle does not exceed the maximum load capacity. Equations (10), (11), and (12) are characteristics and decision variables.

3. Proposed HYSGA Procedure for FCVRPSPD

In this section, this paper describes the proposed HYSGA procedure for solving the FCVRPSPD problem. The HYSGA algorithm is a meta-heuristic algorithm inspired by the behavioral intelligence of Yellow Saddle Goatfish with natural hunting strategies. The HYSGA algorithm is modified from the YSGA algorithm proposed by Zaldívar, et al. [49] by combining the neighborhood exchange procedure. This research modifies the YSGA to solve the combinatorial problem. VRP is a combinatorial problem and non-deterministic polynomial-time hard (NP-Hard) problem that cannot be solved in polynomial time [53] [54]. The pure YSGA algorithm has four main stages, namely (1). HYSGA initialization stage; (2) Clustering and Role Sharing of the Goatfish; (3) Updating of Goatfish Hunter and Blocker Position; and (4) Zone Shifting. To solve the FCVRPSPD problem, the Goatfish Hunter and Blocker positions must be converted to the travel sequence with the Large Rank Value (LRV) rule. The complete stages of the YSGA algorithm to solve the FCVRPSPD problem can be seen in Algorithm 1.

This study proposed six stages of the HYSGA algorithm to solve the FCVRPSPD problem, which is described as follows: (1) HYSGA initialization stage; (2) Conversion of the goatfish position to the travel sequence; (3) Clustering and Role Sharing of the Goatfish; (4) Updating of Goatfish Hunter and Blocker Position; (5) Zone Shifting; and (6) Neighborhood exchange. The HYSGA pseudo-code for solving the FCVRPSPD problem is presented in Algorithm 2. The five stages of HYSGA are described in the following sub-section.

3.1 HYSGA initialization stage

At this stage, the HYSGA parameters have to be defined a number of populations, iteration, group, a cluster of Goatfish, the lower limit (lb), and the upper limit (ub) of the goatfish position. The population of the Goatfish has a different position with certain dimensions. In the FCVRPSPD problem, the goatfish dimensions are based on the number of customers served. Initialization of the goatfish position is presented in Equation (13), where p_g is the goatfish position, and $Rand$ is a real uniform random number with a range of 0 to 1. At this stage, the position of the Goatfish must be ensured that there is no repetition. The illustration of the position of the Goatfish in the population is shown in Fig. 1. Then, Fig. 1 b shows the wrong goatfish position because goatfish 1 has the same value for dimension 1 and dimension 2, which is 0.75. Therefore, the goatfish position's value repetition must be avoided to convert the goatfish position to the travel sequence.

$$p_g = (ub - lb)Rand + lb \tag{13}$$

$$Pop\ goatfish = \begin{Bmatrix} 0.60 & 0.75 & 0.82 \\ 0.49 & 0.74 & 0.13 \\ 0.98 & 0.14 & 0.56 \end{Bmatrix} \qquad Pop\ goatfish = \begin{Bmatrix} 0.75 & 0.75 & 0.82 \\ 0.49 & 0.74 & 0.74 \\ 0.98 & 0.74 & 0.56 \end{Bmatrix}$$

(a) (b)

Fig. 1. Initialization of the position (a) Accepted position (b) Wrong position

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3.2 Converting the goatfish position to travel order

This section describes converting the goatfish position to a travel sequence. As stated earlier, FCVRPSPD is a combinatorial problem solved in discrete space. Therefore, the goatfish position needs to be converted into the travel sequence. LRV is an appropriate procedure for converting trip sequences for this conversion [13] [55]. Therefore, the Goatfish's real number position needs to be converted into a travel sequence. The principle of LRV is simple because it only ranks by the position value of the largest value to the smallest in each dimension [56] [57] [18] [58].

Fig. 2 illustrates applying LRV for conversion from real numbers to travel sequences. The decision-maker can determine the number of routes based on delivery demand and pick-up from the sequence of trips. Fig. 3 illustrates determining the route of each Goatfish by considering the delivery demand and pick-up. This LRV procedure is applied to each fitness search in each Goatfish. The calculation of the fitness value for the FCVRPSPD problem is shown in Equation (1).

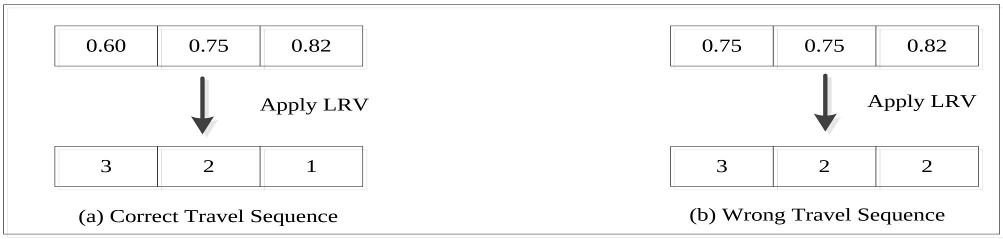

Fig. 2. LRV Implementation

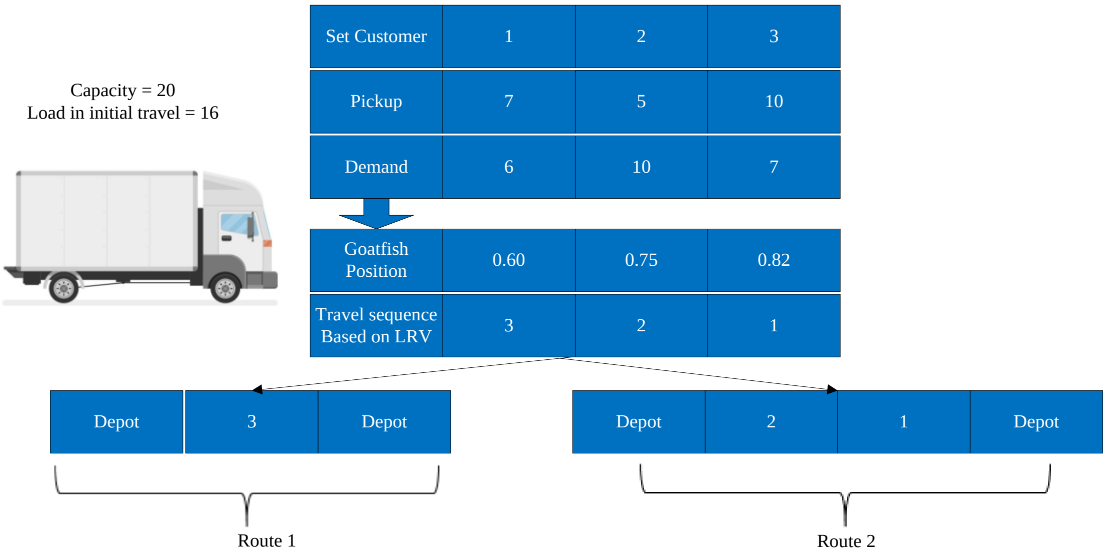

Fig. 3. Illustration of determining the route of each Goatfish

3.3 Clustering and Role Sharing of the Goatfish

This section describes the formation of clusters and the division of the roles of the Goatfish. The formation of the cluster is also known as forming the group of Goatfish. Fig. 4 illustrates the population's division into k clusters, where each cluster $\boldsymbol{c}_k$ has $\boldsymbol{\Phi}_l$ hunter fish and $\boldsymbol{\varphi}_g$ blocker fish. In the HYSGA algorithm, the clusters/groups of Goatfish were formed based on the K-Means method. The results of the goatfish cluster were used to identify the roles of hunters and blockers.

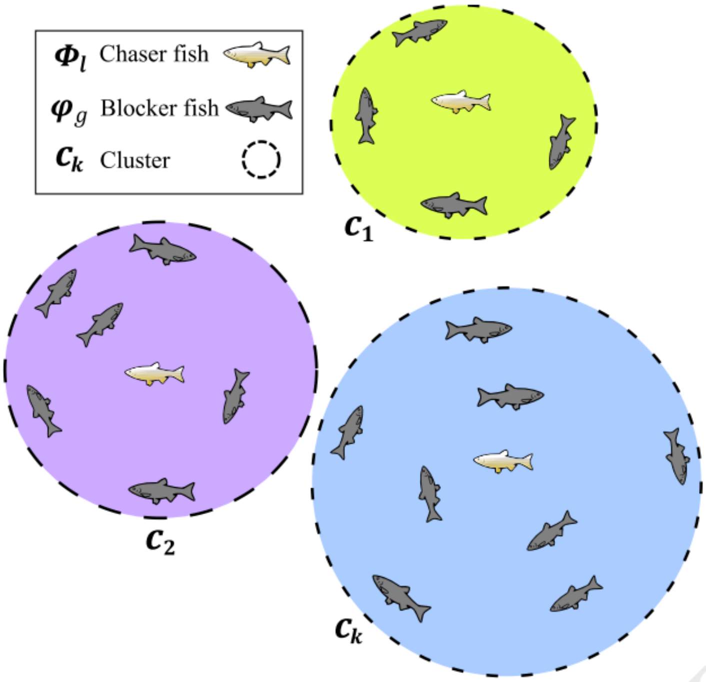

Fig. 4. Illustration of clusters in the goatfish population

The hunter's role was determined based on the Goatfish, which had the best fitness in each cluster. After the hunter goatfish was selected, several other Goatfish acted as blockers which helped the hunter's role. The formation of each cluster in HYSGA was based on the euclidean metric value (e) used to calculate the distance between the data points and the clusters' average. This calculation is formulated in Equation (14). Where p_g was the goatfish position and μ_l was the global best goatfish position. The cluster of Goatfish was denoted by c_l. According to the K-Means algorithm, h can have different values for each cluster c_l.

$$e(c_l) = \sum_{p_g \in c_l} \left\| p_g - \mu_l \right\|^2 \tag{14}$$

$g = 1, 2, \dots, h;\ l = 1, 2, \dots, k$

3.4 Updating of Goatfish Hunter and Blocker Positions

When looking for food, Goatfish had position-changing properties. This change in the position applied to the goatfish hunter and blocker. Goatfish hunters were Goatfish with the best fitness in each cluster. This Goatfish had a position close to a food source. When hunting, a hunter can get optimal food. The update of the hunter's goatfish position is based on Equation (15), where Φ_l^{t+1} indicated the new position of the goatfish hunter and Φ_l^t t explained the current position of the goatfish hunter. The step size was defined as α. The β parameter was known as the Lévy index. The β parameter had a value of $0 < \beta \leq 2$. If the value of $\beta = 1$, the probability distribution function was the Cauchy distribution. On the other hand, for $\beta = 2$, the probability distribution corresponded to the Gaussian distribution.

$$\Phi_l^{t+1} = \Phi_l^t + \alpha \oplus Levy(\beta) \tag{15}$$

In the case of the Blocker goatfish, it was their job to surround the food. This activity was used to block the way out of the prey. The blocker goatfish had a logarithmic spiral behavior model, where the Goatfish followed a spiral line around the hunter goatfish. The blockers' position update was based on Equation (16) where D_g was the distance between hunter blocker positions. Φ_l showed the hunter position, whereas ρ was a random number between $[a,\ 1]$ which determined how close the blocker was to the hunter. To intensify exploitation, a was derived linear from -1 to -2 according to the iterations.

$$\varphi_g^{t+1} = D_g . e^{b\rho} . cos2\pi\rho + \Phi_l \tag{16}$$

3.5 Zone Shift

After the cluster goatfish exploited the food search, they changed their position to find new food. The displacement formula for the goatfish zone is presented in Equation (17). Where p_g^{t+1} was the new position of the Goatfish. Φ_{best} indicated the best current solution based on hunter-fish. The current position of the members of the goatfish cluster (hunter or blocker) is formulated as p_g^t.

$$p_g^{t+1} = \Phi_{best} + p_g^t \tag{17}$$

3.6 Neighborhood exchange

In this section, neighborhood exchange rules are adopted to improve the performance of YSGA. YSGA archives the temporary best solution and vector positions for each iteration. The best position vector in iteration t is improved with three neighborhood exchange rules. They are swap, flip, and slide. These are applied in each iteration to improve the solution's performance at iteration t. Swap is a two-dimensional/vector exchange rule from Goatfish. Two vectors of Goatfish are selected at random to be exchanged. The flip is applied by reversing the vector/dimensionality of the Goatfish. Two Goatfish vectors are selected randomly. Then the vector is reversed. The slide is a neighborhood exchange rule by shifting the vector/dimension of Goatfish. One Goatfish vector is selected at random, then shifted to one vector at random.

In each iteration, this research proposes $0.1 \times n$ times looping for each neighborhood exchange rule. Where n is the number of customers, illustrations of the neighborhood exchange using swap, flip, and slide rules can be seen in Fig. 5, Fig. 6, and Fig. 7. Each neighborhood exchange's position vector of the new Goatfish is converted to a travel sequence using the LRV principle. Then, the travel sequence from the neighborhood exchange is evaluated based on the previous FCVRPSPD solution. Suppose the solution resulting from the neighborhood exchange is better than before. In that case, the best solution is replaced based on the neighborhood exchange. However, if the neighborhood exchange solution is not better, the previous solution is maintained as the best.

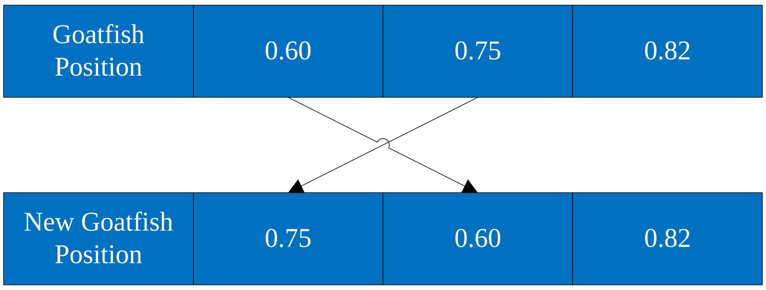

Fig. 5. Swap rule illustration

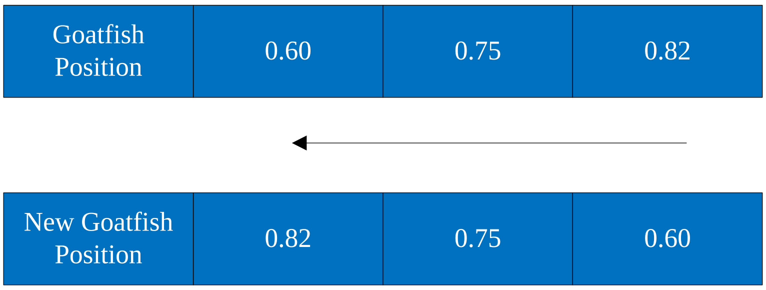

Fig. 6. Flip rule illustration

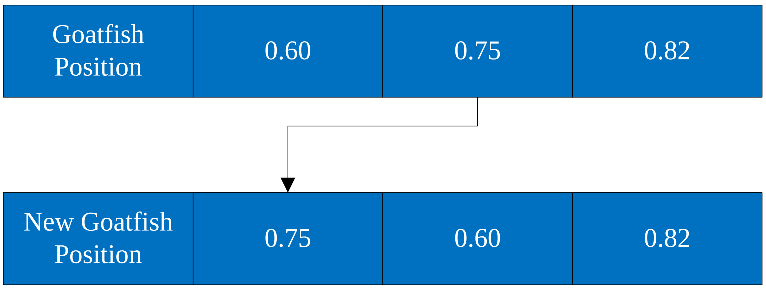

Fig. 7. Slide rule illustration

4. Experiment Data and Setup

4.1 Data

This research's data were based on a case study of a company distributing Liquified Petroleum Gas canisters in Indonesia. Vehicle capacity, fuel prices, and Fuel Consumption Rate (FCR) are presented in Table 1. The number of demand delivery and pick-ups for each customer (node) is presented in Table 2. Finally, the distance between customers and depots is presented in Table 3.

Table 1. Vehicle capacity, Fuel price, and FCR

Capacity (G_m) (kg)	Fuel price per liter (c_0) IDR	FCR when the vehicle is unloaded (ρ_0)(liter/km)	FCR when the vehicle is fully loaded (ρ^*)(liter/km)
4480	5400	0.1	0.143

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Table 2. The number of demand delivery and pick-ups at each node

Node	Delivery (di)(kg)	Pickup (pi)(kg)
1	680	640
2	600	600
3	680	640
4	640	600
5	640	600
6	680	640
7	600	600
8	640	600
9	680	640
10	720	680
11	680	640
12	600	600

Algorithm 1. Pseudo-code YSGA for FCVRPSPD

```
Input the parameters: number of Goatfish, number of clusters, iterations (tmax)
Initialize the population of goatfish P = ( p_1, p_2, p_3 ... p_n)
Initialize the goatfish position to determine the initialization of the route
Order the position of Goatfish using the Large Rank Value method (LRV)
Calculate the fitness value for each Goatfish
Identify global best Φ_best
Divide the P population into several clusters (c_1, c_2, c_3 ..... c_k)
Identify goatfish hunter Φ_l and goatfish blocker φ_g in each cluster
While (t < tmax)
  For every cluster c_l
        Perform the hunting procedure by goatfish hunters
        Perform the blocking procedure by the goatfish blockers
        Calculate the fitness for each Goatfish
        If φ_g have a fitness value better than Φ_l
              Perform the role swap procedure goatfish
        End If
        If Φ_l has a higher value than φ_g
              Update the Φ_best
        End If
        If the fitness value of Φ_l does not improve
              q ← q + 1
        End If
        If q > λ
              Do the zone shift procedure
              q ←0
        End If
  End For
  t ← t+1
  End While
  Output Φ_best
```

Algorithm 2. Pseudo-code HYSGA for FCVRPSPD

```
Input the parameters: number of Goatfish, clusters, iterations (tmax)
Initialize the population of goatfish P = (p_1, p_2, p_3 ... p_n)
Initialize the goatfish position to determine the initialization of the route
Order the position of Goatfish using the Large Rank Value method (LRV)
Calculate the fitness value for each Goatfish
Identify global best Φ_best
Divide the P population into several clusters (c_1, c_2, c_3 ..... c_k)
Identify goatfish hunter Φ_l and goatfish blocker φ_g in each cluster
While (t<tmax)
  For every cluster c_l
        Perform the hunting procedure by goatfish hunters
        Perform the blocking procedure by the goatfish blockers
        Calculate the fitness for each Goatfish
        If φ_g have a fitness value better than Φ_l
            Perform the role swap procedure goatfish
        End If
        If Φ_l has a higher value than φ_g
            Update the Φ_best
        End If
        If the fitness value of Φ_l does not improve
            q ← q + 1
        End If
        If q > λ
            Do the zone shift procedure
            q ←0
        End If
  End For
      for i = 0: 0.1 × n
        Perform swap mutation on Φ_best position
        if (evaluate (Φ_swap) < evaluate (Φ_best))
            Φ_best = Φ_swap
        end if
      end for
      for i = 0: 0.1 × n
        Perform flip mutation on Φ_best position
        if (evaluate (Φ_flip) < evaluate (Φ_best))
            Φ_best = Φ_flip
        end if
      end for
      for i = 0: 0.1 × n
        Perform slide on Φ_best position
        if (evaluate (Φ_slide ) < evaluate (Φ_best))
            Φ_best = Φ_slide
        end if
      end for
  t ← t+1
  End While
  Output Φ_best
```

Table 3. Matrix of the distance between customers and depots (kilometers)

Node	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	14.6	20.3	4.6	5.6	5.4	14.8	2.9	20.9	3.4	4.2	19.2	23.1
1	14.6	0	18.2	19.2	20.3	20.1	3	17.6	6.9	17.9	18.6	9.5	17
2	20.3	18.2	0	25.4	24.8	26.2	16.9	23.7	19.9	24	19.1	25.6	5.5
3	4.6	19.2	25.4	0	1.1	1.9	13.9	3	25.4	3.9	5.4	22.9	26.1
4	5.6	20.3	24.8	1.1	0	2.9	15	4	26.5	6	7.1	24	25.7
5	5.4	20.1	26.2	1.9	2.9	0	14.8	3.8	26.3	14.8	5.8	23.8	26.1
6	14.8	3	16.9	13.9	15	14.8	0	12.5	8.5	12.8	11	9.2	18.9
7	2.9	17.6	23.7	3	4	3.8	12.5	0	23.8	2.2	4.4	21.3	24.5
8	20.9	6.9	19.9	25.4	26.5	26.3	8.5	23.8	0	23	23.7	5.6	21.2
9	3.4	17.9	24	3.9	6	14.8	12.8	2.2	23	0	4.7	21.6	24.8
10	4.2	18.6	19.1	5.4	7.1	5.8	11	4.4	23.7	4.7	0	22.2	21.5
11	19.2	9.5	25.6	22.9	24	23.8	9.2	21.3	5.6	21.6	22.2	0	27
12	23.1	17	5.5	26.1	25.7	26.1	18.9	24.5	21.2	24.8	21.5	27	0

4.2 Experiment setup

This study examined the effect of the initial load on the vehicle's delivery, the number of Goatfish, iterations, and the number of goatfish clusters on fuel costs. This study implemented three (3) variations in load loads to examine the effect on fuel costs, namely 85%, 90%, and 95% of vehicle capacity. Meanwhile, the population and iteration parameters used were four (4) variations ranging from 15 to 100. Furthermore, to determine the performance of HYSGA in solving FCVRPSPD, this study tried to apply three (3) cluster variations, namely 2, 5, and 7 clusters per population. The total number of experiments on this data processing was 225 times. Each experiment recorded fuel costs and computation time.

The next experiment was to test the effect of variables (sensitivity analysis) on fuel costs. Some of the variables tested for sensitivity were the FCR variable when the vehicle was unloaded (ρ_0), the FCR when the vehicle was fully loaded (ρ^*) and the variable fuel price. Ten (10) data variations were presented to test each variable.

This research compared the algorithm performance based on fuel cost and computation time to test the algorithm performance. The algorithms used for comparison were GA [28], PSO [29], ACO [32], DE [33], ALNS [45], ILSVN [47], and YSGA. This test divided three experimental data variations into small, medium, and large. The small case consisted of 15 and 25 nodes. The medium case had several nodes of 50 and 60. Finally, large cases included 80 and 100 nodes. Node data were generated randomly from the data presented in Table 2, Table 1, and Table 3. Experiments were carried out using Matlab 2014a software and were run on a computer i5 core CPU Processor, 500Gb Hard disk, 4Gb memory on Microsoft Windows 10.

5. Results And Discussion

5.1 Optimization of FCVRPSPD with HYSGA

The experiment results on the effect of the HYSGA parameters on fuel costs for the initial load of 95%, 90%, and 85% of the vehicle load capacity are presented in Table 4,

Table 5, and Table 6. Based on the initial orders consisting of 95%, 90%, and 85 % of the vehicle load capacity, the experimental results showed that the initial load greatly affects the cost of fuel consumption. Therefore, the FCVRPSPD decision needs to consider the initial load quantity of the vehicle. The results also indicated that 90% initial load capacity of the vehicle's maximum capacity resulted in the optimal solution. This result is very reasonable because if the load capacity is very large and small, the number of routes produced is large. Therefore, it causes higher fuel costs. Therefore, the initial load quantity of the vehicle significantly affects fuel costs.

From the point of view of the number of Goatfish and the iterations used, the experimental results pointed out that the larger the Goatfish and the iterations used, the lower the fuel cost tends to be. On the other hand, the fewer Goatfish and iterations used, the higher the fuel cost tends to be. This result is very reasonable because the greater the number of Goatfish and iterations, the more space for finding solutions will be generated. Therefore, the number of Goatfish and iterations significantly affects fuel costs. However, based on the number of HYSGA clusters used, the results described that the number of HYSGA clusters has no significant effect on fuel costs.

Table 4. The experimental results of the effect of the HYSGA parameter on fuel costs with an initial load capacity of 95% (IDR)

Population	cluster	Iteration				
		15	25	50	75	100
15	2	92,185	80,098	104,927	87,727	77,846
	5	105,041	92,851	79,679	81,023	82,517
	7	99,762	86,733	91,490	77,978	77,226
25	2	92,621	93,477	96,821	100,865	91,766
	5	103,077	79,179	92,713	76,996	90,818
	7	90,588	89,037	85,510	86,906	79,868
50	2	84,780	77,266	76,818	93,024	77,852
	5	77,898	77,295	77,025	77,944	81,827
	7	85,785	79,644	90,605	78,472	77,117
75	2	100,285	96,057	83,177	82,011	89,709
	5	77,616	91,944	77,277	77,484	76,806
	7	80,403	91,070	89,473	77,703	78,306
100	2	77,576	77,662	92,173	77,025	76,806
	5	78,880	91,116	77,249	77,668	79,506
	7	90,174	77,703	79,282	76,806	77,490

5.2 Effect of HYSGA Parameters on Computation Time

Based on the experimental results presented in Table 7, Table 8, and Table 9, it can be concluded that the number of iterations, the goatfish population, and the goatfish cluster affected the computation time for solving the FCVRPSPD problem. Furthermore, the results also projected that the greater the number of iterations and the goatfish and cluster goatfish populations, the higher the duration of the problem-solving computation time. Conversely, the smaller the number of iterations, the goatfish and cluster goatfish populations, the lower the computation duration for solving the problem. Therefore, the numbers of iterations, the Goatfish, and cluster goatfish populations are directly proportional to the computation time used for problem-solving.

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Table 5. The experimental results of the effect of HYSGA parameters on fuel costs with an initial load capacity of 90% (IDR)

Population	cluster	Iteration				
		15	25	50	15	100
15	2	99,371	77,731	76,760	93,334	76,841
	5	80,213	90,243	100,457	93,431	88,393
	7	92,507	99,481	91,903	78,513	93,765
25	2	93,845	85,153	77,869	76.525	94.804
	5	106,794	79,397	93,994	77,421	76,295
	7	96,482	76,887	97,970	78,260	77,254
50	2	92,426	76,289	76,944	88,054	76,927
	5	86,084	89,313	90,530	76,289	77,938
	7	79,254	75,813	76,117	77,829	75,933
75	2	80,713	93,391	75,979	79,208	77,668
	5	77,576	77,668	77,869	78,254	88,009
	7	95,770	76,714	90,393	77,306	76,083
100	2	76,508	76,387	91,949	88,031	75,623
	5	77,605	77,869	76,289	78,949	75,640
	7	77,364	75,772	75,623	76,657	75,824

Table 6. The experimental results of the effect of the HYSGA parameter on fuel costs with an initial load capacity of 85% (IDR)

Population	cluster	Iteration				
		15	25	50	15	100
15	2	91,731	94,937	96,557	92,501	105,041
	5	96,109	95,207	100,360	95,873	94,667
	7	103,703	98,630	99,234	103,444	94,040
25	2	98,619	100,474	93,983	90,766	92,748
	5	95,827	95,448	92,478	99,440	91,444
	7	99,101	95,396	95,287	91,610	90,008
50	2	85,722	85,849	99,234	90,008	90,393
	5	87,015	101,991	93,144	92,443	85,722
	7	100,549	86,997	98,171	91,794	92,501
75	2	89,111	107,242	91,990	92,047	91,076
	5	88,945	92,621	87,980	88,859	91,760
	7	91,461	92,047	86,911	87,296	88,267
100	2	90,249	93,604	86,406	90,766	90,031
	5	88,853	92,610	90,329	89,192	89,255
	7	95,591	96,235	91,191	89,399	87,796

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Table 7. Computation time for an initial vehicle load of 95% (seconds)

Population	cluster	Iteration				
		15	25	50	15	100
15	2	0.350	0.581	1.230	1.729	2.312
	5	0.811	1.292	2.591	4.199	5.431
	7	1.122	1.818	3.751	5.357	6.938
25	2	0.400	0.682	1.356	1.940	2.583
	5	0.886	1.386	2.752	4.137	5.435
	7	1.159	1.869	3.833	5.499	7.572
50	2	0.547	0.831	1.613	2.430	3.264
	5	0.999	1.564	3.014	4.542	5.981
	7	1.270	1.988	4.020	5.957	8.905
75	2	0.610	1.005	1.970	4.593	3.941
	5	1.067	1.986	3.354	5.004	6.775
	7	1.381	2.290	4.333	6.479	8.475
100	2	0.741	1.166	2.259	3.550	4.565
	5	1.238	1.915	3.657	5.725	7.310
	7	1.467	2.462	4.978	7.289	9.260

Table 8. Computation time for an initial vehicle load of 90% (seconds)

Population	cluster	Iteration				
		15	25	50	15	100
15	2	0.478	0.635	1.241	1.718	2.438
	5	0.832	1.306	2.659	3.942	5.241
	7	1.109	1.783	3.746	5.340	7.325
25	2	0.434	0.861	1.330	2.364	2.602
	5	0.880	1.471	2.696	4.091	5.654
	7	1.193	1.830	3.665	5.546	7.281
50	2	0.511	0.853	1.632	2.354	3.189
	5	0.942	1.590	3.080	4.632	6.151
	7	1.289	2.055	4.061	6.281	7.855
75	2	0.674	1.010	2.032	2.934	3.854
	5	1.105	1.764	3.430	4.866	6.844
	7	1.381	2.244	4.328	6.143	1.044
100	2	0.737	1.157	2.333	3.510	4.634
	5	1.188	1.969	3.793	5.532	8.388
	7	1.484	2.414	4.639	7.008	9.306

5.3 Sensitivity Analysis

The effect of changes in Fuel Consumption Rate (FCR) when the vehicle was unloaded (ρ_0) on the vehicle fuel consumption costs is presented in Fig. 8. These results indicated that the greater the ρ_0, the resulting fuel costs are greater. Conversely, the smaller the ρ_0, the resulting fuel costs are small. The implication is that when the vehicle used in the distribution process had a high Fuel Consumption Rate, the fuel cost when

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distributing the product also increased. Choosing the right type of vehicle can affect the cost of fuel.

Table 9. Computation time for an initial vehicle load of 85% (seconds)

Population	cluster	Iteration				
		15	25	50	15	100
15	2	0.401	0.649	1.235	1.676	2.402
	5	0.836	1.383	2.723	4.089	5.527
	7	1.148	1.842	3.775	5.407	7.465
25	2	0.425	0.723	1.415	2.067	2.717
	5	0.893	1.457	2.826	4.269	5.704
	7	1.193	1.958	3.798	5.750	7.658
50	2	0.594	0.906	1.733	2.667	3.425
	5	1.019	1.662	3.377	4.819	6.458
	7	1.365	2.240	4.223	6.327	8.514
75	2	0.683	1.154	2.108	3.151	4.304
	5	1.146	1.899	3.638	5.266	7.750
	7	1.610	2.321	4.617	6.864	9.977
100	2	0.887	1.266	2.493	3.784	5.053
	5	1.258	2.093	4.029	5.923	8.153
	7	1.602	2.578	5.119	7.653	10.004

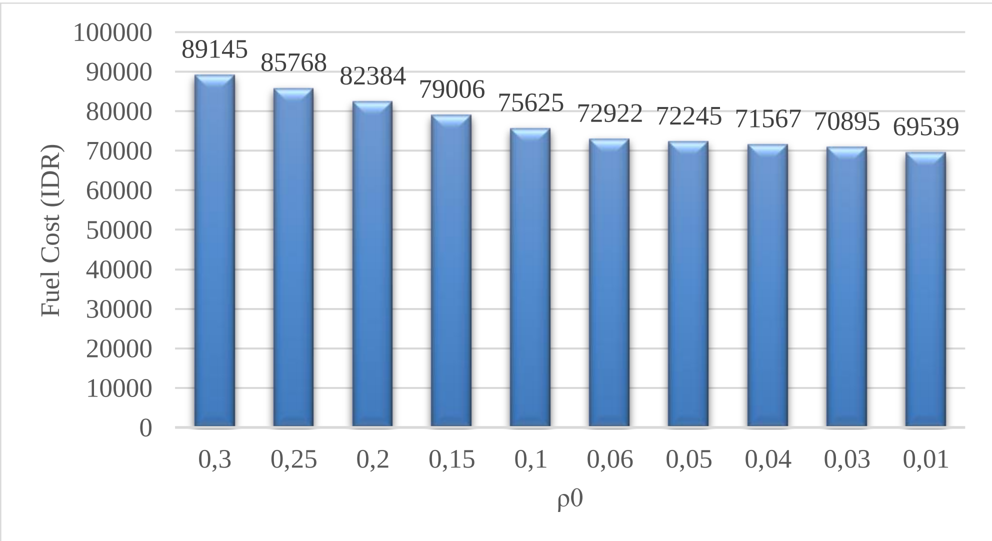

Fig. 8. Effect of changes in ρ_0 on the cost of vehicle fuel consumption

The effect of ρ^* change in the total cost of vehicle fuel is shown in Fig. 9. The results projected that the effect of the increase in ρ^* variable value is directly proportional to the total cost of fuel. The greater the value of the ρ^* fuel consumption rate of a vehicle used, the greater the fuel costs incurred. The implication is that companies need to consider the vehicle that has the smallest ρ^* in the distribution of goods.

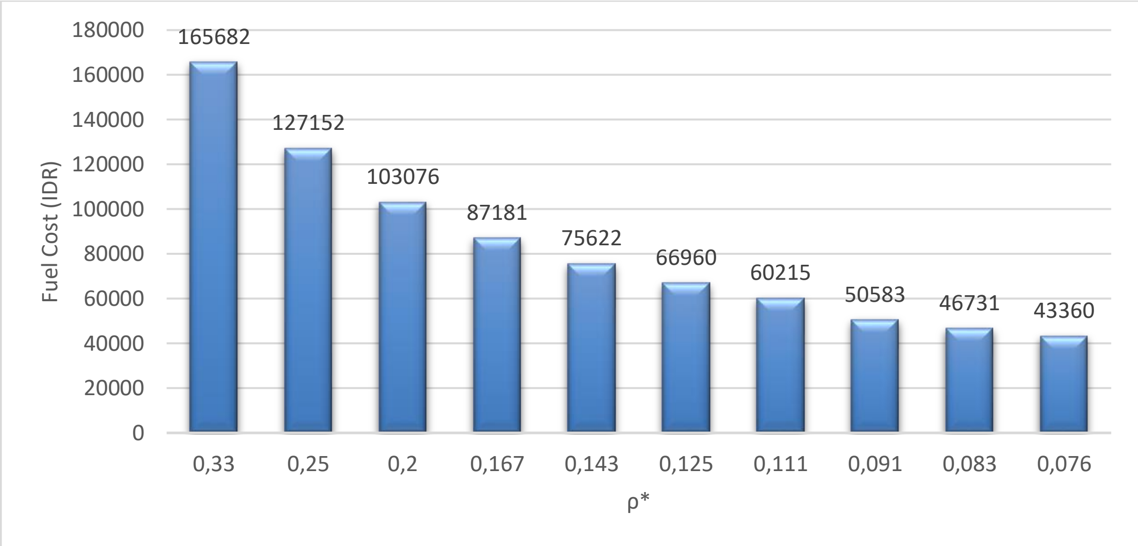

Fig. 9. Effect of changes in ρ^* on the total cost of fuel for the vehicle

The effect of c_0 change in the cost of vehicle fuel is presented in Fig. 10. The price of fuel per liter (c_0) often increases and decreases. Meanwhile, the results of the sensitivity analysis of the c_0 variable to the cost of fuel consumption showed that the higher the price of fuel per liter (c_0), the higher the cost of fuel consumption. Based on this review, the company can make a policy by choosing a more energy-efficient vehicle in the case of FCVRPSPD.

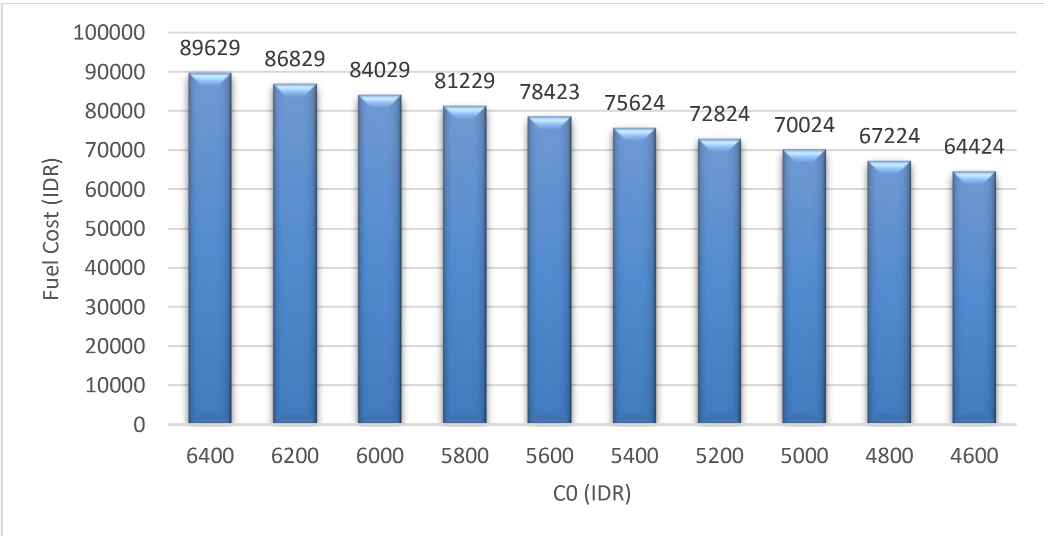

Fig. 10. Effect of c_0 changes on vehicle fuel costs

5.4 Algorithm Comparison

This section presents the results of case experiments on several algorithms. The comparison of the algorithm based on fuel costs for three (3) case variants is presented in Table 10. The experimental results suggested that for medium and large case problems, the proposed HYSGA algorithm provided minimal fuel costs compared to the GA [28], PSO [29], ACO [32], DE [33], and YSGA algorithms. However, the proposed algorithm has the

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same solution as ALNS [45] and ILSVN [47] in the small and medium cases. In the small case, the proposed algorithm produced the same solution as the GA [28], PSO [29], ACO [32], ALNS [45], ILSVN [47], and YSGA algorithms. However, the proposed algorithm is better for solving large cases than the comparison algorithm.

Table 10. Comparison of algorithms based on fuel costs for 3 case variants (IDR)

Varian Case	Node	Algorithms							
		DE	GA	PSO	ACO	YSGA	ILSVN	ALNS	HYSGA
Small	15	**176,890**	**176,890**	**176,890**	**176,890**	**176,890**	**176,890**	**176,890**	**176,890**
	25	316,770	**305,440**	**305,440**	**305,440**	**305,440**	**305,440**	**305,440**	**305,440**
Medium	50	1,149,800	**1,100,800**	**1,100,800**	1,125,900	**1,100,800**	**1,100,800**	**1,100,800**	**1,100,800**
	60	1,399,500	1,392,500	1,402,000	1,362,100	1,392,500	**1,327,400**	**1,327,400**	**1,327,400**
Large	80	2,074,900	2,083,700	2,076,100	2,130,300	2,076,100	2,076,100	2,074,900	**2,060,000**
	100	2,850,000	2,842,500	2,861,400	2,807,000	2,807,000	2,807,000	2,807,000	**2,800,000**

Table 11. Comparison of computation time in various case studies (Second)

Varian Case	Node	Algorithms							
		DE	GA	PSO	ACO	YSGA	ILSVN	ALNS	HYSGA
Small	15	2.92	4.05	5.87	5.16	5.38	5.73	5.48	8.03
	25	2.22	3.25	5.27	5.39	5.86	5.34	5.35	10.44
Medium	50	5.31	5.95	10.44	8.61	10.83	10.24	10.29	20.02
	60	3.51	5.44	9.35	6.92	9.65	9.57	9.74	18.39
Large	80	4.43	6.97	12.38	8.73	12.85	12.78	12.65	24.68
	100	5.15	8.17	15.46	10.39	15.78	15.65	15.47	27.95

Results of the comparison of computation time on various case studies are presented in Table 11. The experimental results presented that the HYSGA computation time was more significant than GA [28], PSO [29], ACO [32], DE [33], ALNS [45], ILSVN [47], and YSGA. The findings from this experiment were the relationship between the number of nodes and the computation time. Thus, computation time increases as the number of nodes increases. This result is in line with the findings of Fisher and Jaikumar [59], which stated that the greater the scope of a case study, the greater the level of difficulty and computation time required.

6. Conclusion

This study aims to propose the Yellow Saddle Goatfish Algorithm (HYSGA) to solve the FCVRPSPD problem. HYSGA was proposed to minimize fuel costs. The research results on the effect of the HYSGA parameter on fuel costs showed that the greater the population and iteration, the better the resulting solution. Experiments on several case variants indicated that the resulting computation time was proportional to the nodes' number. This research also made comparisons with several other algorithms. The results showed that the proposed HYSGA algorithm effectively solved the FCVRPSPD problem. One limitation of this study is that the demand (delivery) and pick-up assumptions are fixed. Further research must investigate the FCVRPSPD problem with dynamic, probabilistic, and fuzzy data.

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