Capacitated Vehicle Routing Problem Optimization for Bali and Nusa Tenggara Natural Gas Distribution

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Abstract. Utilization of gas as an energy source has become a principal issue in recent years. The Minister of Energy and Mineral Resources of the Republic of Indonesia have a plan to guarantee national energy security and improve the national trade balance, as well as accelerate the use of gas in the electricity sector. The Ministry of Energy and Mineral Resources issued a regulation to conduct the gasification process at 52 power plants in Indonesia through Ministerial Decree No. 13K of 2020. In this study, LNG distribution was designed using the Capacitated Vehicle Routing Problem (CVRP) method to minimize the transportation costs and optimal use of the fleet. The vehicles used have a limited capacity and can supply all demands at nine power plants in the Bali and Nusa Tenggara regions. In the distribution there is also have a Hub which purpose to reduce the distance travelled by a ship. The ships that will be used are Mini LNG-Carrier for the route from the LNG refinery to HUB, LCT ship for the route from HUB to each port near the power plant, and ISO Tank transport truck for the route from the port to the plant. The distribution uses four Vessel 1, and one LCT 300 vessel, with Hubs located in Benoa and Flores, and two Mini LNG-Carriers with a capacity of 15,600 m³ to Benoa and 10,000 m³ to Flores. The total cost for this scenario is US$ 51,398,568, with a minimum sales margin of US$ 2.5 per MMBTU.

1. Introduction
In today's life, electrical energy is one of the primary needs [1]. The Minister of Energy and Mineral Resources of the Republic of Indonesia currently plans to ensure national energy security and improve the national trade balance, as well as accelerate the use of gas in the electric power sector, by reducing the use of HSD (High Speed Diesel) fuel. With this plan, the Ministry of Energy and Mineral Resources has assigned suppliers and construction of LNG (Liquefied Natural Gas) infrastructure to provide electricity. The use of natural gas as a fuel will be more environmentally friendly and cheaper than the price of HSD fuel which has a price above Rp. 7500/liter and the selling price of PLN electricity is still Rp. 1467.28/kWh [2]. In the Bali-Nusra Region, there are already nine PLTG whose needs must be met.

As stipulated by the Ministry of Energy and Mineral Resources No. 13K of 2020 concerning the Assignment of the Implementation of the Supply and Development of Liquefied Natural Gas (LNG) Infrastructure, as well as the Conversion of Oil Fuel Use with Liquefied Natural Gas (LNG) in the...
Provision of Electric Power, PT PERTAMINA (Persero) assigned (Persero) and PT Perusahaan Listrik Negara (Persero) to conduct gasification activities for power plants [3]. These nine power plants were chosen because they are close to each other in terms of the distance between the islands, and the areas of Bali, NTT, and NTB are included in the management area of PT. Pelindo III. With the need for natural gas from nine PLTG, natural gas as fuel must be distributed to nine power plants located in Bali-Nusra. Distribution of gas distribution is done by changing the form of the gas into a liquid called LNG, because in the liquid state the volume of gas that can be carried can be increased and carried by ships to consumers.

![Figure 1. The Location of The Power Plant](image)

From what is shown on the map the distribution of power plants is very wide, therefore clustering is needed to group each generator. K-Mean Cluster is used to group each generator into 2 clusters based on the closest distance criteria [4]. These nine regions are archipelagic regions, Therefore, mini carriers and LCT ships are needed in their distribution. This research is necessary because the distribution of LNG needs to be optimized to get the best scenario to get the best technical and economic feasibility with the object of research, namely small-scale PLTMG in the Bali-Nusra region.

There are several types of VRP described in the study conducted by Suresh et. al as well as approach methods to solve VRP problems [5]. Researchers Lysgaard et al describe a branch-cut-and-price method for solving capacity-based transport cases [6]. CVRP (Capacitated Vehicle Routing Problem) is one of the VRP variants with each vehicle having a limited capacity and the same for all vehicles that must serve requests from depots with a single type of goods from distributors that produce minimum mileage [7]. However, the constraint of Capacitated Vehicle Routing Problem method is the capacity of the ship used for the optimization is limited.

### 2. Method

The research methodology used for the distribution of LNG used is the Capacitated Vehicle Routing Problem method for route formation and K-Mean Clusters used for grouping plant locations. This study provides output in the form of transportation costs from each route. Then the investment costs for each HUB are calculated and the investment costs for each power plant are calculated.

#### 2.1. K-Mean Clusters

K-Means Clusters are used to group the closest locations into two groups out of a total of nine power plants to be distributed by LNG with the formula:

\[
d(x_y, C_c) = \sqrt{(x_n - C_{cx})^2 + (y_n - C_{cy})^2} \quad (1)
\]

\[
D(x_y, C_{c_n}) < D(x_y, C_{c_{n+2}}) \quad (2)
\]
Formula 2 shows if a location can be said to be included in a cluster, that is, by having the closest distance to the initial center point of another cluster.

\[ C_x = \frac{x_1 + x_2 + \cdots + x_n}{n} \quad (3) \]

\[ C_y = \frac{y_1 + y_2 + \cdots + y_n}{n} \quad (4) \]

Formulas 3 and 4 are the calculation of the new center point that will be used as input to calculate the return distance as in formula 1. The calculation from 1 to 4 continues to be repeated until the center point value does not change.

2.2. Capacitated Vehicle Routing Problem

CVRP (Capacitated Vehicle Routing Problem) is a variant of the VRP method where the vehicles used have a limited and the same capacity, for all vehicles that must serve requests from sources with a single type of goods transported, which results in minimum mileage. The LNG distribution problem in this study is included in the Capacitated Vehicle Routed Problem (CVRP) category. LNG ship capacity will be a limitation in LNG transportation problems.

| Power Plant       | Capacity (MW) | LNG Need in a Day (TEUS) |
|-------------------|---------------|--------------------------|
| PLTMG Gilimanuk   | 134           | 18                       |
| MPP Jeranjang     | 50            | 9                        |
| PLTMG Sumbawa     | 50            | 14                       |
| PLTMG Bima        | 50            | 14                       |
| PLTMG Waingapu    | 10            | 3                        |
| PLTMG Flores      | 23            | 4                        |
| PLTMG Maumere     | 40            | 7                        |
| PLTMG Alor        | 10            | 3                        |
| PLTMG Kupang      | 40            | 7                        |

The first step, understand the real problem to be optimized the solution in this case is called the optimization problem [8]. With the main goal of optimization results is to get the minimum cost [9]. The difference in the capacity of the LNG ship used will provide variations in route results and transportation costs. with the equation:

\[ \text{Min} = \sum_{k \in K} \sum_{i \in R} \sum_{j \in R, j \neq i} x_{ijk} s_{ij} c_{ijk} \quad (5) \]

With limitations:

\[ \sum_{i \in R} d_i \sum_{j \in R, j \neq i} x_{ijk} \leq Q, \forall k \in \{1, 2, 3\} \quad (6) \]

Equation 6 shows the limit to ensure the number of requests for receiving terminals served by each ship must be less than or equal to the loading capacity of ships serving that route.

\[ \sum_{k \in K} \sum_{i \in R, j \neq i} x_{ijk} = 1, \forall i = \{1, 2, 3, 4\} \quad (7) \]

\[ \sum_{k \in K} \sum_{i \in R, j \neq i} x_{ijk} = 1, \forall i = \{5, 6, 7\} \quad (8) \]

\[ \sum_{k \in K} \sum_{j \in R, j \neq i} x_{ijk} = 1, \forall j = \{1, 2, 3, 4\} \quad (9) \]

\[ \sum_{k \in K} \sum_{j \in R, j \neq i} x_{ijk} = 1, \forall j = \{5, 6, 7\} \quad (10) \]

The limitation in equation 7 to 10 aims to ensure that each receiving terminal is served exactly once by one ship with a certain capacity.

\[ \sum_{j \in R} x_{0jk} = 1, \forall k = \{1, 2, 3\} \quad (11) \]
\[ \sum_{i \in R} x_{i0k} = 1, \forall k = 1, \{1,2,3\} \] (12)

The limitations in equation 11 and 12 show that each route with a particular ship starts from the HUB then after serving the LNG distribution, the ship returns to the HUB.

\[ \sum_{i \in R, i \neq h} x_{ihk} - \sum_{j \in R, j \neq h} x_{hjk} = 0, \forall h = 1, \forall k = 1, \{1,2,3\} \] (13)

Equation 13 ensures the continuation of the route of LNG distribution, meaning that every ship that finishes serving a receiving terminal will leave the receiving terminal to continue distributing LNG or return to the LNG source.

\[ x_{ijk} \in \{0,1\}, \forall i,j = \{1,2,3,4\}, j = \{5,6,7\}, i,j \in R, i \neq j, \forall k = \{1,2,3\} \] (14)

The Constraint in equation 14 ensures that the decision variables used only use integers, 0 or 1.

The purpose of the problem is to design a vehicle route, one route for a vehicle, so that all consumers are only visited once with a minimum total cost for that route [10].

| Parameter     | Unit | Kapal 1 | LCT 200 | LCT 300 |
|---------------|------|---------|---------|---------|
| Loa           | Meter| 78.1    | 65      | 91.4    |
| B             | Meter| 16      | 14      | 20.8    |
| T             | Meter| 3.5     | 3.3     | 4.5     |
| GT            | Ton  | 1668    | 727     | 2852    |
| Speed         | Knots| 9.5     | 6       | 6       |
| SFOC          | g/kw | 204     | 316.2   | 213.4   |
| Price         | $    | 1,000,000 | 1,350,500 | 1,460,000 |
| Capacity      | TEUS | 54      | 80      | 200     |
| Engine Power  | Kw   | 783     | 448     | 747     |

2.3. Net Present Value (NPV)
Net Present Value (NPV) is commonly used to calculate the return on an investment. So that you know whether the investment value is profitable or vice versa. Here is the formula for calculating NPV:

\[ NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \] (9)

Where Bt is the profit in year t, Ct is the cost incurred in year t, (1+i)t is the discount factor, t is year t, and n is the age of the business.

2.4. Internal Rate of Return (IRR)
Internal Rate of Return (IRR) is used to find out at what interest rate an investment can provide a profit. If the interest rate is more than the IRR, then the investment is better not to continue. Here is the formula for calculating IRR:

\[ IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2} (i_1 - i_2) \] (10)

Where i1 is a discount that produces a positive NPV, i2 is a discount that produces a negative NPV, NPV1 is a positive NPV, and NPV2 is a negative NPV.

3. Results and Discussion
3.1. Clustering and Determination of HUB
The purpose of clustering is to group the near locations of the power plant. Grouping the locations of power plant uses the K-Mean Clusters method which will be divided into two clusters. With the cauteration, the route selection is narrowed down to only one cluster, and in each cluster only one HUB is selected as the destination for LNG supplied from the LNG plant.

**Table 3. Cauteration Results.**

| Location   | Type of Clusters |
|------------|------------------|
| Benoa      | Clusters 1       |
| Jeranjang  | Clusters 1       |
| Sumbawa    | Clusters 1       |
| Bima       | Clusters 1       |
| Waingapu   | Clusters 2       |
| Flores     | Clusters 2       |
| Maumere    | Clusters 2       |
| Alor       | Clusters 2       |
| Kupang     | Clusters 2       |

HUB in each cluster will be selected by comparing the operational costs and capital costs incurred in each alternative HUB.

**Table 4. Facilities Available at The Port HUB.**

| Location   | Port Facilities                        | Draft | Distance | Area of Stockyard ISO Tank |
|------------|----------------------------------------|-------|----------|---------------------------|
| Benoa      | Reach Stacker, Forklift, Spreader       | 10m   | 1,121    | 1383 m2                   |
|            | Reach Stacker, Forklift, Mobile Crane  |       |          |                           |
| Jeranjang  | Forklift, Mobile Crane                 | 7m    | 1,064    | 1425 m2                   |
| Flores     | Reach Stacker, Forklift                | 10m   | 1,005    | 9140 m2                   |
| Maumere    | Reach Stacker, Forklift, Spreader      | 9m    | 1,247    | 12000 m2                  |

3.2. Distribution Route optimization

The optimization of the LNG distribution route is strongly influenced by the type of ship and the destination route that must be reached by the ship. The capacity parameter of a ship will limit the number of ports that will be served by a ship. The greater the capacity of the ship, the greater the number of ports or receiving terminals that can be served. This also applies to the distribution of LNG. In optimizing the LNG distribution route, ship size variations will be conducted which will provide different LNG distribution routes. Optimization of the LNG distribution route using the CVRP method which considers the variables of ship capacity, ship service speed, shipping distance, transportation costs, and power generation demand.

Alternative routes are formed in each cluster by calculating all routes for each receiving terminal location that combines variations in the size of each ship, then from each alternative route in each ship combination optimization will be conducted to get the cheapest transportation costs from each route and variations boat.

The results of the optimization of each HUB can be seen in **Table 5 to Table 8.**
### Table 5. Optimization of The Benoa and Flores Hub Routes.

| Location | Route                                      | Distance (Mil) | Time Sailing | Ship Type |
|----------|--------------------------------------------|----------------|--------------|-----------|
| Benoa    | Benoa-Bima-Benoa                           | 451.6          | 2.6 day      | Kapal 1   |
| Benoa    | Benoa-Jeranjang-Sumbawa-Benoa              | 302.5          | 3.2 day      | LCT 300   |
| Flores   | Flores-Waingapu-Kupang-Flores              | 697.5          | 4.2 day      | Kapal 1   |
| Flores   | Flores-Maumere-Alor-Flores                 | 614.3          | 3.8 day      | Kapal 1   |

### Table 6. Optimization of The Benoa and Maumere Hub Routes.

| Location | Route                                      | Distance (Mil) | Time Sailing | Ship Type |
|----------|--------------------------------------------|----------------|--------------|-----------|
| Benoa    | Benoa-Bima-Benoa                           | 451.6          | 2.6 day      | Kapal 1   |
| Benoa    | Benoa-Jeranjang-Sumbawa-Benoa              | 302.5          | 3.2 day      | LCT 300   |
| Maumere  | Maumere-Waingapu-Flores-Maumere            | 599.4          | 3.8 day      | Kapal 1   |
| Maumere  | Maumere-Alor-Kupang-Maumere                | 572.9          | 3.7 day      | Kapal 1   |

### Table 7. Optimization of The Jeranjang and Flores Hub Routes.

| Location | Route                                      | Distance (Mil) | Time Sailing | Ship Type |
|----------|--------------------------------------------|----------------|--------------|-----------|
| Jeranjang| Jeranjang-Gilimanuk-Jeranjang              | 444.0          | 1.6 day      | Kapal 1   |
| Jeranjang| Jeranjang-Sumbawa-Bima-Jeranjang           | 768.0          | 3.9 day      | LCT 300   |
| Flores   | Flores-Waingapu-Kupang-Flores              | 1316           | 4.2 day      | Kapal 1   |
| Flores   | Flores-Maumere-Alor-Flores                 | 1159           | 3.8 day      | Kapal 1   |

### Table 8. Optimization of The Jeranjang and Maumere Hub Routes.

| Location | Route                                      | Distance (Mil) | Time Sailing | Ship Type |
|----------|--------------------------------------------|----------------|--------------|-----------|
| Jeranjang| Jeranjang-Gilimanuk-Jeranjang              | 444.0          | 1.6 day      | Kapal 1   |
| Jeranjang| Jeranjang-Sumbawa-Bima-Jeranjang           | 768.0          | 3.9 day      | LCT 300   |
| Maumere  | Maumere-Waingapu-Flores-Maumere            | 599.4          | 3.8 day      | Kapal 1   |
| Maumere  | Maumere-Alor-Kupang-Maumere                | 572.9          | 3.7 day      | Kapal 1   |
From the optimization results on each HUB, four alternative routes are obtained, and the lowest cost of the four alternative routes is located at HUB which is in Benoa and Flores with an operational cost of $25,941.114.

3.3. Economic Analysis

The economic analysis conducted in this study only includes financial feasibility parameters related to costs incurred in LNG distribution activities using LNG ship transportation and investment in LNG receiving terminal facilities. Economic analysis based on financial feasibility parameters is conducted using the assumption of income received from wages for payment of LNG transportation services from the source to the power plant which will become the margin of the LNG selling price. Practically, this selling price margin can be analogized as a cost that must be paid by the gas buyer to the LNG supply company which buys LNG from the LNG producer and then sends it to the gas buyer.

In the economic analysis conducted, there are two variables that are considered in the economic calculation. The two variables are Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). While the parameters or criteria for financial feasibility used in this economic analysis are the Internal Rate of Return (IRR), Payback Periods (PP), and Net Present Value (NPV).

With investment planning in each HUB and power plant between LNG Storage Tanks, LNG Filling Stations, and Jetties. Investment in power plants requires regasification facilities and other safety devices that support the regasification process. In Table 9 we can see a comparison of the investment costs of each alternative HUB.

Judging from the results of the calculation of investment cost planning for HUB and power plants, it can be seen in Table 9 that the cheapest investment costs are in HUB Benoa and Flores, therefore for the next calculation, namely NPV, PP, and IRR will be conducted at HUB located in Benoa and Flores.

Table 9. Investing in the HUB and Power Plants.

| Hub Location   | Total Investment Cost |
|----------------|-----------------------|
| Benoa-Flores   | $25,607,614           |
| Benoa-Maumere  | $26,958,900           |
| Jeranjang-Flores | $27,434,690      |
| Jeranjang-Maumere | $28,785,976    |

3.4. Economic Studies

Revenue referred to in this research is income derived from transportation services and LNG regasification until it can be used as fuel by machines for power generation purposes. Profits are obtained from the difference between the LNG purchase price and the LNG selling price or it can be called LNG sales margin. LNG sales unit is unit of money per million British thermal unit (MMBtu) or in this study $/MMBtu. MMBTU is a unit of heat energy produced by natural gas per unit volume.

To determine the sensitivity of the LNG sales margin at the end of the 10th year period, a variation of the LNG sales price margin was conducted. This study uses five margin scales from the lowest margin of US$ 1.5 to US$ 3.5 per MMBtu with an increase of US$ 0.5. The sales margin is then multiplied by the amount of LNG sold in one year to obtain revenue per sales margin. The income obtained is certainly different for each variation in the sales margin. This different revenue will affect the payback period. Payback period (PP) is the period of return-on-investment capital that has been issued. The total revenue calculation for the six LNG sales margins can be seen in Table 10.
Table 10. Revenue with Sales Margin Variations.

| Total Gas Demand | MMBTU Per Day | 33,810 |
|------------------|---------------|--------|
| MMBTU Per year   | 12,340,650    |        |

Revenue Margin Income

| Margin | Income       |
|--------|--------------|
| $1.50  | $18,510,975  |
| $2.00  | $24,681,300  |
| $2.50  | $30,851,625  |
| $3.00  | $37,021,950  |
| $3.50  | $43,192,275  |

For the average income, each year is considered constant because the consumers of gas here are power plants, so the gas demand is considered the same every year.

The input data needed to calculate the Net Present Value, Internal Rate of Return, and Payback Periods include the total investment costs in HUB and each plant, the total operational costs used to distribute LNG from the LNG plant to each plant, annual depreciation, and the duration of the contract which can be seen in Table 11.

Table 11. Economic Analysis Input Data.

| Total Investment | US$       |
|------------------|-----------|
| Operating Costs  | US$       |
| Contract Duration| Year      |
| Annual Depreciation| US$     |

Total Investment US$ $25,607,614
Operating Costs US$ $25,941,114
Contract Duration Year 10
Annual Depreciation US$ $896,266

With the input data in Table 11, the calculation of the Net Present Value, Internal Rate of Return, and Payback Periods can be done by getting results for a minimum sales margin of US$ 2.5 per MMBtu. Assuming an investment period of 10 years, with a sales margin of US$ 2.5 per MMBtu and an income of US$ 24,681,300 per year, the investment will return on investment (GDP) after 6 years of operation. In addition to the payback period, other parameter values if the sales margin is US$ 2.5 per MMBtu include the Internal Rate of Return (IRR) of 10.4%, and the Net Present Value (NPV) after 10 years of US$ 365,746. The results for each margin can be seen in Table 12.

Table 12. Economic Study Calculation Results.

| Margin (USD) | IRR  | PP (Year) | NPV            |
|--------------|------|-----------|----------------|
| $1.50        | -    | -         | -$56,505,218   |
| $2.00        | -    | -         | -$28,069,736   |
| $2.50        | 10.4%| 6.1       | $365,746       |
| $3.00        | 32.5%| 2.9       | $28,801,228    |
| $3.50        | 51.9%| 1.9       | $57,236,710    |

4. Conclusion

Results of Optimization of LNG Distribution using the CVRP Method with the objective function of transportation costs at least two ships with a capacity of 54 TEUs and 200 TEUs that will serve two route clusters. in Clusters 1 with HUB located in Benoa were served by ships with a capacity of 54 TEUs on the Benoa-Bima-Benoa route with a total annual transportation cost of US $1,956,330 and ships with a size of 200 TEUs serving the Benoa-Jeranjang-Sumbawa-Benoa route with a total transportation cost per year is US$ 2,565,473. For Clusters 2 with HUB located in Flores it is served by two ships with a capacity of 54 Teus with the Flores-Waingapu-Kupang-Flores route with a total
transportation cost per year of US $ 1,896,413 and the Flores-Maumere-Alor-Flores route with a total transportation cost per year of US $ 1,885,218.

To accommodate the distribution of LNG to 9 PLTMG, 9 receiving terminal facilities must be built in Gilimanuk, Jeranjang, Sumbawa, Bima, Waingapu, Flores, Maumere, Alor, and Kupang.

Economic analysis shows that with a total CAPEX of US $ 25,607,614 and annual OPEX of US $ 25,941,114, the minimum LNG sales price margin is US $ 2.5 per MMBtu so that the distribution of LNG to power plants in Bali and Nusa Tenggara can be categorized as financially feasible with payback period of 6 years, IRR 10.4% and a positive NPV of US$ 365,746 at the end of year 10.

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