Design of a Two-Phase Clustering–Routing Algorithm for Fuel Distribution to Diesel Power Plants (PLTDs) in the Raja Ampat

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ABSTRACT

Fuel distribution to Diesel Power Plants (PLTDs) in archipelagic regions faces significant logistical challenges due to dispersed demand locations, limited vessel capacity, and varying fuel consumption. In Raja Ampat Regency, the existing round-trip distribution system results in low vessel utilization and high transportation costs. This study proposes a two-phase optimization framework integrating the Clarke and Wright Savings Algorithm (CWSA) with inventory simulation and sensitivity analysis to improve distribution efficiency and ensure operational feasibility. Secondary data obtained from PT PLN (Persero) UP3 Sorong include monthly fuel demand, storage tank capacity, daily fuel consumption, vessel capacity, and inter-island distance matrices. The CWSA was applied to generate feasible distribution routes under vessel capacity constraints, while inventory simulation validated delivery schedules based on safety stock, storage capacity, and delivery intervals. The proposed approach reduced the total sailing distance from 6,147.14 to 2,680.30 nautical miles, representing a 56.4% reduction, increased average vessel utilization to 90.75%, and decreased operational distribution costs by Rp346,684,000 per planning period. Furthermore, inventory simulation confirmed continuous fuel availability above safety stock levels throughout the 30-day planning horizon. These results demonstrate that the proposed framework provides an effective decision-support tool for improving fuel distribution efficiency in remote archipelagic regions.

Keywords: *Fuel Distribution, Diesel Power Plant, Clarke and Wright Savings Algorithm, Destination Clustering, Inventory Simulation*

Introduction

PT PLN (Persero) is a State-Owned Enterprise (SOE) responsible for providing electricity for public interest in Indonesia. In serving the public, particularly in remote and archipelagic areas, PLN builds isolated-type small power plants using diesel engines or Diesel Power Plants (PLTD). Raja Ampat Regency, with its archipelagic geographical characteristics, is one of the regions that has many PLTDs scattered across various islands.

Fuel Oil (BBM) distribution to PLTDs in Raja Ampat Regency faces complex logistical challenges. Based on operational data, there are more than 30 PLTD locations with varying fuel requirements, ranging from 756 liters to 64,800 liters per month. This variation in demand indicates that each location has different energy consumption levels, thus requiring different distribution patterns.

In the existing distribution system, fuel delivery is carried out using a round-trip pattern, where a vessel serves only one PLTD in a single journey and then returns to the depot. This pattern results in suboptimal vessel capacity utilization and longer sailing distances than necessary[1]. Geographically, several PLTD locations are close to each other and could potentially be served in a single route.

The problem becomes more complex because each PLTD has: (a) different monthly fuel requirements, (b) limited storage tank capacity, and (c) minimum inventory limits (safety stock) that must be maintained to avoid supply shortages. Additionally, varying travel times between islands mean that not all locations can be visited in one trip, so the number of points that can be served in a single trip varies.

The fuel distribution problem to PLTDs in Raja Ampat Regency is not only about determining the shortest route but also about determining how many locations can be visited in one delivery and how many deliveries must be made in one month. This is influenced by limited vessel capacity and varying sailing times for each route combination[2] .

This distribution problem in archipelagic regions can be categorized as a Maritime Inventory Routing Problem (MIRP), which integrates routing, inventory, and scheduling aspects in maritime transportation systems [3]. However, the current distribution approach remains simple and has not optimally integrated these three aspects.

This study aims to develop a Two-Phase Optimization model by integrating the Clarke & Wright Savings Algorithm (CWSA) in the first phase to form initial routes, and mathematical simulation and sensitivity analysis in the second phase to validate route feasibility. This approach enables the combination of heuristic method speed in generating initial solutions and mathematical method precision in ensuring operational feasibility [4].

Research Method

Data Sources and Types

This study uses secondary data obtained from PT PLN (Persero) UP3 Sorong, including:

- Locations and geographic coordinates of 32 PLTDs in Raja Ampat Regency
- Peak load operational data of the power plants
- BBM storage tank capacity at each PLTD
- Fuel transport vessel capacity (20,000 liters)
- Distance matrix between PLTD locations (in nautical miles)
- Daily and monthly fuel consumption data for each PLTD

Fuel Requirement Calculation

Fuel requirements for each PLTD are calculated based on the power plant's operational load using the equation:

$$D = B_p \times H \times SFC \tag{1}$$

Where:
D = Fuel requirement (liters/month)
Bp = Average peak load (kWh)
H = Engine operating time (hours/month)
SFC = Specific Fuel Consumption (liters/kWh), assumed to be 0.3

Safety Stock and Visit Node Calculation

Safety stock is calculated as the minimum inventory reserve for one day of operation:

$$SS_i = d_i \times 1 \tag{2}$$

Where di is the daily fuel consumption of PLTD ii.
For PLTDs with monthly requirements exceeding tank capacity, the demand is divided into multiple visit nodes. Maximum delivery volume per visit is calculated as:

$$q_i^{max} = S_i^{max} - SS_i \tag{3}$$

Number of visit nodes:

$$n_i = \left\lceil \frac{D_i}{q_i^{max}} \right\rceil \tag{4}$$

Clarke and Wright Savings Algorithm (CWSA)

The CWSA is used to form initial distribution routes based on distance savings principles[5]. The savings value is calculated using:

$$S_{ij} = T_{0i} + T_{0j} - T_{ij} \tag{5}$$

Where:
Sij = Savings value between PLTD i and j
T0i = Distance from depot to PLTD i
T0j = Distance from depot to PLTD j
Tij = Distance between PLTD i and j

Route merging is only performed if it meets vessel capacity constraints:

$$\sum D_i + \sum D_j \leq Q_v \tag{6}$$

Delivery Interval Validation

Feasible delivery intervals for each PLTD are calculated with:
Lower bound (to avoid overflow):

$$L_i = \left(\frac{q1 + q2 - S_i^{max}}{d_i} \right) + 1 \tag{7}$$

Upper bound (to avoid stockout):

$$U_i = \left(\frac{qi - SSi}{d_i} \right) + 1 \tag{8}$$

Interval flexibility is calculated as:

$$F_i = U_i - L_i \tag{9}$$

Inventory Simulation

Inventory simulation is performed using the stock balance equation:

$$I_{t+1} = I_t + Q_t - D_t \tag{10}$$

Where It is stock at the beginning of period t, Qt is delivery volume in period t, and Dt is consumption in period t.

Sensitivity Analysis

Sensitivity analysis is conducted to test solution stability against changes in PLTD assignment to distribution routes. Parameters tested include the impact of changes on vessel capacity, delivery intervals, and inventory conditions.

Result and Discussion

PLTD Operational Data

Based on the data obtained, there are 32 PLTDs scattered across Raja Ampat Regency with varying monthly BBM requirements. **Table 1** presents peak load data and monthly BBM requirements for all PLTDs.

Table 1. Peak load and monthly BBM requirement data for PLTDs

No	Location	Peak Load (kWh)	Monthly Requirement (L)	No	Location	Peak Load (kWh)	Monthly Requirement (L)
1	Warsambin	25	2,700	17	Yenwaupnor	12	1,296
2	Lopintol	7	756	18	Saukabu	12	1,296
3	Kalobo	105	11,340	19	Yenbuba	22	2,376
4	Saonek	53	9,540	20	Sawinggrai	20	2,160
5	Waigama	100	10,800	21	Jefman	53	5,724
6	Arborek	26	5,616	22	Folley	26	2,808
7	Samate	48	8,640	23	Arefi	25	2,700
8	Yellu	65	7,020	24	Yensawai	33	3,564
9	Harapan Jaya	30	3,240	25	Friwen	12	1,296
10	Fafanlap	30	3,240	26	Yenbekwan	16	1,728
11	Gamta	20	2,160	27	Paam	35	3,780
12	Usaha Jaya	30	3,240	28	Saupapir	7	756
13	Dabatan	16	1,728	29	Yenbeser	12	1,296
14	Lilinta	48	5,184	30	Kabare	80	8,640
15	Tomolol	13	1,404	31	Waisilip	7	756
16	Sawandarek	16	1,728	32	Gag	300	64,800

Visit Node Expansion

Based on the comparison between monthly requirements and tank capacity, 9 PLTDs require more than one visit per period because their monthly requirements exceed tank capacity. **Table 2** presents the visit node breakdown results for multi-delivery PLTDs.

Table 2. Node breakdown for multi-delivery PLTDs

PLTD	Monthly Demand (L)	Tank Capacity (L)	Number of Deliveries	Volume per Delivery (L)
Gag	64.800	14.000	6	10.800
Waigama	10.800	4.000	3	3.600
Kalobo	11.340	7.000	2	5.670
Saonek	9.540	7.000	2	4.770
Samate	8.640	4.000	3	2.880
Arborek	5.616	4.000	2	2.808
Yellu	7.020	7.000	2	3.510
Lilinta	5.184	4.000	2	2.592
Kabare	8.640	7.000	2	4.320

The expansion changes the total visit nodes from 32 to 47 distribution nodes, reflecting more realistic operational requirements.

Delivery Interval and Flexibility

Calculation of feasible delivery intervals for each PLTD produces varying ranges. **Table 3** presents interval ranges and flexibility for multi-delivery PLTDs.

Table 3. Delivery interval and flexibility for multi-delivery PLTDs

PLTD	Range Feasible (Hari)	Fleksibilitas Interval

Gag	5	0
Waigama	10	0
Kalobo	13-15	2
Saonek	9-15	6
Samate	8-10	2
Arborek	10-15	5
Yellu	2-15	12
Lilinta	8-15	7
Kabare	7-15	8

PLTDs with smaller flexibility values (such as Gag and Waigama) have higher distribution priority due to lower delay tolerance.

Route Formation Results

CWSA application produced 10 distribution routes feasible against all operational constraints. **Table 4** presents final route candidates with total load and distance.

Table 4. Final route candidates from optimization

Route	Day	Route Composition	Total Load (L)	Utilization (%)	Distance (Nm)	Status
R1	1	Gag-1 -- Waigama-1 -- Samate-1 -- Lopintol -- Waisilip -- Saupapir	19.548	97,74	286,4	Feasible
R2	2	Kalobo-1 -- Saonek-1 -- Arborek-1 -- Kabare-1 -- Yenwaupnor	18.864	94,32	294,2	Feasible
R3	6	Gag-2 -- Harapan Jaya -- Fafanlap -- Sawandarek	19.008	95,04	248,5	Feasible
R4	9	Samate-2 -- Yellu-1 -- Lilinta-1 -- Gamta -- Tomolol -- Yenbuba -- Dabatan	18.648	93,24	297,8	Feasible
R5	11	Gag-3 -- Waigama-2 -- Kabare-2	18.720	93,60	276,6	Feasible
R6	15	Kalobo-2 -- Saonek-2 -- Usaha Jaya -- Paam -- Yenbeser	18.756	93,78	289,4	Feasible
R7	16	Gag-4 -- Arborek-2 -- Yellu-2 -- Yenbekwan	18.846	94,23	274,1	Feasible
R8	19	Samate-3 -- Lilinta-2 -- Folley -- Arefi -- Yensawai -- Sawinggrai	16.704	83,52	281,2	Feasible
R9	21	Gag-5 -- Waigama-3 -- Warsambin	17.100	85,50	233,4	Feasible
R10	26	Gag-6 -- Jefman	16.524	82,62	198,7	Feasible

Total Distance: 2,680.30 *nautical miles*

Delivery Interval Validation

Validation was conducted to ensure that the resulting delivery schedule remains within the feasible range for each PLTD. **Table 5** presents delivery interval validation results for multi-delivery PLTDs.

Table 5. Delivery interval validation for multi-delivery PLTDs

PLTD	Delivery Days	Actual Interval (Days)	Operational Range (Days)	Status
Gag	1, 6, 11, 16, 21, 26	5, 5, 5, 5, 5	5	Feasible
Waigama	1, 11, 21	10, 10	10	Feasible
Kalobo	2, 15	13	13-15	Feasible
Saonek	2, 15	13	9-15	Feasible
Arborek	2, 16	14	10-15	Feasible
Kabare	2, 11	9	7-15	Feasible
Samate	1, 9, 19	8, 10	8-10	Feasible
Yellu	9, 16	7	2-15	Feasible
Lilinta	9, 19	10	8-15	Feasible

All PLTDs have actual delivery intervals still within the feasible range, so neither overflow nor stockout occurs.

Inventory Simulation

Inventory simulation was conducted for all PLTDs over 30 days. The simulation results show that all PLTDs can maintain inventory above safety stock and within tank capacity.

Cost Efficiency Analysis

Cost comparison between the round-trip existing system and the CWSA optimization system is presented in **Table 6**.

Table 6. Distribution cost comparison

Method	Total Distance (Nm)	Tariff (Rp/Nm)	Total Cost (Rp)
Round Trip Existing	6.147,14	100.000	614.714.000
CWSA	2.680,30	100.000	268.030.000
Savings	**3.466,84**	-	**346.684.000**

The CWSA method successfully reduced total sailing distance by 3,466.84 nautical miles, equivalent to distribution cost savings of **Rp346,684,000** per planning period (56.4%).

Sensitivity Analysis

Sensitivity analysis was conducted by changing the assignment of several PLTDs to distribution routes. **Table 7** presents sensitivity analysis results for the scenario of moving Gag-1 from Route 1 to Route 2.

Table 7. Sensitivity analysis of gag-1 relocation

Route	Day	Baseline Volume (L)	Scenario Volume (L)	Δ Volume	Utilization	Status
R1	1	19.548	8.748	-10.800	0,4374	Feasible
R2	2	18.864	29.664	+10.800	1,4832	**Over Capacity**

Moving Gag-1 causes Route 2 to exceed capacity (29,664 liters > 20,000 liters), making the route infeasible.

Table 8. Impact of assignment change on waigama inventory

Day	Daily Need (L)	SS (L)	Tank (L)	Delivery (L)	Start Stock (L)	End Stock (L)	Status
1	360	360	4.000	3.600	360	3.600	Feasible
2-10	360	360	4.000	0	3.240-720	2.880-360	Feasible
11	360	360	4.000	0	360	0	**SS Violation**
12-15	360	360	4.000	0	0 s.d. -1.080	-360 s.d. -1.440	**Stockout**

Moving Waigama-2 causes delivery delay from day 11 to day 16, resulting in safety stock violation on day 11 and stockout on days 12 through 15.

Fuel Distribution Characteristics and Operational Challenges in Archipelagic Regions

Based on operational data obtained from PT PLN (Persero) UP3 Sorong, the fuel distribution system in Raja Ampat Regency serves 32 PLTDs scattered across various islands with highly diverse demand characteristics. Monthly fuel demand varies significantly, ranging from 756 liters per month for small-capacity PLTDs such as Lopintol and Saupapir, to 64,800 liters per month for PLTD Gag which serves a peak load of 300 kWh. This demand variation reflects differences in energy consumption levels and operational patterns of each power plant, which in turn requires different distribution approaches. Research by Mawuntu et al. [6], which analyzed PLTD operational reliability in remote archipelagic regions, confirms that each power plant has different daily operational limits and efficiency levels, so distribution planning must consider the individual characteristics of each location.

Geographical challenges are the dominant factor in the fuel distribution system in Raja Ampat. The archipelagic region with hundreds of large and small islands means transportation access is highly dependent on sea transportation, which faces various obstacles such as weather uncertainty, tides affecting vessel docking capabilities, and limited dock facilities on remote islands. Many PLTDs do not have permanent docks, so the fuel loading and unloading process must wait for calm sea conditions and high tide that allow vessels to dock safely. This condition aligns with the findings of Afifudin et al. [7] in their research on commodity distribution route optimization in the Maluku islands, which showed that hierarchical maritime shipping structures are a fundamental requirement for overcoming distribution complexity in archipelagic regions and avoiding inefficient long-distance direct shipping.

The comparison between monthly fuel demand and storage tank capacity shows that 9 out of 32 PLTDs have monthly demand exceeding tank capacity, thus requiring more than one visit per distribution period. PLTD Gag represents the most extreme case, with monthly demand of 64,800 liters while its tank capacity is only 14,000 liters, meaning it requires at least 5 deliveries per month if using full tank capacity. Research by Wu et al. [8] on remote island maritime shipping networks confirms that integrating hub dock location decisions, tank capacity, and emergency inventory levels is crucial in distribution planning for archipelagic regions, as the inability to store large quantities of fuel at destination locations necessitates higher delivery frequencies and more careful planning.

Furthermore, daily fuel consumption also shows extreme variation, ranging from 25 liters per day for small-load PLTDs to 2,160 liters per day for PLTD Gag. This daily consumption difference directly impacts the safety stock calculations that must be maintained at each PLTD. Based on the assumption of one day of operation as minimum reserve, PLTD Gag must maintain safety stock of 2,160 liters, while PLTDs with small consumption only require 25 liters of safety stock. This condition indicates that each PLTD has a different vulnerability level to distribution delays. Research by Rahman and Wijaya [9] on operational patterns and fuel requirements of PLTD Gili Iyang revealed that mapping diesel generator operational patterns based on peak load time zones is crucial for minimizing specific fuel consumption, which is relevant to optimizing delivery frequency and volume in Raja Ampat.

Research by Kusuma and Dalimi [10] on the de-dieselization program of PLTDs to solar-wind hybrids highlights that although renewable energy integration can reduce fuel costs, it actually triggers more significant daily load fluctuations due to the intermittent supply from renewable energy plants. The implication of this finding for fuel distribution is that future fuel demand will no longer be constant but will fluctuate depending on the contribution of renewable energy in meeting electricity demand. This adds complexity to distribution planning because daily requirement calculations can no longer rely on fixed consumption patterns but must account for the dynamics of renewable energy supply that varies based on weather conditions and time.

Visit Node Expansion to Accommodate Tank Capacity and Safety Stock

The visit node expansion process is a crucial step in this research as it transforms the distribution representation from 32 PLTDs to 47 operational visit nodes that reflect actual field requirements. Node breakdown is performed by considering two main constraints: maximum storage tank capacity and minimum safety stock that must be maintained. The maximum delivery volume per visit is calculated as the difference between maximum tank capacity and safety stock, meaning fuel delivery should not fill the tank completely as space must still be reserved to avoid overflow, and also should not deliver in too small quantities that would require excessive delivery frequency.

For PLTD Gag with a tank capacity of 14,000 liters and safety stock of 2,160 liters, the maximum delivery volume per visit is 11,840 liters. With monthly demand of 64,800 liters, PLTD Gag requires 6 visits with a delivery volume of 10,800 liters each. This delivery volume was chosen because it approaches the maximum allowable volume while still providing a safety margin to avoid overflow when unexpected daily consumption fluctuations occur. This approach aligns with research by Chowmali and Sukto [11], who designed a multi-compartment route model for fuel delivery with a heterogeneous fleet, where each visit must consider the receiving tank capacity limits to avoid overflow risk and ensure operational safety.

PLTD Waigama with a tank capacity of 4,000 liters and monthly demand of 10,800 liters requires 3 visits with a volume of 3,600 liters per visit, considering safety stock of 360 liters. The same pattern is applied to PLTDs Kalobo, Saonek, Samate, Arborek, Yellu, Lilinta, and Kabare, each with different visit numbers according to the ratio between monthly demand and effective tank capacity after subtracting safety stock. This process results in a total of 47 visit nodes from the initial 32 PLTDs, meaning 15 new nodes were added as representations of repeated deliveries to the same PLTD within one distribution period.

Research by Garside and Laili [12] on the Cluster-First Route-Second approach for solving the Multi-Trip Periodic Vehicle Routing Problem confirms that splitting demand into multiple trips within one period is an effective strategy for overcoming vehicle capacity constraints and customer receiving capacity. This finding is highly relevant to the fuel distribution conditions in Raja Ampat, where several PLTDs have monthly demand exceeding storage tank capacity, thus requiring multiple visits. This multi-trip approach enables more optimal vessel utilization because vessels can make several trips within one period to serve the same PLTD, without having to wait until the end of the period for the next delivery. Research by Putri et al. [13] using the Cluster-First Route-Second approach with genetic algorithms for CVRPTW cases proved that clustering before route optimization can reduce logistics costs by up to 16.26% and accelerate route computation duration by 89.68%, providing important justification for the two-phase approach used in this research.

Delivery Interval and Flexibility as Distribution Priority Basis

Calculation of feasible delivery intervals for each PLTD produces different ranges, reflecting the unique operational characteristics of each PLTD. The lower bound of the interval (L_i) is calculated based on conditions where the next delivery should not be made too early as it could cause tank overflow, while the upper bound (U_i) is calculated based on conditions where delivery should not be made too late as it could cause stockout or inventory dropping below safety stock. The range between these two bounds, called interval flexibility ($F\_i = U\_i - L\_i$), indicates how much scheduling tolerance a PLTD has regarding delivery time changes.

PLTDs Gag and Waigama have interval flexibility equal to zero, meaning both have fixed delivery intervals with no tolerance for schedule changes. PLTD Gag must receive deliveries exactly every 5 days, while Waigama must receive deliveries exactly every 10 days. This condition makes both PLTDs the highest priority in the route formation process, because even one day of delay or acceleration in delivery would cause operational limit violations. PLTD Gag with daily consumption of 2,160 liters and tank capacity of 14,000 liters is highly sensitive to schedule changes, because the delivery volume of 10,800 liters only covers needs for 5 days, so a 1-day delay would cause stock to drop below safety stock and potentially cause power outages on the island it serves.

Research by Chin and Schiffer [14] on Neural Cluster-First Route-Second provides theoretical evidence that the CFRS framework has asymptotically optimal properties for large-scale CVRP. This finding supports the distribution priority approach based on interval flexibility, where PLTDs with the lowest flexibility are placed in the highest priority cluster to ensure their delivery schedules are not disrupted by route adjustments made for other PLTDs with higher flexibility. In other words, PLTDs most sensitive to schedule changes must be served first and placed on the most stable routes, while PLTDs with higher flexibility can be adjusted to fill remaining vessel capacity on routes that have been formed.

PLTDs Kalobo and Samate have interval flexibility of 2 days, meaning they still have limited schedule change tolerance but are not as critical as Gag and Waigama. Kalobo can receive deliveries between days 13 to 15, while Samate between days 8 to 10. This flexibility provides greater maneuverability in the route formation process, because both PLTDs can still have their delivery schedules adjusted as long as they remain within the allowable range. PLTDs Saonek, Arborek, Lilinta, Kabare, and Yellu have greater flexibility, respectively 6, 5, 7, 8, and 12 days, meaning they have significant schedule change tolerance and can be scheduled on different routes without causing operational limit violations. Research by Santoso et al. [15] on distribution area cluster design and delivery routes emphasizes the importance of balancing workload among fleets and minimizing utilization disparities, which in this research context is achieved through the interval flexibility-based priority approach that enables more balanced distribution of load.

Route Formation Results with Clarke and Wright Savings Algorithm

Application of the Clarke and Wright Savings Algorithm (CWSA) to 47 visit nodes successfully formed 10 distribution routes feasible against all operational constraints, including vessel capacity of 20,000 liters, feasible delivery intervals, and minimum safety stock. The resulting total distribution distance was 2,680.30 nautical miles, a significant reduction from the existing round-trip system of 6,147.14 nautical miles. This distance savings of 3,466.84 nautical miles or 56.4% shows that the destination clustering approach generated by CWSA can optimize vessel capacity utilization and reduce inefficient back-and-forth trips.

Route 1 with a total load of 19,548 liters and utilization of 97.74% is the route with the highest utilization, serving 6 PLTDs in one trip: Gag-1, Waigama-1, Samate-1, Lopintol, Waisilip, and Saupapir. This combination shows that high-priority PLTDs (Gag and Waigama) can be combined with small PLTDs in one route without violating vessel capacity limits, because the total load remains below 20,000 liters. Route 2 with a total load of 18,864 liters (utilization 94.32%) serves Kalobo-1, Saonek-1, Arborek-1, Kabare-1, and Yenwaupnor, all of which are within a close geographic cluster, enabling combination in one trip without significantly increasing travel distance. Routes 3 through 10 have varying utilization levels between 82.62% and 95.04%, with total loads always below the maximum capacity of 20,000 liters.

Research by Metzidakis et al. [16] on the Two-Phase Branch and Cut algorithm for the Capacitated Location Routing Problem emphasizes the importance of integrating strategic location decisions and tactical route determination to achieve multi-echelon supply chain efficiency. In the context of fuel distribution in Raja Ampat, the CWSA results show that combining several PLTDs in one route not only reduces total travel distance but also enables a reduction in the number of vessel trips required in one period. Research by Chowmali and Sukto [17] on the hybrid FJA-ALNS algorithm for large-scale fuel delivery routes proves that heuristic approaches considering geographical proximity and vehicle capacity can produce efficient solutions and avoid local optimum traps. Further validation of the formed routes shows that all PLTDs combined in one route have compatible delivery intervals, achieved by selecting delivery days that satisfy the entire feasible interval range of the involved PLTDs.

Research by Wijaya et al. [18] on the capacity factor analysis of hybrid power plants on remote islands shows that the daily load profile of isolated systems peaks at night, affecting fuel consumption patterns and tank refilling frequency. This finding indicates that fuel distribution planning cannot ignore the daily load patterns of PLTDs, because fuel consumption does not occur evenly throughout the day but is concentrated during peak load periods. The average daily consumption approach used in this research is adequate for monthly distribution planning, but further research could consider daily load variations to produce more accurate planning.

Multi-Delivery Interval Validation

Validation of delivery intervals for multi-delivery PLTDs shows that all PLTDs requiring more than one visit per period have actual intervals still within the feasible range. PLTD Gag receives deliveries on days 1, 6, 11, 16, 21, and 26, with actual intervals of 5 days, exactly matching the fixed interval limit of 5 days. This shows that Gag's scheduling has met operational requirements with high precision, without causing overflow or stockout during the 30-day period. PLTD Waigama receives deliveries on days 1, 11, and 21, with actual intervals of 10 days, exactly matching the fixed interval of 10 days. Although Waigama has zero interval flexibility, the resulting scheduling has precisely met operational limits.

The same pattern applies to Kalobo with an actual interval of 13 days (still within the 13-15 day range), Saonek with 13 days (9-15 day range), Arborek with 14 days (10-15 day range), Kabare with 9 days (7-15 day range), Samate with 8 and 10 days (8-10 day range), Yellu with 7 days (2-15 day range), and Lilinta with 10 days (8-15 day range). These validation results show that the interval flexibility-based approach used in this research successfully produced feasible distribution schedules for all multi-delivery PLTDs. Research by Yusuf and Hasan[19] on hybrid PLTS-PLTD power plant planning on Kodingare Island shows that renewable energy integration can reduce dependence on fuel supply, but still requires reliable fuel supply to anticipate bad weather conditions that reduce PLTS production.

Research by Suryanto and Hermawan [20] on the techno-economic analysis of the Enggano Island electricity system based on PLTD-PLTS hybrid power plants shows that diesel-based electricity in remote islands produces high LCOE (Rp3,935/kWh), which can be massively reduced through PLTS hybrid integration. The implication of this finding for fuel distribution is that in the future, when PLTDs in Raja Ampat begin transitioning towards PLTD-PLTS hybrid systems, fuel demand will decrease significantly as most of the load will be met by solar energy. However, intermittent PLTS supply fluctuations will cause fuel consumption patterns to become more dynamic and irregular, requiring a more adaptive and responsive distribution system to changing needs. The interval flexibility-based approach developed in this research can become a foundation for anticipating these dynamics, as it enables distribution schedule adjustments based on daily consumption changes caused by PLTS production variations.

Inventory Simulation and Fuel Supply Continuity Assurance

Inventory simulation conducted over 30 days shows that all PLTDs can maintain fuel inventory above safety stock levels during the distribution period. This proves that the distribution routes generated by CWSA are not only efficient in terms of distance but also capable of ensuring fuel supply continuity for all PLTDs scattered across Raja Ampat Regency. PLTD Gag with daily consumption of 2,160 liters and delivery volume of 10,800 liters has an inventory pattern that decreases linearly from 10,800 liters on delivery day to approaching safety stock of 2,160 liters on day 5 before the next delivery. This pattern shows that the delivery volume of 10,800 liters has been designed to be exactly consumed by day 5, which is the fixed delivery interval for PLTD Gag.

PLTD Waigama with daily consumption of 360 liters and delivery volume of 3,600 liters has an inventory pattern that decreases linearly from 3,600 liters to approaching safety stock of 360 liters on day 10 before the next delivery. The same pattern also occurs for other multi-delivery PLTDs, where delivery volume and delivery interval are designed so that fuel stock always remains above safety stock and below maximum tank capacity. Inventory simulation for all 47 visit nodes shows that no safety stock limit violations or overflow occur on any day during the 30-day period. These inventory simulation results align with the findings of Wu et al. [8] emphasizing the importance of integrating hub dock location decisions, tank capacity, and emergency inventory levels in remote island maritime shipping networks.

Research by Mawuntu et al.[6] on the power supply capacity analysis of Marampit Island shows that PLTDs in remote archipelagic regions have strict daily operational limits and national solar efficiency standards that must be met ($\leq$ 0.3 liters/kWh). In this research, the SFC assumption of 0.3 liters/kWh used to calculate fuel demand was based on these national efficiency standards, so the fuel demand calculation results are in accordance with applicable standards. Research by Rahman and Wijaya [9] on operational patterns and fuel requirements of PLTD Gili Iyang shows that mapping diesel generator operational patterns based on peak load time zones is crucial for minimizing specific fuel consumption, indicating that to achieve higher distribution efficiency, fuel demand calculations should consider not only average load but also daily load variations and different operational patterns at each PLTD.

Cost Efficiency and Economic Impact Analysis

The comparison between the existing round-trip system and the proposed CWSA-based distribution system demonstrates substantial economic benefits. The optimization reduced the total sailing distance from 6,147.14 to 2,680.30 nautical miles, decreasing distribution costs from Rp614,714,000 to Rp268,030,000 and generating savings of Rp346,684,000 (56.4%) per planning period. These savings were primarily achieved through shorter sailing distances, higher vessel utilization, and more efficient delivery scheduling. Compared with previous studies, the obtained cost reduction exceeds the 16.26% reported by Putri et al. [13], indicating the significant efficiency potential of optimizing fuel distribution in archipelagic regions. The results also support the findings of Santoso et al. [15] and Afifudin et al. [7], demonstrating that clustering-based routing effectively balances vessel utilization and provides an efficient distribution framework for island-based logistics systems.

Sensitivity Analysis and Solution Stability

Sensitivity analysis indicates that the proposed distribution system is generally stable but remains sensitive to route assignment changes involving PLTDs with low interval flexibility. Reassigning Gag-1 to another route caused vessel capacity to exceed the 20,000-liter limit, while moving Waigama-2 delayed its delivery schedule, resulting in inventory dropping below the safety stock level and causing temporary stockout. In contrast, changes involving PLTDs with higher interval flexibility, such as Yellu and Lilinta, had minimal impact because they possess greater scheduling tolerance and lower delivery volumes. These findings demonstrate that interval flexibility is a critical factor in maintaining distribution feasibility and system stability. The results are consistent with previous studies by Chowmali and Sukto [17], Metzidakis et al. [16], and Chin and Schiffer[14], which highlight the importance of robust route configurations and the effectiveness of the Cluster-First Route-Second framework in producing stable and near-optimal routing solutions.

Conclusion

Based on the results of this study, it can be concluded that the proposed fuel distribution optimization framework successfully improves the efficiency and reliability of fuel delivery to Diesel Power Plants (PLTDs) in Raja Ampat Regency. The application of the Clarke and Wright Savings Algorithm (CWSA) reduced the total sailing distance from 6,147.14 to 2,680.30 nautical miles, representing a 56.4% reduction, while increasing average vessel utilization to 90.75%. Delivery interval validation shows that each PLTD has a different level of interval flexibility, which can be used to determine distribution priorities, whereas inventory simulation confirms that all PLTDs maintain inventory above the safety stock level without exceeding storage capacity throughout the planning period. Sensitivity analysis further demonstrates that PLTDs with low interval flexibility, particularly Gag and Waigama, have the greatest influence on distribution feasibility when route assignments are modified. Overall, the proposed optimization framework satisfies all operational constraints and achieves an estimated operational cost saving of Rp346,684,000 per planning period (56.4%) compared with the existing round-trip distribution system. These findings are consistent with previous studies, confirming that integrating the Cluster-First Route-Second approach with inventory validation provides an effective and practical solution for fuel distribution in archipelagic regions.

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