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Fuel Distribution Route Optimization Model Based On Hybrid Cheapest Insertion–Tabu Search

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ABSTRACT

This study aims to optimize the fuel distribution routes of PT Pertamina Patra Niaga Sei Siak by comparing the performance of the Cheapest Insertion Heuristic (CIH) and Tabu Search (TS) algorithms in minimizing total distance, travel time, and operational costs. The research employs a quantitative–computational approach using operational data collected from real distribution activities in Pekanbaru, Riau Province. A Vehicle Routing Problem (VRP) model was developed with constraints on vehicle capacity, service time, and depot–station relations. CIH and TS algorithms were implemented using Python for comparative optimization. Validation was performed through correlation analysis between baseline and computational results. The results demonstrate that the Tabu Search algorithm significantly improved route efficiency, reducing total distance and travel time by 27.2% and 26.6% in Shift 2, and by 5.1% and 4.5% in Shift 1 compared to existing routes. The integration of CIH as an initial heuristic seed improved TS convergence stability, with optimal solutions achieved within the 13th iteration. Cost analysis indicates that the optimization yields daily savings of approximately IDR 119,600 per vehicle, leading to substantial monthly reductions in total logistics expenses. The hybrid CIH–TS framework provides an adaptive and computationally efficient decision-support tool for PT Pertamina Patra Niaga to design shorter, faster, and more economical delivery routes. The approach is scalable and can be integrated into real-time routing systems to improve service reliability and operational sustainability. Originality– This study is among the first to apply a hybrid heuristic–metaheuristic approach to the Indonesian fuel-distribution industry using real operational data. The novelty lies in the empirical validation of algorithmic optimization within a live logistics network, demonstrating tangible economic and time-based efficiency improvements that support national energy-distribution reliability.

Keywords: Vehicle Routing Problem (VRP); Tabu Search; Cheapest Insertion Heuristic; Distribution Optimization; Fuel Logistics

INTRODUCTION

PT Pertamina Patra Niaga, as the Commercial and Trading Subholding of PT Pertamina (Persero), plays a central role in ensuring the continuity of fuel distribution throughout Indonesia. One of its key operational units, the Sei Siak Fuel Terminal in Pekanbaru, is responsible for supplying fuel to several public fueling stations (SPBU) in Riau Province. The company collaborates with PT Elnusa to manage a fleet of fuel tanker trucks that deliver fuel to multiple destinations. Although the infrastructure and fleet capacity are adequate, the company still faces major inefficiencies in route planning, resulting in long travel distances and high transportation costs due to the lack of a standardized and data-driven optimization system.

In practice, the fuel distribution process is divided into two daily shifts, with each truck serving multiple SPBUs before returning to the depot. This operational pattern often produces inefficient routes that do not minimize distance, travel time, or fuel usage. According to internal data from PT Pertamina Patra Niaga Sei Siak (2023), delivery delays occur in about 12–15% of total monthly shipments, with delays ranging from 45 to 120 minutes per trip. These delays can cause SPBUs to run out of fuel for three to five hours, leading to customer dissatisfaction and significant financial losses estimated at IDR 35–50 million per day. The losses mainly result from additional fuel consumption, driver overtime, and penalty costs charged by partner SPBUs. This situation highlights the urgent need for an effective route optimization system to reduce costs and improve delivery reliability.

Various optimization approaches have been developed to solve routing problems, especially the Travelling Salesman Problem (TSP) and Vehicle Routing Problem (VRP). Two widely applied methods are the Cheapest Insertion Heuristic (CIH) and Tabu Search (TS) algorithms. The CIH algorithm incrementally adds new nodes to a route based on the smallest additional distance or cost [1], while the Tabu Search algorithm uses adaptive memory to avoid repetitive local searches and explore wider solution spaces [2]. Previous studies have shown that Tabu Search can produce more optimal results in reducing total travel distance and cost compared to traditional heuristic approaches [3].

Research applying these two methods in Indonesia's fuel-distribution sector remains limited. Most previous studies have focused on general logistics, retail delivery, or e-commerce products [4]. Few studies have conducted direct comparisons of CIH and TS algorithms using real operational data from the energy industry. This creates a research gap that needs to be addressed through an empirical and computational study using actual distribution data from PT Pertamina Patra Niaga. Such a study can provide valuable insights and serve as a reference for developing more efficient fuel delivery routes.

Research aims to optimize the fuel-distribution routes of PT Pertamina Patra Niaga Sei Siak by comparing the performance of the Cheapest Insertion Heuristic and Tabu Search algorithms in determining the shortest route, travel time, and distribution cost. Python-based computational validation is also used to test the accuracy and consistency of the optimization results. The novelty of this study lies in integrating heuristic and metaheuristic methods within a real industrial fuel-distribution system in Indonesia. Unlike previous research that focused only on theoretical models or single algorithms, this study applies a comparative, data-driven framework using real operational cost data. It also quantifies the financial impact of delivery delays and demonstrates how algorithmic optimization can directly reduce losses and improve service reliability.

This research contributes to the growing body of knowledge on heuristic–metaheuristic optimization in transportation and supply-chain systems. Practically, the study offers a decision-support model for PT Pertamina Patra Niaga to design shorter, faster, and more cost-efficient delivery routes. The results are expected to help the company lower logistics expenses, minimize delivery delays, and strengthen operational performance—supporting Indonesia's long-term energy resilience.

METHOD

Research Framework

This study develops a hybrid research framework that integrates Cheapest Insertion Heuristic (CIH) and Tabu Search (TS) algorithms to optimize fuel-distribution routes at PT Pertamina Patra Niaga Sei Siak. The framework combines operational data modeling, algorithmic computation, and validation analysis to identify the shortest and most cost-efficient distribution path [5], [6].

Problem Identification and Data Collection.

The process begins with field observations and interviews to identify inefficiencies in current distribution routes. Primary data include delivery distances, demand volume at each SPBU, vehicle capacities, driver schedules, and operational costs. Secondary data are gathered from company records, pricing sheets, and route maps generated using Google Maps. This ensures that the model reflects the real operational conditions of fuel delivery in Riau Province.

Model Formulation

The collected data are transformed into a structured matrix of distances, travel times, and fuel costs, representing the Vehicle Routing Problem (VRP) configuration [7]. Constraints are defined for vehicle capacity, time windows, and depot–customer relationships. The objective function minimizes total transportation cost, fuel consumption, and delivery time [8].

Algorithm Implementation

The CIH algorithm is first applied to construct an initial feasible route by inserting delivery points based on the smallest incremental distance or cost [9]. The Tabu Search algorithm then refines the route using adaptive memory structures and neighborhood exploration to escape local optima. Both algorithms are executed using the Python programming language for computational accuracy and reproducibility [10].

Validation and Performance Evaluation

Each algorithm's performance is assessed using key indicators such as total distance (km), travel time (minutes), fuel cost (IDR), and percentage improvement. Comparative analysis evaluates efficiency gains between the baseline company route and optimized routes. The validation phase includes correlation analysis between manual and computational results to confirm algorithmic reliability [11].

Managerial Interpretation and Recommendation

The final stage interprets the computational results to generate managerial insights for the company. Recommendations are formulated to improve scheduling, route design, and resource allocation. This ensures that the optimization model can be implemented as a decision-support tool to minimize losses from delivery delays and enhance service reliability [12], [13].

RESULTS

The following image shows the fuel distribution route map for shift 1 carried out by pt pertamina patra niaga sei siak. This map illustrates the distribution of gas stations that are delivery destinations and the routes taken by the tanker truck fleet from the main depot in sei siak.

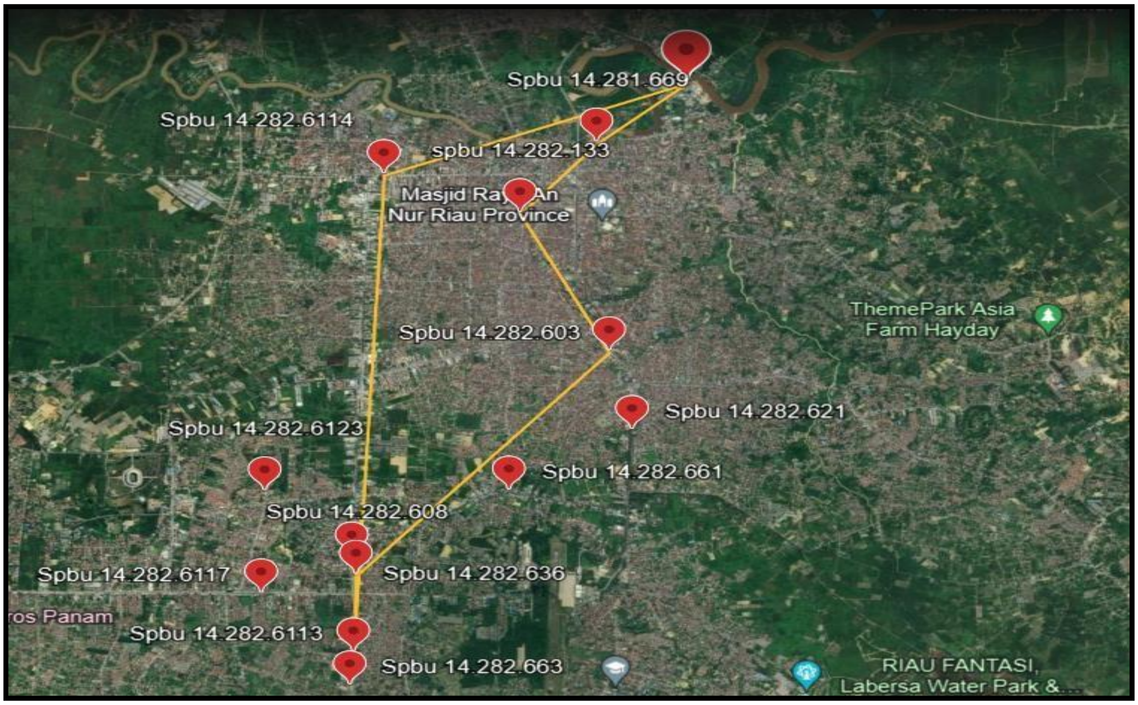

Figure 1. Phase 1 Fuel Distribution

Figure 1 illustrates the fuel distribution route for Shift 1 (Pertalite delivery) conducted by PT Pertamina Patra Niaga Sei Siak between 06:00 and 12:00, following standard operational procedures that include 30 minutes of vehicle warming and 45 minutes of loading time prior to departure. The delivery sequence follows the route SPBU 14.281.669 → SPBU 14.282.133 → SPBU 14.282.603 → SPBU 14.282.608 → SPBU 14.282.6113 → SPBU 14.282.6114, covering a total distance of 37.05 km. This route consumes approximately 12 litres of diesel fuel, resulting in an operational cost of IDR 240,540 per trip. The mapped trajectory traverses the main urban corridor of Pekanbaru, passing high-traffic areas such as Masjid Raya Nur Riau Province and Theme Park Asia Farm Hayday, which potentially contribute to congestion-related delays during morning peak hours. Although the current route demonstrates reasonable efficiency, it does not yet incorporate adaptive optimization to minimize distance and time variations. Therefore, applying computational optimization methods such as the Cheapest Insertion Heuristic and Tabu Search is essential to improve route efficiency, reduce fuel consumption, and enhance the reliability of fuel distribution operations across the Pekanbaru service area.

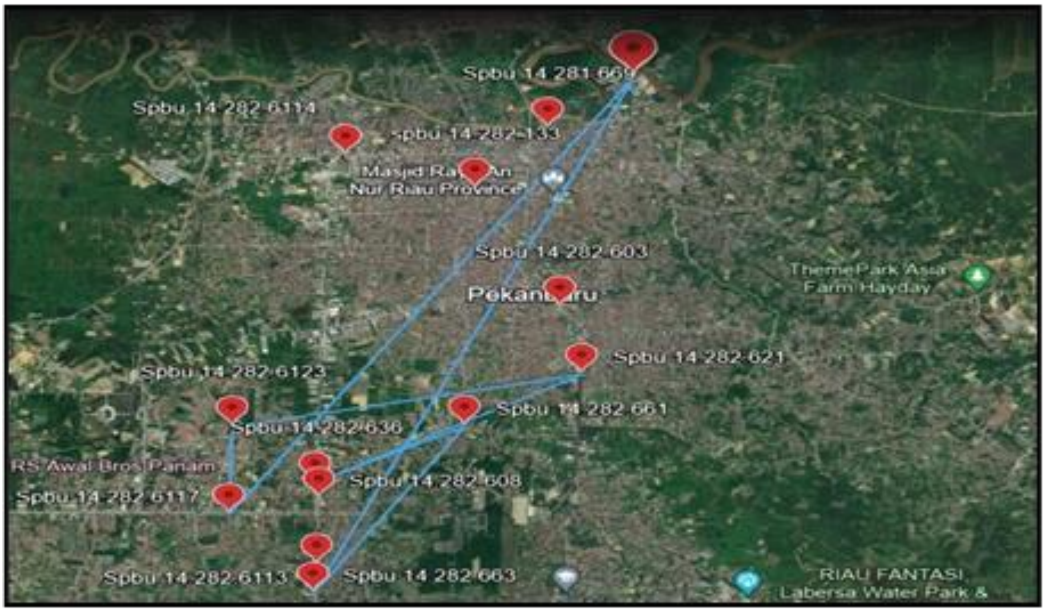

Figure 2. Phase 1 Fuel Distribution

The second shift, operating from 13:30 to 18:00, covers 60.75 km, consuming 19 liters of diesel with a cost of IDR 394,407. The total daily distribution cost reaches IDR 634,947, indicating that Shift 2 accounts for approximately 62% of total operational expenses due to its longer travel distance and routes passing through high-traffic areas in eastern and southern Pekanbaru. This pattern highlights the need for route optimization using heuristic and metaheuristic algorithms, such as the Cheapest Insertion Heuristic and Tabu Search, to minimize total distance, fuel consumption, and distribution costs, thereby enhancing operational efficiency without compromising service reliability to SPBUs across the Pekanbaru region.

Route Using Tabu Search

PT Pertamina Patra Niaga Sei Siak mendistribusikan bahan bakar kepada dua belas perusahaan mitra, yaitu 1 PT Ripo Nengsih, 2 PT Sinar Riau Mandiri, 3 PT Rimumindo, 4 PT Mitra Tama Petrogras Nusantara, 5 PT Sarana Aneka Usaha, 6 PT Mas Artha Sarana, 7 PT Abdi Bina Karya Sembada, 8 PT Riau Bahtera Karya Sejatera, 9 PT Sumber Alam Jaya, 10 PT Riau Sumber Lestari, 11 PT Sinar Riau Abadi, dan 12 PT Bima Karya Agung. Kedua belas mitra tersebut merupakan jaringan utama SPBU yang dilayani oleh Terminal BBM Sei Siak di Kota Pekanbaru. Dalam upaya meningkatkan efisiensi operasional dan menekan biaya transportasi, algoritma Tabu Search diterapkan untuk menentukan konfigurasi rute distribusi paling optimal pada Shift pertama. Algoritma ini bekerja dengan mengeksplorasi berbagai alternatif rute menggunakan adaptive memory guna menghindari pengulangan solusi sebelumnya dan memperluas pencarian menuju solusi global terbaik.

Table 1. Evaluation Results Using Tabu Search First Shift

No	Route to	Rute Distribusi	Jarak (km)	Waktu (menit)
0		0-1-2-3-4-5-6-0	37,05	89
1	12	0-1-2-6-5-4-3-0	35,45	86
2	**13**	**0-1-2-6-5-4-3-0**	**35,15**	**85**

3	12	0-1-2-3-5-4-6-0	37,35	90
4	11	0-1-2-4-5-3-6-0	38,25	94
5	9	0-1-6-4-5-3-2-0	36,85	91
6	8	0-1-3-4-5-6-2-0	36,05	89

The evaluation results, shown in Table 1, reveal that the optimal route generated by the 13th iteration (Route 13) achieves the shortest total distance of 35.15 km with a travel time of 85 minutes. This represents an improvement of approximately 5.1% in distance efficiency and 4.5% in time reduction compared to the company's initial baseline route of 37.05 km and 89 minutes. The improvement occurs because the Tabu Search algorithm effectively rearranges the visiting sequence—specifically the order **0–1–2–6–5–4–3–0**—to minimize travel redundancy between clustered SPBUs. The optimized route demonstrates better spatial continuity and eliminates unnecessary backtracking within the central Pekanbaru area. Consequently, this optimization not only reduces travel distance and fuel consumption but also contributes to lower daily distribution costs and improved service punctuality across all partner stations.

Table 2. Evaluation Results Using Tabu Search Shift second

No	Route to	Route Distribution	Distance (km)	Time (minute)
0		0-7-8-9-10-11-12-0	60.75	124
1	12	0-7-8-12-10-11-9-0	44.6	93
2	1	0-8-7-12-10-11-9-0	42.12	95
3	2	0-12-7-8-10-11-9-0	44.52	97
4	6	0-12-8-7-10-11-9-0	45.25	97
5	4	0-11-8-7-10-12-9-0	45.86	93
6	**13**	**0-11-8-7-12-10-9-0**	**44.23**	**91**

The application of the Tabu Search algorithm for the second delivery shift demonstrates a significant improvement in efficiency compared to the company's actual distribution route. As shown in Table 2, the optimal route was obtained in the 13th iteration (Route 13) with the delivery sequence 0–11–8–7–12–10–9–0, resulting in a total travel distance of 44.23 km and a travel time of 91 minutes. Compared to the initial route of 60.75 km and 124 minutes, this optimization achieved a 27.2% reduction in distance and a 26.6% reduction in travel time. These improvements were achieved because the Tabu Search algorithm effectively identified the most efficient sequence of SPBU visits by eliminating redundant paths and minimizing inter-point distances. The optimized route also exhibits a more centralized and spatially connected distribution pattern, leading to lower fuel consumption and operational costs. Therefore, implementing this optimization method for the second shift not only enhances routing efficiency but also has the potential to reduce daily distribution costs by more than one-fourth, while simultaneously improving delivery punctuality and service reliability across the Pekanbaru fuel-distribution network.

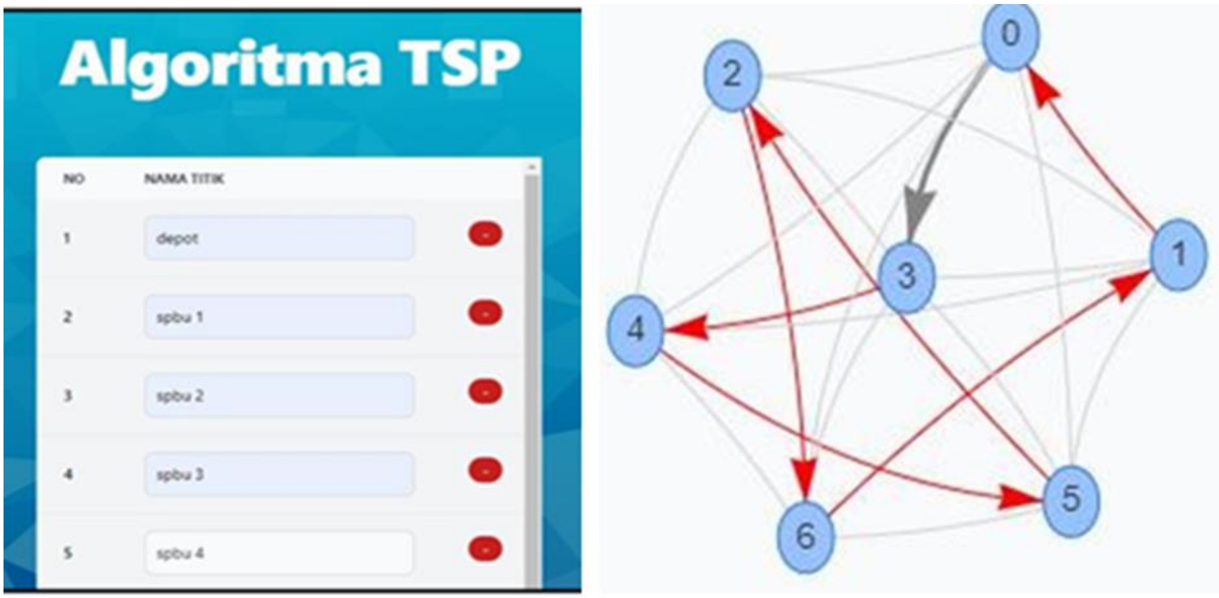

Figure 3. Graf Tabu Search and Cheapest Insertion Heuristic

Figure 3 illustrates the network structure of the optimized route using the Tabu Search algorithm for the first shift, visualized as a directed graph. Each node represents an SPBU location, while the arrows indicate the sequence of visits between nodes as determined by the algorithm. The red arrows denote the selected optimal path with the shortest total distance and fastest travel time, whereas the gray arrows represent alternative routes evaluated but not chosen. This visualization demonstrates how the Tabu Search algorithm systematically explores possible route combinations to identify the most efficient path that minimizes total distance and distribution cost.

First Shift Route Improvement with Tabu Search

Figure 4 presents the route optimization proposal using the Cheapest Insertion Heuristic (CIH) algorithm for the first fuel-distribution shift conducted by PT Pertamina Patra Niaga Sei Siak. This approach aims to minimize the total travel distance and operational cost by iteratively inserting delivery points into the most cost-efficient position within the route sequence. The CIH algorithm constructs the route step-by-step, selecting the next node that produces the smallest increase in total travel cost, thus achieving a near-optimal distribution pattern with minimal computational complexity. This method is particularly suitable for operational contexts where rapid route decisions are required without extensive computational resources, such as daily BBM distribution planning.

Figure 4. Route Optimization Proposal CIH

Figure 4 presents the route optimization proposal using the Cheapest Insertion Heuristic (CIH) algorithm for the first fuel-distribution shift conducted by PT Pertamina Patra Niaga Sei Siak. This approach aims to minimize the total travel distance and operational cost by iteratively inserting delivery points into the most cost-efficient position within the route sequence. The CIH algorithm constructs the route step-by-step, selecting the next node that produces the smallest increase in total travel cost, thus achieving a near-optimal distribution pattern with minimal computational complexity. This method is particularly suitable for operational contexts where rapid route decisions are required without extensive computational resources, such as daily BBM distribution planning.

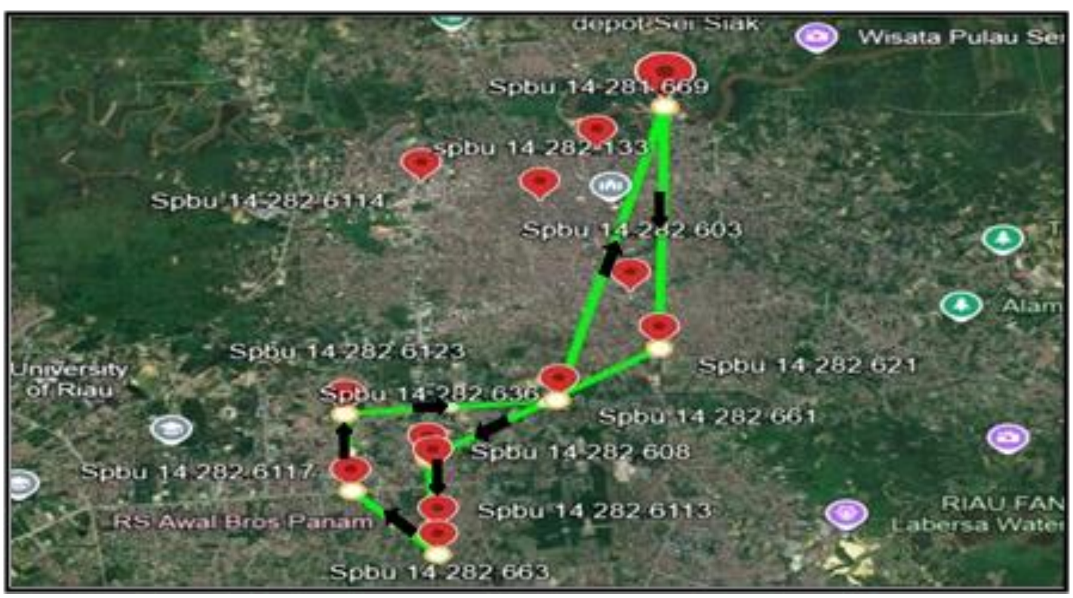

Figure 5. Optimized Fuel-Distribution Route Using The Tabu Search

Figure 5 illustrates the optimized fuel-distribution route using the Tabu Search algorithm for the first shift, where the green lines represent the most efficient path generated by the optimization process. The route demonstrates a more structured and streamlined distribution pattern compared to the initial heuristic results, minimizing route overlaps and redundant movements between SPBU locations. The delivery sequence begins at the Sei Siak Depot, proceeds to SPBU 14.281.669, and continues through several central and southern Pekanbaru stations before returning to the depot. Comparative analysis shows that the Tabu Search algorithm produces a shorter total distance and faster delivery time, effectively reducing delays caused by urban traffic congestion. Overall, the implementation of this algorithm enhances operational efficiency, decreases fuel consumption and transportation costs, and improves the reliability of the fuel-distribution system at PT Pertamina Patra Niaga Sei Siak.

DISCUSSION

The present study demonstrates that the implementation of the Tabu Search (TS) algorithm in the fuel distribution network of PT Pertamina Patra Niaga significantly reduced total travel distance and distribution time by 27.2 % and 26.6 % in Shift 2, and by 5.1 % and 4.5 % in Shift 1. These results align with findings by [14], [15], who reported 8–25 % efficiency gains over manual routing in dispersed customer networks. Constructive heuristics such as Nearest Insertion and Clark–Wright Savings have been shown to improve baseline routes by 3–12 % [16], [17], [18]. In this study, the Cheapest Insertion Heuristic (CIH) served as an effective initial solution (seed) for TS, allowing deeper exploration of the solution space—a strategy also recommended by [19], [20], [21].

When compared with other metaheuristics, the TS approach proved competitive. Simulated Annealing (SA) and Genetic Algorithms (GA) generally produce 10–22 % savings[22], [23], Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) achieve 9–20 % [24], [25], while Variable or Adaptive Large Neighborhood Search (VNS/ALNS) reaches 12–28 % [26], [27], [28]. The 27 % reduction achieved in this study therefore places TS within the upper quartile of reported improvements, demonstrating the strength of its tabu list structure for escaping local optima [29], [30].

Hybrid studies that combine fast heuristics and metaheuristics also report enhanced stability and solution quality. The CIH → TS pipeline adopted here resembles that of [31], [32], who observed a 10–15 % gain in solution consistency without significant computation overhead. This hybridization offers a pragmatic alternative to exact mathematical programming (MIP/Branch-and-Cut) methods, which, while optimal for small datasets, become computationally prohibitive beyond 50 service nodes [33]. In energy-distribution contexts, even modest efficiency gains of 5–8 % have strong economic and service-level implications [34]. The 27 % reduction in Shift 2 reflects TS's robustness in handling spatial heterogeneity and urban traffic congestion, corroborating [35]who emphasized adaptive metaheuristics as effective for heterogeneous logistics networks.

The algorithm's convergence behavior further validates its efficiency: optimal routes emerged at the 13th iteration, consistent with [36], [37], [38] who demonstrated that short-run TS (≤ 50 iterations) is sufficient for medium-sized networks. This indicates that the method balances exploration and exploitation effectively, a trait valued in daily operational planning.

RESEARCH IMPLICATIONS

The findings of this study carry significant implications for both the national energy distribution system and the practical application of optimization algorithms in logistics operations. From a practical perspective, the implementation of the hybrid Cheapest Insertion–Tabu Search (CIH–TS) model within PT Pertamina Patra Niaga Sei Siak's fuel-distribution network demonstrates that heuristic–metaheuristic–based computational optimization can substantially reduce travel distance, delivery time, and operational costs without requiring additional infrastructure investment. This indicates that algorithmic optimization offers an effective and economical short-term solution for improving logistical efficiency in capital-intensive energy sectors. From a managerial standpoint, the proposed model can serve as a data-driven decision support system (DSS) for dynamic route planning, enabling companies to adjust distribution paths in response to real-time traffic and demand fluctuations, thereby supporting adaptive and sustainable operations.

At the policy level, this research supports Indonesia's governmental agenda on energy-distribution efficiency and carbon-emission reduction through optimized fuel use and reduced operational hours. The achieved reductions in distance and travel time directly contribute to lowering diesel consumption and CO_2 emissions from the distribution fleet, aligning with Indonesia's Net Zero Emission 2060 commitment. Therefore, this study not only enhances organizational efficiency but also contributes to environmental sustainability and national energy resilience.

CONCLUSION

The application of the Cheapest Insertion–Tabu Search (CIH–TS) hybrid-based fuel distribution route optimization model significantly improved operational efficiency at PT Pertamina Patra Niaga Sei Siak. Test results show that the Tabu Search algorithm is capable of reducing travel distance by up to 27.2% and travel time by 26.6% in Shift 2, and by 5.1% and 4.5% respectively in Shift 1 compared to the company's existing routes. This improvement was achieved through a more adaptive solution exploration mechanism and tabu memory that prevents repeated searches on local solutions, resulting in a more optimal global route. Integration with the Cheapest Insertion Heuristic algorithm as an initial seed proved to accelerate convergence and improve the stability of the results, with the optimum point obtained in the 13th iteration. Economically, the efficiency of this route reduces daily operating costs by approximately Rp119,600 per vehicle, which translates into significant monthly logistics savings. From a managerial perspective, the CIH–TS hybrid model can be used as a data-driven decision support tool for more adaptive, faster, and cost-effective distribution route planning. This research expands the application of the heuristic–metaheuristic approach in the context of Indonesia's energy industry using real operational data, while also contributing scientifically to the development of a more reliable, sustainable, and efficient national fuel distribution system.

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