Optimization of Fuel Distribution Routes for Green Logistics in Multi Compartment Vehicle Routing Problem (MCVRP) using Branch and Bound Algorithm (Case Study: Boyolali Fuel Terminal)

Millenia S. Anggraeni, Osel N. Tazkiya, Exga Mawandi,
And Harummi S. Amarilies
Logistics Engineering Department
Universitas Pertamina
Jakarta, Indonesia
milleniashinta50@gmail.com, oseltaz@gmail.com,
exga.mawandi@gmail.com, harummi.sa@universitaspertamina.ac.id

Abstract

This study focuses on gasoline and diesel fuel distribution process at Boyolali fuel terminal, Indonesia. This terminal is responsible to deliver fuel to more than 294 fuel stations in Central and East Java provinces. The distribution area is divided into three zones, utilizing both single and multi-destination methods. Since the deliveries are done based on order priority and time windows, single-destination method is preferable, especially when delivering fuel to 47 gas station in Zone 3, causing a not optimal distribution scenario. Thus, a more effective and efficient distribution process for Zone 3 is needed. Creating an optimized distribution cost is started by clustering gas stations using P-Median, considering the distance between points. The optimization model is Multi Compartment Vehicle Routing Problem (MCVRP) with split delivery and multi product with the objective function of minimizing total distribution costs (considering tank truck's fuel cost and carbon emission cost). Branch and Bound (B&B) algorithm is applied to solve the exact method of distribution route optimization, using LINGO software. The results show that by clustering Zone 3 gas stations into 9, the total daily distribution costs are reduced from IDR 12,712,435.20 to IDR 9,179,116.80, resulting to 28% reduction.

Keywords:
Fuel, Clustering, MCVRP, Split Delivery, Branch and Bound

1. Introduction

The demand for fossil fuel is increasing in line with Indonesians' dependence on this non-renewable source of energy (Kushariyadi and Sugito 2022). Oil and gas companies are required to have high competitiveness against changes that occur to be able to keep up with their competitors. Therefore, the quantity and quality of the products, as well as the optimized distribution process are mandatory.

The distribution system shows the relationship of each activity, where transportation as a link or bridge that connects between manufacturers and customers (Nasution 2008). Thus, it is necessary to manage transportation effectively and efficiently in order to optimize the company's operational costs. According to Zaroni (2015), transportation costs are the largest cost component in the logistics cost structure, covering for up to 50% of total logistics costs (Chopra et al. 2016). Zaroni (2017) also conveys no less than 70% of logistics activities come from transportation and almost 90% of CO_2 emissions are mostly caused by transportation activities. Thus, it is necessary to improve transportation management in a sustainable and consistent manner to reduce CO_2 emissions. Efficiency and effectiveness of transportation can be achieved by optimizing the route that considers the distance travelled as well as the capacity and number of trucks used.

One approach to determine the optimal distribution route undertaken by a fleet of vehicles to serve a particular set of customers is the Vehicle Routing Problem or VRP (Fauzi et al. 2021), and the type of VRP used in this study is the VRP model that considers multi compartment, because the tank trucks used for fuel delivery, consist of several compartments. The model is known as multi-product delivery because each compartment contains different class of gasoline or diesel fuel. It is a split delivery because each point can be visited by more than one vehicle with the aim to produce minimum distribution costs. The case study is done at Boyolali Fuel Terminal, Central Java, Indonesia. The management of Boyolali Fuel Terminal is committed to providing fuel sustainably. This fuel terminal is responsible to deliver fuel to 294 gas stations in 14 cities and districts in Central and East Java. The distribution area is divided into 3 zones based on the distance of each gas station. Since each gas station has its own operating hours, Boyolali Fuel Terminal divides its operating hours into 3 shifts and plans the distribution process using both single and multi-destination methods. For the 47 gas stations in Zone 3, the furthest from the terminal, single-destination method is preferrable. This causes a not yet optimum use of compartments in each vehicle and increases the total distribution costs. The utilization of compartments for each zone can be seen in Figure. 1, where P is the calculation obtained from the demand of each gas station divided by the capacity of each compartment, which is 8,000 Liters or 8 KL, while K is the actual use of compartments. From the picture, we can see that the difference between the calculation and the actual compartment use in Zone 3 excesses of 72 compartments. It happens because in Zone 3 delivery is done using 32 KL tank trucks with single-destination method, thus, a lot of compartments are empty during delivery, resulting to high distribution costs for Zone 3.

Since the management of Boyolali Fuel Terminal hasn't done any study concerning the carbon emissions, it is necessary to calculate the production of carbon emissions generated during the distribution process. In this study, the carbon emissions produced is converted into carbon emission costs. That is why, the reduction in total delivery distance will, at the same time, reduce the total distribution cost and carbon emission. Determination of the cost of carbon emissions is to approach the mileage, fuel consumption, and emission factors of vehicle fuel. (Hoen et al. 2010)

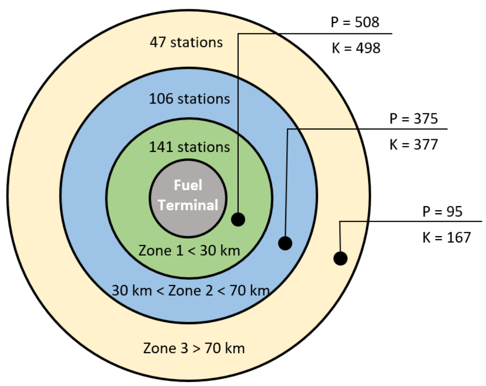

Figure 1. Utilization of Vehicle Compartments in Each Zone

1.1 Objectives

Based on the problems in Boyolali Fuel Terminal, it is necessary to conduct research to get the proposed route of optimal fuel distribution, especially in Zone 3 using a multi compartment vehicle size 24 KL. To solve the problem in this study, LINGO software package is used to solve the exact method using the Branch and Bound (B&B) algorithm. This model has the function to minimize the cost of fuel distribution process, considering both the cost of fuel consumption and the cost of carbon emissions for each route.

The use of exact methods is chosen because it guarantees that the optimal solution can be achieved, although its efficiency depends on the size of the problem and the computation time (Reed et al. 2014). In accordance with the problems in this study with 47 gas stations, the exact method has limitations in running the program, so it is necessary to simplify the problem. In this case, Chen and Liestma (2003) explained that clustering can be done to simplify routing problem. In this study, the gas station in Zone 3 is clustered into 9 areas based on the number of cities and districts in the zone using P-Median Clustering.

With the determination of distribution routes using the B&B algorithm, it is expected that the fuel distribution process at Boyolali Fuel Terminal, especially for Zone 3 can be more effective and efficient, allowing the company to meet customer demand with the right amount and optimal costs and minimize carbon emissions produced.

2. Literature Review

This research raises several theoretical foundations as a theoretical framework, namely:

2.1 Haversine Formula

Farid and Yunus (2017) suggested the haversine formula as a method of determining the distance between two points on the Earth based on the length of a straight line between two points by considering that the Earth is not a flat plane but is a plane that has a degree of curvature. The following is haversine formula.

$$x = (\text{Longitude}_2 - \text{Longitude}_1) \times \text{Cos}\left(\frac{(\text{Latitude}_2) + (\text{Latitude}_1)}{2}\right)$$

$$y = (\text{Latitude}_2) - (\text{Latitude}_1)$$

$$d = \sqrt{(x)^2 + (y)^2} \times R$$

Where:
x = Longitude
y = Latitude
d = Distance
R = Earth radius = 6,371 km

2.2 Multi Compartment Vehicle Routing Problem

Multi Compartment Vehicle Routing Problem (MCVRP) is a development of ordinary VRP, where in one vehicle there are several compartments. Muyldermans and Pang (2010) explaining the benefits of distribution by vehicles with multiple compartments is that when more types of products are transported, the customer sites are more dispersed, or the vehicles have greater capacity, the advantages of using vehicles with multiple compartments will be higher.

Vehicles with multiple compartments are used to allow the transport of heterogeneous products in one transport in the same vehicle, but in different compartments with the aim of saving transportation costs. A simpler explanation can be seen in Figure 2 which is an example of distribution for vehicles with many compartments, where each vehicle consists of 3 compartments that can be used to deliver several types of products. (Ostermeier et al. 2021)

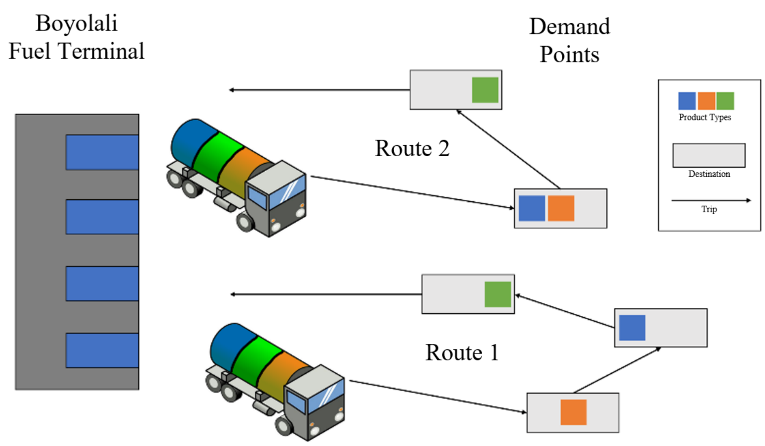

Figure 2. Distribution Process with Multi Compartment Vehicle

2.3 Split Delivery Vehicle Routing Problem

Split Delivery Vehicle Routing Problem (SDVRP) was introduced by Dror and Trudeau in 1989 by removing the restriction that consumers should only be visited once. In SDVRP, customers can be served by more than one vehicle, so customer requests can be shared among multiple vehicles on the same or different routes. In addition, SDVRP degrades the structural properties of an optimal SDVRP solution and empirically shows that split delivery can result in considerable cost savings. With separate shipments, the resulting costs can potentially be reduced by as much as 50%. (Archetti et al. 2006)

2.4 P-Median Clustering

P-Median is generally useful for modelling many situations in the real world, such as determining the location of factories, warehouses, and public facilities or commonly known as location allocation problems (Mladenovic et al. 2007). In the problem of allocation location, the chosen median point is to represent the location that will be used for the manufacture of facilities with the aim of minimizing costs. The P-Median can also be interpreted in terms of cluster analysis, where the demand point that was originally a facility candidate is now a cluster candidate (Hansen et al. 2009). Clustering with P-Median can distribute the dataset into several separate groups, where the number of clusters formed is equal to p based on the proximity of the distance between the data. This study uses P-Median clustering method with consideration of the closest distance between gas station points. In this study, the data is a collection of gas stations or demand points, so that every gas station in the same cluster is a gas station that is close to each other, where the cluster in this study shows the number of cities and districts in Zone 3 doing fuel distribution, which is as many as 9 clusters.

2.5 Branch and Bound

Branch and Bound (B&B) is a general algorithm for the search for optimal solutions of various optimization problems, in particular for discrete and combinatorial optimization (Suyanto 2010). In addition, Branch and Bound algorithm is an algorithm that breaks the problem into smaller sub-problems that lead to solutions by branching and bounding to get the optimal solution. Branching is the formation of a problem into a search tree structure. The branching process is carried out to build all the branches of the tree that go to the solution, while the restriction process is carried out by calculating the estimated value of the node with respect to the boundary. (Margiyani and Mussafi 2014)

2.6 Green Logistics

Green logistics first introduced by Jim Cooper in 1994, the name then evolved into Green-Vehicle Routing Problem (Iswardani et al. 2020). Green Vehicle Routing is a branch of green logistics that refers to Vehicle Routing problems where externalities of vehicle use, such as carbon dioxide emissions produced, are explicitly considered so that they can be reduced if good planning is carried out (Bektaş et al. 2016).

3. Methods

The type of this research using quantitative approach with Mixed Integer Linear Programming (MILP) as a mathematical model which generate route suggestions for fuel distribution from TBBM Boyolali to all clusters of gas stations formed in Zone 3. Suggestions for fuel distribution routes are obtained through three stages of data processing, namely the processing of gas station coordinate data used to determine the distance matrix of each point, grouping gas stations in Zone 3 into several clusters by considering the proximity of the distance between gas stations using the P-Median, and determining the distribution routes for each cluster using the exact method with the help of LINGO software to determine the lowest cost of the fuel distribution process, where the distribution cost is calculated based on the fuel used and the cost of production of carbon emissions generated during the distribution process.
This study uses several limitations and assumptions to focus research and centralize data processing, among others:

1) Limitations
   - Product demand is deterministic, and the type of truck tanks used is 24 KL in capacity with 3 compartments (8 KL each).
   - The number of tank trucks used by each cluster is adjusted to the needs of each cluster compartment.
   - The determination of the distribution route does not consider the delivery time.
   - Determination of distribution routes only for Zone 3.
   - The distribution cost calculation only considers the cost of fuel consumption and the cost of carbon emissions.
   - 4 types of products are delivered daily, and they are identified as product 1, 2, 3, and 4.

2) Assumptions
   - Depot capacity is not considered so that the depot can always meet consumer demand.
   - The number of consumers (gas stations) is fixed.
   - The distance from the starting point to the destination point is the same as the reverse distance.
   - There is no road congestion taken into consideration, and tank trucks are always available.
   - Products delivered to one consumer can be broken down into one or more vehicles.
   - The vehicle has more than one compartment and one compartment can only be filled with one type of product.

Here is a mathematical model of P-Median Clustering and Multi Compartment Vehicle Routing Problem with Split Delivery and Multi Product.

1) P-Median Clustering

The mathematical model used in this study for clustering using *P-Median* referring to the research of Mladenovic, Brimberg, Hansen, & Moreno-Perez (2007) as follows:

Index

i : Request point Set

j : Cluster candidates point Set

Parameters

p : Number of clusters

d_{ij} : Distance from request point i to cluster candidate point j

Decision Variables

$$x_{ij} : \begin{cases} 1, & \text{if request point i belongs to cluster } j \\ 0, & \text{others} \end{cases}$$

$$y_j : \begin{cases} 1, & \text{if the candidate point of cluster } j \text{ is selected} \\ 0, & \text{others} \end{cases}$$

Objective Function

$$\min \sum_i \sum_j d_{ij} x_{ij} \qquad (3.1)$$

Subject to

$$\sum_j x_{ij} = 1 \qquad \forall i \qquad (3.2)$$

$$\sum_j y_j = p \qquad (3.3)$$

$$y_j \geq x_{ij} \qquad \forall i, j \qquad (3.4)$$

$$x_{ij} \in \{0,1\} \qquad (3.5)$$

$$y_j \in \{0,1\} \qquad (3.6)$$

Objective function (3.1) of this study is to minimize the total distance between request points in a cluster. Constraint (3.2) ensures that each request point is joined in exactly one cluster. Constraint (3.3) ensures that the number of clusters formed must be equal to p. Constraint (3.4) ensures that each request point can only be joined to the selected cluster. Constraints (3.5) and (3.6) define binary variables.

2) Multi Compartment Vehicle Routing Problem with Split Delivery and Multi Product

Determination of the optimal route using the approach MCVRP with Split Delivery and Multi Product which refers to the study (Normasari and Warangga 2019) by adding distribution cost and carbon emission components to the destination function and eliminating the time windows limitation as follows:

Sets

N : Set point depot and consumer (h, i, j = 0, 1, 2, …, N)

P : Product Set (p = 1, 2, 3, 4)

K : Vehicle Set (k = 1, …, K)

C : Compartment Set (c = 1, 2, 3)

Parameters

Q_{kc} : Capacity of each compartment c on vehicles k

ds_{ij} : Distance from point i to point j

dm_{jp} : Product request p at the point j

Cf : Cost of fuel consumption per liter

Ce : Cost of carbon emissions per liter

Decision Variables

$$x_{ijk} : \begin{cases} 1, & \text{if vehicle } k \text{ moves from point } i \text{ to point } j \\ 0, & \text{others} \end{cases}$$

$$y_{pck} : \begin{cases} 1, & \text{if vehicle } k \text{ is filled with product } p \text{ in the compartment } c \\ 0, & \text{others} \end{cases}$$

z_{jpk} : Number of products p delivered to customer j by vehicle k

Objective Function

$$\min \sum_i \sum_j \sum_k x_{ijk} \left(0{,}3\, ds_{ij}\, (Cf + Ce)\right) \qquad (3.7)$$

Subject to

$$\sum_j x_{0jk} = 1 \qquad \forall k \qquad (3.8)$$

$$\sum_i x_{ihk} - \sum_j x_{hjk} = 0 \qquad \forall k, h \qquad (3.9)$$

$$x_{ijk} + x_{jik} \leq 1 \qquad \forall i, j, k \quad i, j \backslash \{0\} \qquad (3.10)$$

$$\sum_i \sum_k x_{ijk} \geq 1 \qquad \forall j \qquad (3.11)$$

$$\sum_k x_{iik} = 0 \qquad \forall i \qquad (3.12)$$

$$\sum_p y_{pck} = 1 \qquad \forall c, k \qquad (3.13)$$

$$\sum_{j} z_{jpk} \leq \sum_{c} Q_{kc} y_{pck} \quad \forall p, k \quad (3.14)$$

$$\sum_{k} z_{jpk} = dm_{jp} \quad \forall j, p \quad (3.15)$$

$$z_{jpk} \leq dm_{jp} \sum_{i} x_{ijk} \quad \forall j, p, k \quad (3.16)$$

$$x_{ijk} \in \{0,1\} \quad (3.17)$$

$$y_{pck} \in \{0,1\} \quad (3.18)$$

$$z_{jpk} \geq 0 \quad (3.19)$$

Objective function (3.7) of this study is to minimize the total cost of distribution of the entire vehicle. Constraint (3.8) ensures that the vehicle may only exit the depot once. Constraint (3.9) ensures the continuity of the routing process and ensures that vehicles leaving the depot will return to the depot. Constraint (3.10) ensures that no vehicle returns to the previous point already visited. Constraint (3.11) States each consumer can be visited by multiple vehicles (split delivery). Constraint (3.12) ensures there is no loop process at any point. Constraint (3.13) ensures that one compartment can contain only one type of product. Constraint (3.14) states that the number of products allocated per vehicle does not exceed the capacity of the vehicle itself, in this case the number of compartments. Constraint (3.15) states that the amount of product allocated must be equal to the amount of demand at each point. Constraint (3.16) states that the product is delivered to the consumer by the same vehicle according to the quantity of the product (demand). Constraints (3.17) and (3.18) define binary variables. Constraint (3.19) defines a non-negative variable.

4. Data Collection

Data collection is one of the most important stages in a study, since the decisions taken should be in accordance with the needs of the company. The data collected is divided into two types, primary and secondary. Primary data type is the main data obtained directly from Boyolali Fuel Terminal, while secondary data is data obtained from relevant sources such as websites and books. Data in this study can be seen in Table 1.

Table 1. List of Research Data Requirements

Data	Unit	Data Source	Application
Daily demand	KL	Boyolali Fuel Terminal	Determination of proposed route of fuel distribution at Boyolali Fuel Terminal
Gas station location	-	Boyolali Fuel Terminal	
Distance	km	Boyolali Fuel Terminal	
Vehicle capacity	KL	Boyolali Fuel Terminal	
Fuel cost	IDR/liter	Website Lifepal (Ira 2022)	Calculation of distribution costs
Cost of carbon emissions	IDR/kgCO_2	Official Website of the Ministry of Finance, Republic of Indonesia/*Website Opini Kemenkeu* (Rinaldi 2021)	
Fuel consumption	liter/km	Lean and Green Supply Chain Management (Karagul et al. 2019)	
Emission factor	kgCO_2/ liter of fuel	Technical Basis of Calculating Greenhouse Gas Emission Baseline for Energy Sector/*Pedoman Teknis Perhitungan Baseline Emisi gas Rumah Kaca Sektor Berbasis Energi* (Zacky et al. 2014)	

The followings are additional data needed to complete the calculation:

1) Distribution costs for this study were obtained from the sum of the costs fuel consumption and carbon emission costs are then multiplied by vehicle mileage for each cluster.
2) Diesel fuel cost for the tank truck is IDR 5,150/Liter and fuel consumption for trucks per km is 0.3 liters. Meanwhile, the cost of carbon emissions is IDR 30/kgCO_2 with the emission factor for the type of diesel fuel is 2.2 kgCO_2/Liter of fuel. So that the obtained distribution costs of IDR 1,546.8/km.
3) The calculation of distance (in km) between Fuel Terminal and each gas station and one gas station to another for each cluster is done using Haversine method after acquiring each point's latitude and longitude.

5. Results and Discussion

5.1 Numerical Results

1) Clustering

In the clustering process has been done verification and validation of the model used to ensure the model used is true can run as expected. Recapitulation of clustering results can be seen in the Table 2.

Table 2. Cluster Recapitulation

Cluster	**Gas station point**
1	T1
2	T2, T3
3	T4, T29, T30, T31, T32, T33, T34, T35, T36, T45
4	T5, T6, T10
5	T7, T8, T9
6	T11, T12, T14, T15, T16, T17, T18, T19, T20, T21, T22, T23, T44
7	T13, T24, T25, T26, T27, T28
8	T37, T38, T39, T41, T42, T46
9	T40, T43, T47

There are 9 clusters with different number of gas stations in each cluster. This difference occurs because in P-Median clustering, there is no limit to the number of points each cluster must be the same and the purpose of this clustering is to minimize the distance between points, so that no matter how many points in each cluster as long as it is the best result from all possible combination.

2) **Distribution Routes**
A summary of the route, compartment usage, total distance, and total cost of each cluster can be seen in Table 3 with information in the Route column, for numbers 1 to 47 is the point of each gas station and 0 is TBBM Boyolali, while the Compartment column describes the allocation of each type of product into each compartment consisting of compartments C1, C2, C3, plus C4 (for several types of vehicle) and product types 1 (diesel fuel), 2 (low-grade gasoline), 3 (mid-grade gasoline), and 4 (high-grade gasoline), while the letter x in column about compartments indicates that the compartment is empty during distribution, and the symbol dash (-) indicates that the compartments don't exist, or the tank truck has less number of compartments since each compartment consists of 8 KL of fuel, in comparison to the 32 KL tank trucks being used.

Table 3. Recapitulation of the Optimal Solution for Each Cluster

<table>
<tr><th rowspan="2">Cluster</th><th rowspan="2">Scenarios</th><th rowspan="2">Route</th><th rowspan="2">Tank Size (KL)</th><th colspan="4">Compartments Allocation</th><th rowspan="2">Number of Truck Use</th><th rowspan="2">Total Distance (km)</th><th rowspan="2">Total Cost (IDR)</th></tr>
<tr><th>C1</th><th>C2</th><th>C3</th><th>C4</th></tr>
<tr><td rowspan="2">1</td><td>Existing</td><td>0 – 1 – 0</td><td>32</td><td>1</td><td>3</td><td>4</td><td>x</td><td>1</td><td>174</td><td>272,275.20</td></tr>
<tr><td>New</td><td>0 – 1 – 0</td><td>24</td><td>1</td><td>3</td><td>4</td><td>-</td><td>1</td><td>174</td><td>272,275.20</td></tr>
<tr><td rowspan="5">2</td><td rowspan="2">Existing</td><td>0 – 2 – 0</td><td>32</td><td>1</td><td>3</td><td>4</td><td>x</td><td rowspan="2">2</td><td rowspan="2">306</td><td rowspan="2">478,820.80</td></tr>
<tr><td>0 – 3 – 0</td><td>32</td><td>1</td><td>1</td><td>3</td><td>4</td></tr>
<tr><td rowspan="3">New</td><td>0 – 2 – 0</td><td>24</td><td>1</td><td>3</td><td>4</td><td>-</td><td rowspan="3">3</td><td rowspan="3">456</td><td rowspan="3">713,548.80</td></tr>
<tr><td>0 – 3 – 0</td><td>24</td><td>1</td><td>1</td><td>x</td><td>-</td></tr>
<tr><td>0 – 3 – 0</td><td>24</td><td>3</td><td>4</td><td>3</td><td>-</td></tr>
<tr><td rowspan="12">3</td><td rowspan="10">Existing</td><td>0 – 4 – 0</td><td>32</td><td>1</td><td>1</td><td>3</td><td>4</td><td rowspan="10">8</td><td rowspan="10">1,534</td><td rowspan="10">2,400,403.20</td></tr>
<tr><td>0 – 29 – 0</td><td>32</td><td>3</td><td>3</td><td>x</td><td>x</td></tr>
<tr><td>0 – 30 – 0</td><td>32</td><td>3</td><td>3</td><td>x</td><td>x</td></tr>
<tr><td>0 – 31 – 0</td><td>24</td><td>3</td><td>x</td><td>x</td><td>-</td></tr>
<tr><td>0 – 32 – 0</td><td>24</td><td>3</td><td>x</td><td>x</td><td>-</td></tr>
<tr><td>0 – 33 – 0</td><td>24</td><td>3</td><td>x</td><td>x</td><td>-</td></tr>
<tr><td>0 – 34 – 0</td><td>32</td><td>3</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>0 – 35 – 0</td><td>32</td><td>3</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>0 – 36 – 0</td><td>24</td><td>3</td><td>x</td><td>x</td><td>-</td></tr>
<tr><td>0 – 45 – 0</td><td>16</td><td>3</td><td>x</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">New</td><td>0 – 4 – 45 – 36 – 0</td><td>24</td><td>4</td><td>3</td><td>3</td><td>-</td><td rowspan="2">5</td><td rowspan="2">795</td><td rowspan="2">1,244,016.00</td></tr>
<tr><td>0 – 4 – 0</td><td>24</td><td>1</td><td>1</td><td>3</td><td>-</td></tr>
</table>

Cluster	Scenarios	Route	Tank Size (KL)	Compartments Allocation				Number of Truck Use	Total Distance (km)	Total Cost (IDR)
				C1	C2	C3	C4			
		0 – 30 – 31 – 0	24	3	3	3	-			
		0 – 33 – 35 – 32 – 0	24	3	3	3	-			
		0 – 34 – 29 – 0	24	3	3	3	-			
4	Existing	0 – 5 – 0	32	1	1	3	4	4	468	732,326.4
		0 – 6 – 0	32	1	1	3	4			
		0 – 10 - 0	32	1	3	3	4			
	New	0 – 5 – 0	24	4	1	1	-	5	777	1,215,849.60
		0 – 5 – 0	24	3	3	x	-			
		0 – 6 – 0	24	4	1	3	-			
		0 – 10 – 0	24	1	3	3	-			
		0 – 6 – 10 – 0	24	3	4	1	-			
5	Existing	0 – 7 – 0	16	3	4	x	-	3	464	726,067.2
		0 – 8 – 0	32	1	3	4	x			
		0 – 9 – 0	24	1	3	4	-			
	New	0 – 7 – 0	16	3	4	-	-	3	464	726,067.2
		0 – 8 – 0	32	1	3	4	-			
		0 – 9 – 0	24	1	3	4	-			
6	Existing	0 – 11 – 0	32	1	1	3	x	11	1,560	3,254,784.00
		0 – 12 – 0	32	2	3	x	x			
		0 – 14 – 0	32	3	3	x	x			
		0 – 15 – 0	32	3	x	x	x			
		0 – 16 – 0	32	3	x	x	x			
		0 – 17 – 0	32	2	x	x	x			
		0 – 18 – 0	24	3	x	x	-			
		0 – 20 – 0	32	3	x	x	x			
		0 – 21 – 0	32	3	x	x	x			
		0 – 22 – 0	32	2	x	x	x			
		0 – 23 – 0	32	2	x	x	x			
		0 – 44 – 0	24	3	x	x	-			
	New	0 – 12 – 20 – 0	24	3	2	3	-	6	1,191	1,863,676.80
		0 – 11 – 0	24	1	1	3	-			
		0 – 14 – 17 – 0	24	2	3	3	-			
		0 – 21 – 15 – 18 – 0	24	3	3	3	-			
		0 – 16 – 19 – 23 – 0	24	3	3	2	-			
		0 – 22 – 44 – 0	24	3	3	x	-			
7	Existing	0 – 13 – 0	32	3	x	x	x	6	1,024	1,602,355.20
		0 – 24 – 0	32	3	3	x	x			
		0 – 25 – 0	32	3	3	x	x			
		0 – 26 – 0	32	3	x	x	x			
		0 – 27 – 0	32	3	3	x	x			
		0 – 28 – 0	32	3	3	x	x			
	New	0 – 28 – 0	24	3	3	x	-	4	693	1,084,406.40
		0 – 13- 26 – 25 – 0	24	3	3	3	-			
		0 – 24 – 0	24	3	3	x	-			
		0 – 27 – 25 – 0	24	3	3	3	-			
8	Existing	0 – 37 – 0	32	2	3	3	4	6	1,040	1,605,484.80
		0 – 38 – 0	32	3	3	x	x			
		0 – 39 – 0	24	1	3	4	-			
		0 – 41 – 0	16	1	3	-	-			
		0 – 42 – 0	24	1	1	3	-			
		0 – 46 – 0	24	4	x	x	-			

Cluster	Scenarios	Route	Tank Size (KL)	Compartments Allocation				Number of Truck Use	Total Distance (km)	Total Cost (IDR)
				C1	C2	C3	C4			
	New	0 – 37 – 0	24	2	3	4	-	5	888	1,389,542.00
		0 – 38 – 41 – 0	24	1	4	3	-			
		0 – 41 – 46 – 27 – 0	24	3	1	4	-			
		0 – 42 – 0	24	1	1	3	-			
		0 – 39 – 0	24	4	1	3	-			
9	Existing	0 – 40 – 0	32	3	3	4	-	3	636	995,212.80
		0 – 43 – 0	16	4	x	-	-			
		0 – 47 – 0	16	4	x	-	-			
	New	0 – 40 – 0	24	3	3	4	-	2	428	669,734.40
		0 – 47 – 43 – 0	24	4	4	x	-			

Based on the results shown in tables 3, the use of clustering and routing optimization successfully produces the reduction of total use of trucks, total distance travelled, as well as the total distribution costs (including the emission cost). Using only the 24 KL trucks instead of 16, 24, and 32 KL capacity of tank trucks can simplify the scheduling process and reduce the total number of empty compartments that exist for fuel distribution in Zone 3.

5.2 Graphical Result

The results of clustering are then mapped into My Maps according to the cluster to be able to find out the grouping of gas stations in each cluster as shown in the Figure. 3. The gas station point with red color is the cluster 1, the yellow one is cluster 2, then the green ones are in cluster 3, the blue gas stations are in cluster 4, the brown ones are cluster 5, the black points describe gas stations in cluster 6, the purple ones are in cluster 7, the grey ones are in cluster 8, and the last cluster 9 is described in orange.

Figure 3. Cluster Mapping

5.3 Proposed Improvements

The total travel distance of the entire cluster is 5,866 km and the total distribution cost is IDR 9,179,116.80, while in the existing conditions the total mileage of all points is 8,124 km and the total cost of distribution is IDR 12,712,435.20 as shown in Table 14. Optimization results of this study with the existence of some limitations and assumptions used impact on distribution costs with a decrease of 28%, where distribution costs only consider the cost of vehicle fuel consumption and carbon emission costs. The difference in cost and distance between the optimization results and existing conditions is influenced by the number of tank trucks used in fuel distribution, the optimization results obtained 34 tank trucks to serve 47 gas station points, while the existing conditions applies single-destination method, so the number of tank trucks used is in accordance with the number of gas stations, which is 47.

Table 4. Cost and Distance Comparison

	Optimized (cluster-route)	***Existing***
Distance	5,866 km	8,124 km
Cost	IDR 9,179,116.80	IDR 12,712,435.20
Number of Vehicles	34	47

The decrease in distance and distribution costs by 28% can be used as an input for Boyolali Fuel Terminal to cluster the distribution points of 47 gas stations located in Zone 3. Thus, the commitment of achieving Sustainable Development Goals (SDGs) can be achieved by starting to consider carbon emissions resulting from the fuel distribution process. The calculation of carbon emissions can be an evaluation for the company to continue developing the optimal distribution routes by not only making deliveries according to order priorities but also starting to consider the total carbon emissions.

5.4 Validations

The validation of the mathematical model used in this study is by sensitivity analysis (Smith et al. 2008). Sensitivity analysis was carried out for one of cluster specifically cluster 5, refers to research conducted by (Fauziah et al., 2020) and (Tanjung et al. 2021) by changing the model parameter values which consist of demand and distribution costs, especially diesel prices. The changing of model parameter values are carried out with a certain percentage for the request, i.e., ±1%, ±5%, and ±10%. As for the price of diesel, model parameter values are made by increasing and decreasing price into IDR 1,000, IDR 2,000, and IDR 3,000.

The increase in demand of 5% to 10% affects the determination of the route selected, so that the total mileage and distribution costs are generated in one cluster is also different, resulting 610 km with a total cost of IDR 954,528. This happens because the increase in demand required additional trucks to deliver products to destination thereby affecting the route and fuel distribution costs. For other changing parameters do not affect the resulting distribution routes and costs because changes in demand do not affect the compartment requirements, so the routes and the resulting costs are fixed (does not change).

The effect of changes in distribution costs used is only the price of diesel fuel, because it is the type of fuel whose price can change from time to time depending on government regulations (Ira, 2022). Parameter change carried out using the increase and decrease in diesel prices for the selected route. After processing the data, the results of changes in diesel prices have no effect on route selection for fuel distribution cost. It is proved that the resulting route for every change in the price of diesel is the same (does not change).

6. Conclusion

This chapter, conclusions are drawn on the research that has been carried out and suggestions for the development of further research related to clustering and vehicle routing problem are carried out.

6.1 Conclusions

The clustering of 47 gas stations was carried out using the P-Median Clustering approach where there were 9 clusters based on the number of districts in Zone 3. Determining the number of gas stations for each cluster based on the closest distance calculation between one gas station with another gas station. Thus, the results obtained for Cluster 1 of 1 gas stations, Cluster 2 of 2 gas stations, cluster 3 of 10 gas stations, Cluster 4 and 5 of 3 gas stations each, cluster 6 of 13 gas stations, cluster 7 and 8 of 6 gas stations each, and cluster 9 of 3 gas stations. The results of cluster distribution at gas station points are then used to determine the optimal distribution route in distributing fuel in Zone 3. Determination of the optimal route from TBBM Boyolali to the destination gas station in Zone 3 using multi compartment vehicles by considering multi product, and split delivery in order to minimize distribution costs using the exact method. Based on the results of data processing and analysis of the results proved that the proposed distribution route with the clustering can provide better results than the existing conditions in terms of distribution costs, but keep in mind that the results obtained is to consider the existence of some limitations and assumptions in the study. The total distribution cost of the entire cluster is IDR 9,179,116.80 while the existing conditions obtained the total distribution cost of IDR 12,712,435.20, thus there is a distribution cost reduction as much as of 28%. The distribution costs in this study only consider the cost of vehicle fuel consumption and carbon emission costs.

6.2 Suggestions

Suggestions for further research on similar topics in the future are as follows:

1) The problems solved can be more adapted to the actual conditions such as considering the cost of tank truck, rental and tank car crew costs, as well as the use of heterogeneous vehicles.
2) Calculation of the distance between points can use methods other than Haversine, such as Euclidean distance or Manhattan distance adapted to the needs of determining the distance.
3) For the VRP variant in the next study not only use the Multi Compartment Vehicle Routing Problem with Split Delivery and Multi Product variant but can be developed by increasing time windows, multi trips, multi period, and stochastic demand.
4) The distribution route problem can be solved using methods other than Exact, that is, approach methods such as heuristics and metaheuristics to be able to solve more complex problems.

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Biography

Millenia Shinta Anggraeni is a fresh graduate of the Logistics Engineering Department, Universitas Pertamina, Indonesia. Born in Kediri, East Java, in the year 2000, Millenia was selected to be one of Universitas Pertamina students under the full scholarship scheme in 2018. She has joined the management of the Logistics Engineering Study Program Student Association as Treasurer in the 2020-2021 period. The achievements she has achieved are Second Runner Up in the Poster Competition and Logistics Case Competition in 2020, and she also received Program Permodalan Kewirausahaan Pemuda 2021 from the Indonesian Ministry of Youth and Sport. She has a great interest in Route Optimization and Warehouse Management Systems. The internship activities that she has conducted include participating in the internship program at PT Unilever Indonesia Tbk in the Supply Chain Department, being an internship student at the Directorate of Student and Alumni Affairs at Pertamina University, especially in Social Media Maintenance, and the internship program at PT Binmed Ecomedika Industri in the Logistics Division.

Osel Nur Tazkiya is a final year student at the Logistics Engineering Study Program, Pertamina University, Indonesia. Academically, she was involved in several supply chain related competitions and conferences with various topics such as smart logistics, route optimization, forecasting and demand planning. Besides that, Osel also took responsibility as a Logistics Planning and Control Practicum Assistant Coordinator at the Logistics Distribution System Laboratory. Those academic understandings were strengthened by her internship experience as a contract and claim intern at PT. Pertamina International Shipping in July-October 2022. There, she was responsible in calculating on hire and off hire claims. She was also an intern in the production planning and inventory control section at PT. WasteforChange Alam Indonesia, handling the forecasting of material sales.

Exga Mawandi is a fresh graduate of Logistics Engineering Department, Universitas Pertamina. As a scholarship awardee, Exga was active in various academic activities, such as being a tutor for various subjects (Calculus, Basic Chemistry, Engineering Mathematics, Engineering Economics, as well as Distribution and Transportation System) and as a laboratory work assistant for Basic Chemistry, as well as being an active staff member for MIRAI UP, the Moslem students' organization at Universitas Pertamina. In August 2021, he completed an internship program at Pertamina International Shipping, a sub-holding company of PT Pertamina (Persero). Exga has huge interest in Operation Research, Maritime Logistics, and Oil and Gas Logistics.

Harummi Sekar Amarilies is a lecturer at Logistics Engineering Department, Universitas Pertamina, Jakarta. She holds a Bachelor of Chemical Engineering degree from Institut Teknologi Sepuluh Nopember and a Master Business Administration from Universitas Gadjah Mada. Prior to joining Universitas Pertamina, Harummi has worked as a project engineer for an engineering, procurement, and construction company. As a lecturer of Logistics Engineering Department, for the past six and a half years Harummi has taught Oil and gas Logistics, Project Management, Procurement System, and Packaging in Logistics.