LNG Distribution Optimization using Set Partitioning Problem Method

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Abstract. The Indonesian government's commitment to increase the use of gas for domestic demand, by issuing the Decree of the Minister of Energy and Mineral Resources Number 13K/13/MEM/2020 concerning the Assignment of the Implementation of the Supply and Development of LNG Infrastructure and the Gasification 52 power plants in Indonesia. Therefore, a study on the supply chain design that can support the gasification process of the 52 power plants is crucial. Power plant data is imperative to identify receiving terminals which are then grouped into 8 clusters using the K-Means method. The design will use operating LNG refineries, which will then go to the hub for each cluster. Considering the feasibility factor of the receiving terminal and using the center of gravity method carries the determination of the hub. Considering the investment and operational costs form the feasible route as the most optimal by using the Set Partitioning Problem (SPP) method. The optimization considers several types of ships with six different sizes. The total investment cost required was $107,815,749.11, and the operational cost was $68,993,709.11. The results of the economic analysis indicate the distribution will reach a payback period within 10 years if gas sales use a margin of 1.75 USD.

1. Introduction
Electricity consumption in Indonesia has quite a lot of natural gas reserves with a value as of January 2017 reaching 142.72 TSCF, of which 100.36 TSCF is a proven reserve and 42.36 TSCF is a potential reserve. Compared to proven oil reserves which are currently in the range of 3.17 billion barrels. With a production of around 800 thousand barrels per day. Accordingly, to the reserves data in the next ten years, Indonesia's oil reserves will run out if the new reserves are not found (ESDM, 2017).

| Reserves       | Already In Production Proven | Already In Production Potential | Amount |
|----------------|-------------------------------|---------------------------------|--------|
| Oil (MMSTB)    | 2763.46                       | 3806.29                         | 7534.9 |
| Gas (TSCF)     | 31.74                         | 16.62                           | 142.73 |
| a. Associated  | 3.42                          | 2.67                            | 7.17   |
| b. Non Associated | 28.32                       | 13.95                           | 135.55 |
The Indonesian government's commitment is solid to optimize the use of natural gas to the domestic needs by carrying out the initial stages. Namely, the preparation of several legal umbrellas, one of which is the Decree of the Minister of Energy and Mineral Resources Number 13K/13/MEM/2020 concerning the Assignment of the Implementation of the Supply and Development of LNG Infrastructure and the Conversion of the Use of Fuel with LNG in electricity supply. The provision of electricity referred to above is 52 power plants that use fuel oil which is spread throughout Indonesia.

A total of 52 power plants in the Decree of the Minister of Energy and Mineral Resources 13K of 2020, the government assigned PT. Pertamina (Persero) to provide supply and construction of LNG liquefied natural gas infrastructure which will then cooperate with the electricity supply company PT. PLN (Persero). To provide this supply chain, the government gave Pertamina (Persero) an obligation to produce a lower cost of electricity supply compared to using high-speed diesel fuel.

With the change in power plant's fuel from oil fuel to liquefied natural gas fuel, there will be an increase in domestic liquefied natural gas demand. Therefore, analysis and design related to the supply chain are vital because of the new demand for liquefied natural gas in power plants to be gasified. The supply chain of liquefied natural gas at the 52 power plants needs design to obtain a supply chain with the best route and considerable economic analysis.

Considering the optimal route and ship selection require several stages of analysis. K-Means method will cluster the power plant data to facilitate the distribution of lng to each power plant. K-Means is a non-hierarchical data clustering method that attempts to partition existing data into one or more clusters/groups (Daniati and Nugroho 2016). In this study, the reason behind using K-Means clustering is that the K-Means method was an easy method to use and its ability to cluster large data (Ratnawati et al. 2014). After forming the cluster, a hub is selected and validated for each cluster using the center of gravity method and the hub feasibility factor. With consideration of operational costs and investment, the data formed will be optimized using the set partitioning problem method.

The Set Partitioning modeling's first application was to model assembly lines for tool balancing (Salverson 1995), emergency facilities (Revelle, Marks, and Liebman, 1970). It then progressed towards using models for transportation such as schedule trucking (Pierce 1968); Trains (Charles and Miller 1956) ships (Fisher and Rosenwein 1989). Then developed for each line of ship transportation in the following years. (Ronen 1995) developed a product delivery/distribution system using an elastic set partitioning model by considering all feasible schedules for each ship. The two models developed by (Fisher and Rosenwein 1989; Ronen 1995) allow the user to set limitations such as the maximum time allotted for loading or the maximum time to sail in ballast conditions. These constraints are necessary to limit the number of feasible schedules then later selected to obtain the optimal solution.

To clarify the research, the data of gas demand to be used is attached to the Minister of Energy and Mineral Resources Decree Number 13K/13/MEM/2020 and the ship used in the distribution process is a conventional LNG vessel. So, the results of this study are in the form of choosing the optimal ship and route as a comparison for studies conducted by business entities assigned by the Indonesian government.

2. Methodology

This study will carry several stages of analysis to obtain the optimum route and ship selection. Some of the stages include data collection, clustering, hub selection, optimization, and economic analysis.

2.1. Data Collection

In this study, the data needed are the gas demand for each power plant, the actual location of the power plant, the nearest jetty or port facility for the receiving terminal, data on conventional lng ships, LNG refineries, and available facilities.

2.2. Receiving LNG Terminal Clustering with K-Means Method

Using the K-Means method for clustering, the data needed is the coordinates of the receiving terminal in the form of Latitude and Longitude numbers which are X and Y points. In the K-means method, k means the number of clusters formed. Thus, in this method, the determination of the number of clusters
that will form is the earliest stage. Determination of the number of clusters without a specific selection method, but in this study, the number of clusters is determined based on an objective assessment of the distribution of the mapped power plants. We can objectively determine the distribution of power plants to be 8 clusters. After determining the centroid value, we will calculate the distance between power plants and the selected centroid. This distance calculation uses the euclidean distance formula, as follows:

\[ D(i,j) = \sqrt{(x_{1i} - x_{1j})^2 + (x_{2i} - x_{2j})^2 + (x_{3i} - x_{3j})^2 + \cdots + (x_{ki} - x_{kj})^2} \]  

(1)

\[ D(i,j) = \text{distance } i \text{ to centroid in Cluster } j \]
\[ x_{ki} = \text{data } i \text{ in order } k. \]
\[ x_{kj} = \text{centroid } j \text{ in order } k. \]

After measuring the distance and determining the results of the power plant data entering which cluster it will be iterated over the location of the centroid which is repeated on the distance measurement again until the existing data is no longer in a changed condition.

2.3. Hub Selection Analysis with Center of Gravity Method

The center of gravity method is a quantitative method in finding the location of the distribution center that will minimize distribution costs. This method takes into account the location of the market, the volume of goods shipped to that market, and the cost of transportation (Heizer & Render, 2014). Analysis of the selection of hubs using this method is as a comparison to the selection of hubs based on the feasibility factor of the previous hub. The data used in this method is the coordinate data of the receiving terminal and the demand from the power plant. The data is then processed according to the center of gravity method whose results or outputs are selected coordinates. These coordinates become data for selecting the hub by identifying the distance from the hub location resulting from this method to the receiving terminal in each cluster. the following is the formula used to determine the results of the hub selection based on the center of gravity method:

\[ C_x = \frac{\sum d_{ix}w_i}{\sum w_i} \]  

(2)

\[ C_y = \frac{\sum d_{iy}w_i}{\sum w_i} \]  

(3)

\[ C_x : \text{the x-coordinate of the starting location} \]
\[ C_y : \text{the y-coordinate of the starting location} \]
\[ d_{ix} : \text{x-coordinate of location } i \]
\[ d_{iy} : \text{y-coordinate of location } i \]
\[ w_i : \text{demand of Power Plants} \]

2.4. Hub Selection Analysis Based on Hub Feasibility Factors
2.4.1. Low investment costs.
Investment costs will be low if the hub used is a facility that is already available, where maximizing existing facilities means not creating new facilities that require investment costs and then utilizing available facilities and being able to be used as a Hub.

2.4.2. Low Transportation Costs
Low transportation costs are directly related to fuel consumption, where the longer the distance traveled, the higher the fuel consumption. Minimizing the shipping distance can accomplish the selection of low transportation cost factors. Because in the condition of sailing in one road trip, the ship will return to the point of origin, so placing the hub in the middle position in the series of receiving terminals to be supplied will reduce the voyage distance. Finally, the consideration of the distance from the hub to each receiving terminal will have an effect.

2.4.3. Supply of LNG to power plants is effective.
We can see the effectiveness of supply to power plants in meeting demand from existing power plants. When meeting a greater demand, the LNG supply is said to be effective. Therefore, the factor in choosing the hub will be using the demand consideration

2.4.4. Geographical Conditions Hub.
In the distribution process, the hub is used to store LNG which will be distributed to each receiving terminal. Under these conditions, the hub is required to receive LNG in a capacity that covers the entire cluster so that to meet the demand in one cluster, ships with large capacity and size will be needed to carry out distribution and unloading processes at the receiving terminal which will become the hub. The large size of the ship results in the need for geographical factors to be used for consideration so that the ship can enter the hub area. Geographical conditions include not only the depth of the sea but also the type of water. If the receiving terminal has river waters, it will be less likely to be used as a hub because of the small shipping lanes, while there will be several ships going in and out of the area.

2.4.5. Shipping facilities and networks at the hub.
The facilities in question are not only limited to facilities related to loading-unloading LNG, but also facilities related to ports related to storage facilities that will be used as an LNG tank construction area. The shipping network and business network will show that the selected hub is integrated into a business network and whether the hub already has a shipping network where ships have stopped at the selected hub location.
2.5. Determining Transportation Cost Variables

The data collected regarding the location of the receiving terminal will be reduced to distance. The distribution process from the refinery to the hub then the hub to each receiving terminal has transportation costs that can be derived from the distance from the starting point, namely the refinery to the endpoint at the receiving terminal. Calculating transportation costs by directly calculating ship shipping costs will be determined by the roundtrip time, namely, the time spent by the ship to distribute LNG will be influenced by the distance that determines the sailing time, then sailing time will affect fuel consumption.

The main variables for calculating transportation costs are LNG refineries, hubs, LNG ships, and final receiving terminals. LNG refineries and Hubs will be categorized as supply units, LNG ships are categorized as transportation units as LNG carriers from the refinery to the hub and the hub to the receiving terminal. Then the final receiving terminal will be categorized as a demand unit. From these main variables, it will be derived in this study, namely the distance between supply units and demand units, fuel costs, port costs, ship charter costs. Then from the roundtrip time will be determined the cost for storage. These data will be collected and will produce output in the form of total transportation costs.

2.5.1. Ship Charter Rate

In general, there are three charter schemes, including voyage charters, namely the system of chartering vessels on the basis of transportation routes or the number of ships traveling by the shipowner who bears all costs except loading and unloading costs, time charter is a system of renting ships for a certain period of time with the shipowner, remain responsible for operational risks, and Bareboat charter is a ship rental system where the shipowner submits the ship in an empty condition and receives a rental fee. The cost of renting a ship in this study is calculated within one year, the data available is data on boat rentals per day which will be multiplied in 365 days.

2.5.2. Voyage Cost

Shipping costs are costs incurred to operate to bring goods from the starting point to the destination point. The derivative variables that will have an effect here are fuel costs and port costs.

\[
\text{Voyage Cost} = \text{Fuel Cost} + \text{Port Cost}
\]  
(4)

Fuel costs will be calculated by multiplying the total time the ship operates in 1 trip (Roundtrip) and the price of fuel. Fuel prices will be compiled based on regions in Indonesia, namely Region 1 (Sumatra, Java, Bali), Region 2 (Kalimantan), Region 3 (Sulawesi, NTB), Region 4 (Maluku, Papua, NTT).

\[
\text{Fuel Cost} = \text{Operational Time} \times \text{Fuel Price}
\]  
(5)

The total operating time of the ship is the sum of the time the ship sails at sea (Sea Time), the time the ship operates in the port (Port Time), and the loading-unloading time.

\[
\text{Operational Time} = \text{Sea Time} + \text{Port Time} + \text{Loading Unloading}
\]  
(6)

The time the ship sails at sea (sea time) are the result of the total distance that the ship must travel to sail from the starting point back to the starting point (Distance) divided by the ship's service speed (Vs).

\[
\text{Sea Time} = \frac{\text{Distance}}{\text{Vs}}
\]  
(7)

The time the ship sails in the port (port time) is the result of the distance from the port area. We can assume this to be 16 Nautical Miles divided by the speed of the ship in the port, which is 4 knots with a
fixed value of the time the ship sails in the port (port time) is 2 hours for each receiving terminal that on a visit. Then the loading-unloading time is assumed to be the result of dividing the ship's capacity ($M_k$) with the ship's pumping capacity ($Q_k$).

$$\text{Loading-Unloading Time} = \frac{M_k}{Q_k}$$

Furthermore, the Port Fee will be calculated based on the ship's need for services provided by the port so that the ship can lean on including pilot fees, mooring costs and delay costs by referring to the cost data issued by PT. Pelabuhan Indonesia I (Persero) due to limited data that can be accessed. The tariffs used will be adjusted to the rates issued by PT. Indonesian Port I for clusters 1 and 3, PT. Pelabuhan Indonesia III for clusters 2 and 7 and PT. Indonesian Port IV for clusters 4, 5, 6, and 8. The following data are taken based on the Circular Letter of Adjustment of Port Services Tariffs Number US.11/1/1/PBR-18 dated 03 May 2018.

### 2.6. Determining Receiving LNG Terminal Cost

To build the receiving terminal, the land is required and the construction of supporting buildings, the land cost will be calculated according to the land price at the receiving terminal with data sources from the Ministry of Agrarian and Spatial Planning/BPN. There will be a land price value that is presented in a price range. Then the price of the building is used data on the price of a 1-story building with the price per square meter using data from the National Development Planning Agency.

Another important component in the calculation of the cost of the storage tank, the size of the tank in this study will directly affect the total operational time of the ship in 1 roundtrip. Because in the distribution process the amount of gas that must be stored at the receiving terminal is at least the amount of demand per day multiplied by the total operational time of the ship in 1 roundtrip. For example, in cluster 4, it is known that the Merauke PLTMG has a gas demand of 107.15 m$^3$ per day, then in cluster 4, it is assumed that the ship takes 5 days to do 1 roundtrip on the selected route. Then the tank capacity requirement at the Merauke receiving terminal is at least 535.75 m$^3$. And in this study, it will be multiplied by 1.5 times for safety stock. So the minimum tank size at the Merauke receiving terminal is 803,625 m$^3$. LNG storage tanks in this distribution will be assumed to use tanks with a capacity of 350 m$^3$ each. With an estimated tank price of $250,000 for a tank with a capacity of 350 m$^3$.

Furthermore, in determining the costs to be incurred for investment in the receiving terminal, it is necessary to first know the condition of the selected receiving terminal whether the receiving terminal already has loading-unloading and LNG transfer components or not. The components needed for the LNG loading-unloading and transfer process at the receiving terminal include jetty facilities, LNG offloading facilities, vaporizer, boil-off gas compressor, LNG Pump, cryogenic pipe, and carbon steel pipe. The data that will be measured according to the location of the receiving terminal includes the dock facility at the receiving terminal, the facility will be added to the length measured using Google Earth and compared with Navionics data to determine the depth of the sea that can be reached by the pier to be built. In addition, cryogenic pipes and carbon steel pipes will be calculated based on the distance from the end of the pier to the vacant land that will be used as a storage tank.

In addition, indirect costs are calculated, such as construction costs, taxes, insurance; then calculated operational costs related to employee salaries and maintenance costs. The process of identification and measurement will be presented in the calculation of costs, the following is an estimate of the costs incurred for investment in the receiving terminal.

### 2.7. Optimization of Route and Ship Selection Using the Set Partitioning Method

In optimizing to determine the optimum ship and route, the optimization method to be used is Integer Linear Programming (ILP), called Integer because the output or decision variable will be binary, namely 0 and 1. Performing the optimization process using linear programming there are three parts, namely decision variables, objective functions, and constraints.
The objective function in optimizing route selection with the equation in $C_k^r$ is the investment cost of ship $k$ to serve route $r$, $x_k^r$ is the decision variable whether the ship and route are selected or not.

\[
Z = \text{Min} \sum_{r \in R^k} C_k^r x_k^r \tag{9}
\]

Constraints are used to obtain the most optimal ship and route by serving the receiving terminal once. The following are the limitations of optimizing ship selection and optimal routes:

\[
\sum_{r \in R^k} M_r \leq \text{Cap}_k \tag{10}
\]

\[
x_k^r = \text{Binary} \tag{11}
\]

\[
\sum_{r \in R^k} A_{ir} X_r = 1 \tag{12}
\]

\[
h_t \geq d_k \tag{13}
\]

Constraints (10) is a constraint to ensure that the demand on the $M_r$ route will be less than the capacity of the $\text{Cap}_k$ vessel, so that the vessel can be selected to distribute LNG to the receiving terminal on the $r$ route. Constraint (11) is a constraint that guarantees that the output of the decision variable $x_k^r$ is a binary number with values 0 and 1. Constraint (12) is a constraint that ensures that every route chosen $X_r$ is a combination of route that visits each $A_{ir}$ receiving terminal 1 time so that no $A_{ir}$ receiving terminal on route $r$ must be served and supplied with LNG. Then constraint (13) is a constraint that ensures that the ship is feasible to enter the port waters by making a limitation that the depth of the receiving terminal waters $h_t$ must be greater than the ship's draft $d_k$.

3. Result and Discussion

3.1. Data Collection

3.1.1. Power Plants Data

The data collected is the actual location data and the conversion of gas demand at each power plant

| No | Power Plants     | Receiving Terminal Coordinate Latitude | Capacity (MW) | Gas Demand (BBTUD) | Gas Demand (m3/day) |
|----|------------------|----------------------------------------|---------------|---------------------|---------------------|
| 1  | Krueng Raya      | 5.8686                                 | 165           | 14.6               | 498.0               |
| 2  | Nias             | 1.3063                                 | 25            | 5.2                | 175.9               |
| 3  | MPP Jeranjang    | -8.6597                                | 50            | 3.6                | 122.5               |
| 4  | PLTMG Sumbawa    | -8.4625                                | 50            | 6.1                | 208.5               |
| 5  | PLTMG Bima       | -8.4482                                | 50            | 6.1                | 208.5               |
| 6  | PLTMG Maumere    | -8.6171                                | 40            | 2.9                | 98.6                |
| 7  | PLTMG Alor       | -8.2420                                | 10            | 1.3                | 44.2                |
| 8  | PLTMG Kupang     | -10.1910                               | 40            | 2.9                | 98.6                |
| 9  | PLTMG Waingapu   | -9.6379                                | 10            | 1.3                | 44.2                |
| 37 | PLTMG Bau Bau    | -5.4534                                | 39            | 2.7                | 90.8                |
| 38 | PLTMG Rangko (Flores) | -8.4910                          | 23            | 1.7                | 56.1                |
| 39 | PLTMG Gilimanuk  | -8.1634                                | 134           | 7.9                | 268.7               |
| No | Power Plants          | Receiving Terminal Coordinate Latitude | Receiving Terminal Coordinate Longitude | Capacity (MW) | Gas Demand (BBTUD) | Gas Demand (m3/day) |
|----|-----------------------|----------------------------------------|----------------------------------------|---------------|-------------------|-------------------|
| 10 | MPP Kalbar Jungkat    | 0.0585                                  | 109.2034                               | 50            | 6.0               | 204.1             |
| 11 | Pontianak Peaker      | 0.0591                                  | 109.2039                               | 100           | 3.4               | 117.0             |
| 12 | PLTG Siatan           | -0.0048                                 | 109.3270                               | 30            | 2.8               | 93.5              |
| 16 | PLTMG Langgur         | -5.5626                                 | 132.7655                               | 20            | 1.8               | 60.5              |
| 18 | PLTMG Merauke 2       | -8.2729                                 | 140.2733                               | 20            | 1.5               | 51.7              |
| 19 | PLTMG Merauke         | -8.2729                                 | 140.2733                               | 20            | 1.6               | 55.4              |
| 20 | PLTMG Timika          | -4.8026                                 | 136.7691                               | 10            | 1.0               | 32.3              |
| 22 | PLTMG Saumlaki        | -7.9390                                 | 131.2928                               | 10            | 0.9               | 28.9              |
| 23 | PLTMG Dobo            | -5.8192                                 | 134.2442                               | 10            | 0.6               | 21.8              |
| 25 | PLTG Timika 2         | -4.8026                                 | 136.7691                               | 30            | 1.9               | 63.8              |
| 26 | PLTG Timika 2         | -4.8026                                 | 136.7691                               | 10            | 1.9               | 63.8              |
| 15 | Ambon Peaker          | -3.5511                                 | 128.3357                               | 30            | 2.3               | 77.6              |
| 17 | PLTMG Seram           | -3.3383                                 | 128.9202                               | 20            | 1.0               | 34.4              |
| 21 | PLTMG Namlea          | -3.2310                                 | 127.1097                               | 10            | 0.9               | 28.9              |
| 27 | MPP Fak-Fak           | -2.9316                                 | 132.3098                               | 10            | 0.6               | 21.1              |
| 28 | PLTMG Bula            | -3.0639                                 | 130.4516                               | 10            | 0.4               | 14.3              |
| 40 | PLTMG Sorong          | -1.0241                                 | 131.2426                               | 50            | 4.2               | 143.7             |
| 41 | PLTMG Sorong          | -1.0241                                 | 131.2426                               | 50            | 4.2               | 143.7             |
| 14 | MPP Ternate           | 0.7571                                  | 127.3149                               | 30            | 2.8               | 93.5              |
| 29 | PLTMG Bacan           | -0.6689                                 | 127.4744                               | 10            | 1.0               | 32.7              |
| 30 | PLTMG Morotai         | 2.0497                                  | 128.2892                               | 10            | 0.7               | 22.1              |
| 32 | PLTMG Tobelo          | 1.7191                                  | 128.0153                               | 10            | 0.5               | 16.0              |
| 33 | PLTMG Sofifi          | 0.7357                                  | 127.5522                               | 10            | 0.5               | 16.0              |
| 34 | PLTMG Ternate 2       | 0.7571                                  | 127.3149                               | 30            | 1.9               | 65.0              |
| 13 | Tanjung Selor         | 2.8733                                  | 117.3771                               | 15            | 0.7               | 22.5              |
| 35 | PLTG Maleo            | 0.4634                                  | 122.0055                               | 100           | 17.5              | 596               |
| 36 | PLTMG Nii Tanasa      | -3.9694                                 | 122.5844                               | 59            | 7.5               | 254.4             |
| 24 | PLTMG Serui           | -1.8822                                 | 136.3732                               | 10            | 1.0               | 32.3              |
| 31 | PLTG Kaimana          | -3.6648                                 | 133.7597                               | 10            | 0.6               | 21.1              |
| 42 | MPP Manokwari         | -0.8684                                 | 134.0753                               | 20            | 1.9               | 66.1              |
| 43 | PLTMG Manokwari 2     | -0.8684                                 | 134.0753                               | 20            | 1.9               | 66.1              |
| 44 | PLTMG Manokwari 3     | -0.8684                                 | 134.0753                               | 20            | 1.9               | 66.1              |
| 45 | MPP Nabire            | -3.2270                                 | 135.5800                               | 23            | 1.2               | 39.8              |
| 46 | PLTMG Nabire 2        | -3.2270                                 | 135.5800                               | 10            | 1.2               | 39.8              |
| 47 | PLTMG Nabire 3        | -3.2270                                 | 135.5800                               | 10            | 1.2               | 39.8              |
| 48 | PLTMG Biak            | -1.1857                                 | 136.0770                               | 15            | 1.1               | 38.6              |
| 49 | PLTMG Biak 2          | -1.1857                                 | 136.0770                               | 10            | 1.1               | 38.6              |
| 50 | PLTMG Jayapura        | -2.5452                                 | 140.7127                               | 59            | 4.1               | 139.5             |
| 51 | PLTMG Jayapura        | -2.5452                                 | 140.7127                               | 40            | 4.1               | 139.5             |
| 52 | PLTMG Jayapura 1      | -2.5452                                 | 140.7127                               | 50            | 4.1               | 139.5             |
3.1.2. LNG Vessels Data

The distribution of liquefied natural gas (LNG) in this study is planned to be limited to only using the LNG Carrier ship mode of transportation. The gas distribution is carried out by LNG Carrier ships with various capacities. The data requirements of this type of ship are used to determine the variable costs and loading capacity for supply to power plants. The data requirements needed are vessel capacity, draft, speed, fuel consumption, and vessel charter prices. The following is a table of search results regarding available ships based on data from the Marine Traffic Website, Dewangga Research (2016), and Setyorini Research (2018).

| Parameter       | Unit | Ship 1          | Ship 2          | Ship 3          | Ship 4          | Ship 5          | Ship 6          |
|-----------------|------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Name            |      | Pioneer Knutsen | Shinju Maru     | Cora Methane    | Coral Fucata    | Coral Energy    | Short sea       |
| Cargo Pump      | m3/h | 330             | 350             | 450             | 640             | 1620            | 380             |
| Max Cap.        | m3   | 1078            | 2538            | 7550            | 10000           | 15600           | 4000            |
| Loa             | Meter| 69              | 2538            | 117.8           | 100             | 151             | 99              |
| B               | Meter| 11.83           | 18              | 18.6            | 20              | 28              | 28              |
| T               | Meter| 3.6             | 3.8             | 6.3             | 7               | 8               | 4.3             |
| Speed           | Knots| 12.2            | 13              | 14              | 14              | 15              | 13              |
| Fuel Consumption| ton/day| 4.22           | 7.726           | 20.52           | 26.57           | 40.13           | 6.216           |
| E. Power        | kW   | 1,000           | 1,676           | 4,090           | 5,297           | 8,000           | 1400            |
| Charter Rate    | USD/Day| 5800          | 8426           | 16806           | 20496           | 30000           | 12800           |

3.1.3. LNG Refineries and Facilities Data

The identification of the LNG plant and available facilities with data requirements is the location point and the capacity of the refinery aims to provide an actual picture from where LNG will be supplied, then the available facilities can be used as a hub that will reduce investment costs. In selecting the hub, it will be explained how the actual function of the existence of the available LNG facilities will be. If identification can be carried out, the existing data will be used to analyze whether there are facilities in the cluster that can be utilized or not.

| No. | Name                             | Location          |
|-----|----------------------------------|-------------------|
|     |                                  | Latitude | Longitude       |
| 1   | Tangguh LNG                      | -2.439881834     | 133.1434091     |
| 2   | Donggi-Senoro LNG                | -1.239979543     | 122.5870195     |
| 3   | Bontang LNG                      | 0.105249381      | 117.4806737     |
| 4   | Regasifikasi PT. Perta Arun Gas  | 5.223173193      | 97.07874092     |
| 5   | FSRU Lampung                     | -5.304743871     | 106.1102882     |
| 6   | FSRU Bali                        | -8.746120031     | 115.2103514     |

3.2. Clustering with K-Means Result

The results of the K-Means clustering method formed 8 clusters with details of cluster 1 located in Aceh and North Sumatra, cluster 2 located in Bali and Nusa Tenggara, cluster 3 located in West Kalimantan, cluster 4 located in southern Papua, cluster 5 located in West Papua and Maluku, cluster 6 located in North Maluku, cluster 7 located in North Kalimantan and Sulawesi, cluster 8 located in Northern Papua with the following details:
3.3. Hub Selection Result

The selection of the following hubs explains that there are differences in the results of the two methods used. In cluster 1 of the two methods produced the same results, namely PT. Perta Arun is the Hub so that the selected Hub for cluster 1 is PT. First Arun. Furthermore, in cluster 2 where the result of the first method is the selected hub FSRU Bali, while the second method will use the Bima Receiving Terminal. From the two methods, the Bali FSRU will be chosen as the hub with the consideration that the Bali FSRU is an LNG storage and transfer facility that has been operating so that it can be used to reduce investment costs.

Comparison of the results of the hub in cluster 3, the first method has the result of using the Lampung FSRU as a hub, while the result of the second method is the use of PLTMG Pontianak as a hub location. The Lampung FSRU was then chosen with the justification that the hub could not be located at PLTMG.
Pontianak because access to enter was by entering waters with limited water depths. So that LNG cannot be directly distributed from the source or LNG refinery. Likewise, with cluster 4, the DoBo Receiving Terminal was chosen due to the geographical condition of the Timika Receiving Terminal which is located in a river area, thereby reducing the ability to access ships with large sizes and capacities entering the area.

Furthermore, in determining the hub in cluster 5 where the two methods have the same result, namely the Sorong Receiving Terminal as the Cluster 5 Hub.

For cluster 6, the difference occurs in the election results, namely the first method with the results of the Ternate Receiving Terminal and the second method with the results of the Sofifi Receiving Terminal. In the selection method, the two Hub locations are determined to be close to the Sofifi Receiving Terminal, but the Ternate receiving Terminal is also not far from the selected hub. So, with the consideration that the demand at the Ternate Receiving Terminal is greater, the Ternate Receiving Terminal is chosen as the Hub.

In cluster 7, it is determined not to use a hub because based on distance considerations it is more efficient if the receiving terminal is supplied directly from a nearby refinery. For details of justification for cluster 7 not using the hub, it will be explained in the details of cluster 7 for the selection of hubs based on the feasibility factors of the hub.

Then in cluster 8 where there is a difference in the results of the selection of the two methods, it is determined that the Manokwari Receiving Terminal will be used as a hub by considering the greater demand compared to the Serui receiving terminal.

3.4. Ship and Route Optimization Result

3.4.1. Cluster 1

After optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 2 ships with a shipping capacity of 1100 m$^3$ to serve the 0-1-0 route from Perta Arun Hub - Kruengraya Receiving Terminal – Perta Arun Hub ; 0-2-0 Perta Arun Hub - Nias Receiving Terminal - Perta Arun Hub. With a total transportation cost of $8,343,996.33, the investment cost at the receiving terminal was $3,583,229.34 and the storage tank cost was $1,000,000.00.

3.4.2. Cluster 2

After optimizing ships and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 5 ships with a shipping capacity of 1100 m$^3$ FSRU Bali Hub - Gilimanuk Receiving Terminal - FSRU Bali Hub, 2500 m$^3$ Hub Ship FSRU Bali - Terminal Receiving Terminal - Receiving Terminal Sumbawa - FSRU Bali Hub, 2500 m$^3$ Vessel Hub FSRU Bali.
- Receiving Terminal Bima - Receiving Terminal Flores - FSRU Bali, Vessel 2500 m³ Hub FSRU Bali - Reception Terminal Waingapu - Receiving Terminal Kupang - FSRU Hub Bali, Ship 2500 m³ FSRU Bali Hub - Maumere Receiving Terminal - Alor Receiving Terminal - FSRU Hub. With a total transportation cost of $13,751,322.45, the investment cost in the receiving terminal is $17,573,237.32 and the storage tank cost is $7,750,000.00.

Figure 4. Visualization of Optimization Result in Cluster 2

3.4.3. Cluster 3
In optimizing cluster 3, the large demand and condition of river waters with limited water depths make most of the LNG ships used in this study not feasible to supply LNG to Cluster 3. So the results of the optimization are narrowed to ships with a capacity of 4000 m³. Then after optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 1 ship with a ship capacity of 4000 m³ and the route 0-1-0 Hub FSRU Lampung - Siantan Receiving Terminal - Hub FSRU Lampung. With a total transportation cost of $6,288,195.58, investment costs in receiving terminals $1,826,779.61 and storage tank costs $1,200,000.00.

Figure 5. Visualization of Optimization Result in Cluster 3

3.4.4. Cluster 4
After optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 2 ships with a shipping capacity of 2500 m³ and the route 0-2-3-0 Hub Dobó - Merauke Receiving Terminal - Saumlaki Receiving Terminal - Dobó Hub; 0-1-5-4-0 Dobó Hub - Langgur Receiving Terminal - Kaimana Receiving Terminal - Timika Receiving
Terminal - Dobo Hub with total transportation costs of $9,282,851.80, investment costs on receiving terminals $14,708,612.32 and storage tank costs $2,475,000.00.

### Figure 6. Visualization of Optimization Result in Cluster 4

**3.4.5. Cluster 5**

After optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 2 ships with a shipping capacity of 1100 m³ each for the route 0-2-4-0 Hub Sorong - Fak-Fak Receiving Terminal - Seram Receiving Terminal - Sorong Hub and 2500 m³ for route 0-5-1-3-0 Sorong Hub - Bula Receiving Terminal - Ambon Receiving Terminal - Namlea Receiving Terminal - Sorong Hub. With a total transportation cost of $8,304,242.41, investment costs at receiving terminal $17,475,434.00 and storage tank cost $1,650,000.00.

### Figure 7. Visualization of Optimization Result in Cluster 5

**3.4.6. Cluster 6**

After optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 1 ship with a shipping capacity of 2500 m³ and the route 0-1-2-3-4-0 Hub Ternate - Bacan Receiving Terminal - Morotai Receiving Terminal - Tobelo Receiving Terminal - Sofifi Receiving Terminal - Ternate Hub. With a total transportation cost of $5,117,237.74, the investment cost at the receiving terminal was $16,402,181.00 and the storage tank cost was $825,000.00.
3.4.7. Cluster 7

After optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 2 ships with a shipping capacity of 1100 m$^3$ to serve the 0-2-0 route from Donggi Refinery - Nii Tanasa Receiving Terminal - Refinery Donggi; 0-3-0 Donggi Refinery - Bau Bau Receiving Terminal - Donggi Refinery, 1 vessel with a vessel capacity of 2500 m$^3$ to serve the route 0-4-0 Donggi Refinery - Maleo Receiving Terminal - Donggi Refinery. And 1 truck with a size of 40 feet to supply the Tanjung Selor PLTMG from the Bontang refinery. With a total transportation cost of $13,685,463.86, the investment cost in the receiving terminal is $8,028,449.63 and the storage tank cost is $2,890,000.00.

3.4.8. Cluster 8

After optimizing the ship and the optimum route using the set partitioning problem (SPP) method, the result of the selection is that the cluster is served by 1 ship with a shipping capacity of 2500 m$^3$ to serve the route 0-3-1-2-0 Hub Manokwari - Biak Receiving Terminal - Serui Receiving Terminal - Nabire Receiving Terminal - Manokwari Hub. And 1 ship with a capacity of 4000 m$^3$ to serve the route 0-4-0 Hub Manokwari - Jayapura Receiving Terminal - Hub Manokwari. With a total transportation cost of $10,627,947.92, the investment cost in the receiving terminal is $9,504,573.35 and the storage tank cost is $3,575,000.00.
3.5. Economical Analysis
In this study, the economic analysis will be calculated with the assumption in this investment is 100% use Bank Loan, 8% interest rate, 1.52% Inflation Rate. And with the 1.5-3 USD Margin of Revenue, the investment will be worth to be realized if the margin is 1.75 USD because the investor will get back the investment in 10 Years, the internal rate of return is above the interest bank and in the last period of the contract value of net present value is positive.

| Margin | Payback Period | ROI  | IRR  | NPV               |
|--------|----------------|------|------|-------------------|
| $1.50  | >20            | 0.32%| 3.08%| $(24,559,461.86) |
| $1.75  | 10.21          | 10.88%| 15.81%| 72,679,482.34    |
| $2.00  | 3.24           | 20.06%| 18.88%| 169,918,426.53   |
| $2.25  | 2.83           | 29.25%| 20.25%| 267,157,370.73   |
| $2.50  | 2.08           | 43.73%| 21.39%| 427,212,757.62   |
| $2.75  | 1.68           | 54.33%| 21.84%| 539,411,539.38   |
| $3.00  | 1.43           | 64.93%| 22.12%| 651,610,321.15   |

3.6. Conclusion
Based on the analysis and calculations in the study of the distribution of LNG for power plants spread across Indonesia, it can be concluded as follows:

1. The distribution scenario in this study has several stages. The initial stage is Clustering with the K-Means method for 52 power plants in Indonesia with the results of power plants being divided into 8 clusters. Then do the selection of Hub with the result that Hub Cluster 1 PT. Perta Arun, Cluster Hub 2 FSRU Bali, Cluster Hub 3 FSRU Lampung, Cluster Hub 4 Dobo Receiving Terminal, Cluster Hub 5 Sorong Receiving Terminal, Cluster Hub 6 Ternate Receiving Terminal, Cluster Hub 8 Manokwari Receiving Terminal. Then a routing scenario is carried out with the formation of 617 routes that are feasible for distribution to the Hub to the receiving terminal and 381 routes that are feasible to be distributed from the refinery to the hub.

2. The following are the results of selecting the optimum ship and route in the distribution process for each:
   a. Cluster 1 is a cluster served by 2 vessels with a capacity of 1100 m3 to serve the route 0-1-0 Perta Arun Hub - Kruengraya Receiving Terminal – Perta Arun Hub; 0-2-0 Perta Arun Hub - Nias Receiving Terminal - Perta Arun Hub.
   b. Cluster 2 is served by 5 vessels with a capacity of 1100 m3 Vessel FSRU Bali Hub - Gilimanuk Receiving Terminal - FSRU Bali Hub, 2500 m3 Vessel FSRU Bali Hub - Jetty Receiving
3. Total costs for all distribution activities with investment costs (CAPEX) of $107,815,749.11 and operating costs (OPEX) of $68,263,709.11. The results of the economic analysis are considered that the investment is feasible to be realized is to provide a minimum margin of $1.75 because, at the end of the duration of the contract, the investment will generate a profit of $72,679,482.

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