Study of Green-Ship Routing Problem (G-VRP) Optimization for Indonesia LNG Distribution

Joshua J A Siahaan1, E Pratiwi1,2, P D Setyorini3

1Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
2Center of Excellence in Maritime Safety and Marine Installation (PUI KEKAL), Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
3Department of Marine Engineering, Universitas Hang Tuah, Surabaya, Indonesia

Email: joshuasiahaan27@gmail.com

Abstract. Natural gas is distributed around Indonesia mainly to be used as fuel in electrical power plants. The increase of consumption of electricity in Indonesia is on average of 6.8% annually. In response, the government considers developing gas power plants in central parts of Indonesia. As an archipelago, Indonesia depends heavily in connectivity between islands which is obviously supported by seaborne vessels or ships. These facts make the LNG transportation a complex matter in Indonesia. The distribution of LNG by ship can be designed as a hub and spokes liner shipping. A single hub and spokes network has one hub port and several feeder ports. In LNG supply chain network, the hub is the liquefaction plant and the feeder ports are receiving terminals. Various optimization methods have been established to optimally utilize a fleet. Other than the cost-efficiency, there are other considerations in optimizing the fleet. One of the current trending considerations is the emission. In the past few years, concern about environment has been increasing. IMO released a number based on research that shows that maritime transportation has 2.7% contribution to global anthropogenic emission. The aim of this research is to determine the optimal fleet and its routes of an LNG shipping to minimize the CO$_2$ emission while also minimizing the cost of LNG distribution in central part of Indonesia that covers South Eastern Sulawesi. Demand points are the power plants of Kendari, Baubau, Selayar, Bombana, and Kolaka with a total of 828 m$^3$ daily needs for LNG. The cost calculation was done in a G-VRP framework which took emission into account. A method called Bin Packing Problem within the context of Vehicle Routing Problem was established to minimize the total distribution cost and emission for each cluster. After acquiring the best route and fleet option, this research compared and analysed the benefits of using conventional diesel engine and a dual fuel diesel engine scenario for the chosen vessel. The result of this optimization study shown that the transportation shall use one unit of type-A ships with a capacity of 1100 m$^3$ for the routes Ambon-Bombana-Kolaka Utara-Ambon. And two units of type-B ship with a capacity of 2500 m$^3$ for Ambon-Kendari-Ambon and Ambon-Baubau-Selayar-Ambon route. All ships use LNG as fuel. The total expense for this scenario is $2,980,768.63 and the use of dual fuel diesel engine instead of a conventional diesel engine for the ships can reduce the total costs by $2,434,348.97 or 44.95%.

1. Introduction
In a vast archipelago country like Indonesia, maritime distribution has been given a major role in economic development. Transported commodities vary widely from food supplies, minerals, raw
materials, livestock, and even energy-rich substances. Natural gas is among the most trending transported commodities in Indonesia. The amount of natural gas in confirmed reservoirs scattered across Indonesia exceeds 99.77 Tonne Cubic Feet (TCF) and potential reservoirs exceed 50.21 TCF. However, the domestic usage of natural gas in Indonesia is not optimized, which makes Indonesia the second largest exporter of Natural Gas. [1].

![Figure 1. Indonesia’s Natural Gas Reserves are scattered across Indonesia. In this research, the Masala Abadi gas field, which is the one located in south-eastern Indonesia, will be used as the natural gas source. The hub is the LNG storage located on the island of Ambon.](image)

To increase domestic usage of natural gas, PLN, as a national public enterprise had arranged an electricity development plan for the years 2018 until 2027. The plan was designed to increase the domestic usage of natural gas as a fuel for many newly developed gas power plants. This development was also proposed to satisfy the national electricity demand which increases around 6% every year. This plan is in line with the government regulation which was released in 2014 that stated that the government was planning to increase the domestic usage of natural gas.

There are various ways to transport natural gas. In a country like Indonesia with a lot of power plants scattered across the archipelago with a relatively low capacity, it is believed that transporting natural gas using ships in the form of LNG is the most efficient and economical way of transporting natural gas.[2] That makes LNG Transportation a complex matter in Indonesia and requires a strategic approach in determining the distribution routes and ships.[3]

In the other section of the transportation problem, came another matter that had been a national and even global concern for the last few years. That matter is environmental problems and climate change. The awareness to add environment into account of every decision is expressed by a national regulation released in 2016. The document states that Indonesia has ratified the Paris agreement which means Indonesia is committed to reducing CO₂ emission by 29% due to 2030. This paper will provide the routes and fleet composition in order to distribute natural gas to power plants by taking the overall transportation cost and emission into account.

2. Methodology
PLN is one of Indonesia’s state-owned enterprises which operates in various fields around electricity. In their development plan, PLN had designed several LNG clusters that divide regions for future development in natural gas distributions. In this research paper, one cluster is used as the study object.
which is South-eastern Sulawesi which consists of 5 power plants at Kendari, Baubau, Selayar, Bombana, and Kolaka with a total of 828 m$^3$ daily needs for LNG.

The first step in this research is to do the generation of feasible subsets. This is done by generating all possible routes first and then eliminate the infeasible ones. Each subset is designated to each LNG vessel. In this step also, the distance between hub and spokes and between spokes is measured. The method of doing this step is by simply using the number combination generator in Python iteration module and the polyline tools in Google Earth. After having all possible routes in every LNG vessel, the second step is to calculate each route’s demand and compare it with each ship’s capacity to eliminate the infeasible subsets. Once all the feasible subsets have been gathered, the next step is optimizing the distance in each subset. In this step, a Travelling Salesman Problem Solver Software is used to produce minimum distance for each subset. After acquiring the result, the next step is calculating the capital cost, operational cost, and voyage cost of every feasible subset by considering two types of diesel engines. In this cost calculation, a Green Ship Routing Problem Framework (G-VRP) is applied by adding an Emission Cost as part of the operational cost. The final step in this research is optimization using the Bin Packing Problem algorithm to select the combination of routes and fleet which satisfies the demand of all power plants with minimum cost possible.

VRP is an NP-complete problem. In order to solve the problem, various algorithms can be implemented. In this paper, Bin Packing Problem as an NP-Hard algorithm[4], is chosen for its ability to solve NP problems in small scale VRP like the one solved in this paper.

2.1. Route Generation and Distance Matrix
Table 1 shows all the possible combinations of power plants that make a single route. In this research, each possible route is designated to each vessel. Each subset represents one route and one vessel. There are 31 possible routes that correspond to 5 vessels. There are 155 subsets in total. This task is easily done by utilizing the itertools built-in module in Python.

| Subset $i$ | Route | Subset | Route | Subset | Route |
|-----------|-------|--------|-------|--------|-------|
| 1         | 0-1-0 | 11     | 0-2-4-0 | 21     | 0-1-4-5-0 |
| 2         | 0-2-0 | 12     | 0-2-5-0 | 22     | 0-2-3-4-0 |
| 3         | 0-3-0 | 13     | 0-3-4-0 | 23     | 0-2-3-5-0 |
| 4         | 0-4-0 | 14     | 0-3-5-0 | 24     | 0-2-4-5-0 |
| 5         | 0-5-0 | 15     | 0-4-5-0 | 25     | 0-3-4-5-0 |
| 6         | 0-1-2-0 | 16     | 0-1-2-3-0 | 26     | 0-1-2-3-4-0 |
| 7         | 0-1-3-0 | 17     | 0-1-2-4-0 | 27     | 0-1-3-4-5-0 |
| 8         | 0-1-4-0 | 18     | 0-1-2-5-0 | 28     | 0-1-2-4-5-0 |
| 9         | 0-1-5-0 | 19     | 0-1-3-4-0 | 29     | 0-1-3-4-5-0 |
| 10        | 0-2-3-0 | 20     | 0-1-3-5-0 | 30     | 0-2-3-4-5-0 |
|           |       | 31     |       |        | 0-1-2-3-4-5-0 |
Table 2. The following table presents a list of power plants and the capacity for each. Under the list of power plants there is the distance matrix. The distance is calculated using polyline tool in Google Earth. This distance matrix will be used as the basis of all the calculations in this research.

| Terminal | Power Plant        | Capacity (MW) |
|----------|--------------------|---------------|
| 1        | PLTMG Kendari      | 50            |
| 2        | MPP Bombana        | 10            |
| 3        | MPP Bau-bau        | 30            |
| 4        | MPP Kolaka Utara   | 5             |
| 5        | PLTMG Selayar 1&2  | 20            |

DISTANCE MATRIX CLUSTER SULAWESI TENGGARA

|       | 0    | 1    | 2    | 3    | 4    | 5    |
|-------|------|------|------|------|------|------|
| 0     | 0    | 665  | 737  | 742  | 895  | 937  |
| 1     | 665  | 0    | 188  | 215  | 493  | 438  |
| 2     | 737  | 188  | 0    | 210  | 420  | 435  |
| 3     | 742  | 215  | 210  | 0    | 268  | 283  |
| 4     | 895  | 493  | 420  | 268  | 0    | 284  |
| 5     | 937  | 438  | 435  | 283  | 284  | 0    |

2.2. Route Feasibility Validation Variable
Subsets to be used in the optimization must be assessed to ensure its feasibility. Feasible means that the ship is capable to carry LNG in an amount that satisfies the demands of all power plants in its route, for each specific subset. To do this, the total LNG requirement of all power plants in each subset is compared with the ship capacity. A simple Microsoft Excel formulation is able to solve the problem. Then, the feasibility of a subset would be interpreted as a binary. The value is 0 if the subset is not feasible or 1 if it is feasible.

2.3. Optimizing Feasible Routes using Travelling Salesman Problem and Cost Calculation
Each subset has a set of demand points in a specific sequence. This sequence is not yet optimized. For example, a route of 0-1-2-3-0 has a possibility that it would have a shorter distance if arranged in a different order. It is possible that the order 0-2-1-3-0 is shorter. This problem can be solved using a Python module called the “TSP Module”.

3. Calculation and Optimization
The size of the planned fleet determines how many mini-LNG ships must be prepared. For this reason, the generation of viable routes can be carried out by each variation in the size of the ship. In this paper, the routes will be a collection of single routes. The set of routes are subsets that will be the input from optimization.

Then, a cost calculation for each feasible route is calculated. The cost calculation is done with cost components such as ship charter, fuel consumption cost, maintenance and repair cost, port charges, and carbon emission costs. In addition, the operational costs of each ship will be carried out in two main prime movers namely a conventional diesel engine and a dual-fuel diesel engine.

The fuel used on a mini-LNG vessel depends on the type of diesel used. In this study, there are two types of diesel used, namely conventional diesel and dual-fuel diesel. Conventional diesel in this paper is assumed to use Marine Gas Oil (MGO) which is calculated based on bunker costs incurred by shipandbunker.com. For the dual-fuel variant, according to the Wartsila 20df project guide, the fuel used is Marine Diesel Fuel (MDF) as pilot fuel and natural gas as the main fuel. Natural gas as a bunker is stored on ships in the form of LNG. The LNG bunker price taken for this paper scenario is
taken from the DNV-GL article, which is $4 per mmBtu or equivalent to $186 per ton. The price of HSD oil is $630 per ton.

There are several factors that influence the port's operational tariff as part of the cost of the route. The more terminals that are served on a route, the greater the costs that must be incurred as a port operating tariff. In addition to the number of terminals, the size of the ship and the volume of cargo unloaded also affect the tariff that must be issued. In summary, there are six cost components that are going to be used to evaluate each subset in this research, each with its own sub-components. The total cost will be calculated for each feasible route for each vessel available.

A similar approach with previous research by Setyorini, et al [6] will be implemented. The vessels used in this study are small-scale LNG ships with sizes of 1100 m$^3$, 2500 m$^3$, 7500 m$^3$, 10000 m$^3$, and 15600 m$^3$. The comparison ship is used to determine the cost of rent and the driving machine. The comparison vessels used are: Pioneer Kutsen, Shjinu Maru, Coral Methane, Norgas Conception, and Coral Energy.

Details of technical data and charter costs can be seen in the following table:

| Parameter               | Unit | VALUE           |
|-------------------------|------|-----------------|
| Ship Type               | -    | SMALL LNG CARRIER |
| Capacity                | m$^3$ | 1100 2500 7500 10000 15600 |
| LoA                     | m    | 69 86.25 117.8 100 151 |
| Breadth                 | m    | 11.83 15.1 18.6 20 28 |
| Draft                   | m    | 3.6 3.8 7.15 7.1 8 |
| Service Speed           | knot | 12.2 13 14 14 15 |
| Engine Power @MCR       | kW   | 1000 1676 4090 5297 8000 |
| Charter Cost            | USD/day | 7800 10426 19806 24496 35000 |

Then, in each subset, the Traveling Salesman Problem is applied to determine the shortest distance from the route. The TSP calculation is carried out with the help of the Traveling Salesman Solver software. The shortest distance will then be used as input in the future optimization process.

Onshore Investment Costs that will be analyzed in this paper are the cost of building a jetty for loading and unloading and the cost of providing an LNG skid tank with a capacity of 400 m$^3$ for each tank. The influence of the ship on the jetty selection is the increase in the length of the jetty needed to accommodate the depth requirements due to the ship being loaded.

The cost of building a jetty in this paper is obtained from the cost per land area multiplied by the length and width of the jetty. The cost per square meter of land is set at Rp.50,000,000, - where the fee is set to cover all types of construction. Whereas the LNG storage tank is set at $800,000 per 400m$^3$ tank.

3.1. Cost Calculation Within G-VRP Framework

Current route optimization models or vehicle routing problems (VRP) only consider cost or profit factors and do not consider environmental aspects. GVRP is a development of VRP that is currently being developed by many researchers. GVRP aims to incorporate the emission factors of greenhouse gases produced into the optimization model.

One way to link emissions with human well-being is to use cost indicators or, in other words, is to monetize the emission value. In the form of money, emissions can be more easily analyzed regarding their impact on human-owned systems. Even so, it is not very easy to set a fixed and trustworthy value.[7]

Therefore, Tol conducted a study that analyzed statistically based on the uncertainty of 103 estimated marginal damage costs (MDC). 28 of them are published studies that are then combined statistically to produce a probability density function. In this study, an approach will be applied by
internalizing emission factors on existing models. Namely by adding emission factors into costs by converting marginal damage costs obtained from research conducted by Tol [8].

Figure 2. Probability Density Graph of Marginal Damage Cost according to 133 research articles by Tol (2005).

The graph above is the probability density function of the results of research conducted by Richard S. J. Tol. With a combination of all available studies, the MDC mode is $2 / tC, the median is $14 / tC, with an average of $16 / tC. For all practical applications around the world, the uncertainty of the impact of climate change is quite large, but it can be ascertained that the marginal cost of damaging carbon dioxide emissions is 50 $ / tC and is quite possibly smaller than that.

Table 4. Total Cost for each Subset for ship A.

| Subset (i) | Route (Before TSP) | Route (After TSP) | Total Cost  | Subset (i) | Route (Before TSP) | Route (After TSP) | Total Cost |
|-----------|--------------------|-------------------|-------------|-----------|--------------------|-------------------|------------|
| 1         | 0-1-0              | 0-1-0             | $ 3,730,126.41 | 16        | 0-1-2-3-0         | 0-1-2-3-0         | $ 12,360,356.86 |
| 2         | 0-2-0              | 0-2-0             | $ 3,847,406.86 | 17        | 0-1-2-4-0         | 0-4-2-1-0         | $ 12,379,672.51 |
| 3         | 0-3-0              | 0-3-0             | $ 3,623,880.29 | 18        | 0-1-2-5-0         | 0-1-2-5-0         | $ 14,144,870.42 |
| 4         | 0-4-0              | 0-4-0             | $ 3,868,713.46 | 19        | 0-1-3-4-0         | 0-1-3-4-0         | $ 12,375,395.34 |
| 5         | 0-5-0              | 0-5-0             | $ 8,587,549.71 | 20        | 0-1-3-5-0         | 0-1-3-5-0         | $ 13,261,990.13 |
| 6         | 0-1-2-0            | 0-1-2-0           | $ 9,418,671.70 | 21        | 0-1-4-5-0         | 0-1-5-4-0         | $ 13,269,530.35 |
| 7         | 0-1-3-0            | 0-1-3-0           | $ 9,324,685.15 | 22        | 0-2-3-4-0         | 0-2-3-4-0         | $ 8,853,629.86  |
| 8         | 0-1-4-0            | 0-1-4-0           | $ 9,450,765.33 | 23        | 0-2-3-5-0         | 0-2-3-5-0         | $ 12,379,370.48 |
| 9         | 0-1-5-0            | 0-1-5-0           | $ 7,671,590.53 | 24        | 0-2-4-5-0         | 0-4-5-2-0         | $ 9,753,334.00  |
| 10        | 0-2-3-0            | 0-2-3-0           | $ 5,026,350.22 | 25        | 0-3-4-5-0         | 0-3-5-4-0         | $ 11,510,115.53 |
| 11        | 0-2-4-0            | 0-2-4-0           | $ 5,915,974.21 | 26        | 0-1-2-3-4-0       | 0-1-2-3-4-0       | $ 17,094,299.69 |
| 12        | 0-2-5-0            | 0-2-5-0           | $ 6,785,799.55 | 27        | 0-1-2-3-5-0       | 0-1-2-3-5-0       | $ 18,856,850.66 |
| 13        | 0-3-4-0            | 0-3-4-0           | $ 7,666,477.58 | 28        | 0-1-2-4-5-0       | 0-4-5-2-1-0       | $ 17,118,177.11 |
| 14        | 0-3-5-0            | 0-3-5-0           | $ 5,918,385.71 | 29        | 0-1-3-4-5-0       | 0-1-3-5-4-0       | $ 17,979,382.75 |
| 15        | 0-4-5-0            | 0-4-5-0           | $ 3,730,126.41 | 30        | 0-2-3-4-5-0       | 0-4-5-3-2-0       | $ 14,463,396.67 |
|           |                    |                   |             |           | 31                 | 0-1-2-3-4-5-0     | $ 22,719,180.76 |
3.2. Optimal Fleet and Route Selection using Bin Packing Problem

Set Partitioning, Set Covering, and Traveling Salesman (Shortest Distance), are the most widely integrated linear programming structures applied in many fields in the world.[9] The problem of determining fleets and routes can be formulated as a Set Partitioning Problem.[10] Another development for the Set Partitioning Problem for solving VRP cases is by adding an element of the Bin Packing Problem Algorithm. Since VRP is an NP-complete problem, it is possible to deploy BPP in a similar way with SPP. BPP will arrange the subsets so that all objects can be transported with a minimum amount of containers. In this case, the sum of containers is represented by the total cost.

\[
z = \sum_{i=1}^{n} x_i (C_i + E_i \times p)
\]  
\[\text{Subject to}
\]
\[
w_i \leq c_i v_i
\]
\[
\sum_{i=1}^{n} y_{ij} v_i x_i = 1, \ j \in J
\]
\[
x_{ij} \in \{0,1\}, y_{ij} \in \{0,1\}, i \in I, j \in J
\]

Equation (1) is an objective function to minimize the total costs and emissions of all selected subsets. Equation (2) ensures that the total LNG demand in the selected subset does not exceed the capacity of the transporting ship. Equation (3) ensures that each plant is served by one LNG carrier. Equation (4) ensures that the value of the decision variable is a binary integer. The notation \(C\) in the equation expresses the total operating cost and land investment cost. The notation \(E_i\) is the \(CO_2\) expresses the Total Emission in Subset \(i\). The notation \(p\) expresses the Marginal Damage Cost. The notation \(z\) expresses the Total Subset Cost. The decision variable \(x_i\) has a value of 1 if subset \(i\) is chosen, otherwise, \(x_i\) is 0. The variable \(y_{ij}\) Has a value of 1 if subset \(i\) serves port \(j\), 0 otherwise. The notation \(I\) is a Set of Subsets. The notation \(J\) is a Set of Power Plants. The notation \(CI\) expresses the Carrying Capacity of Subset \(i\). The notation \(wi\) expresses the Total Demand to be Satisfied in subset \(i\) time-bound. The Boolean variable \(v_i\) expresses the feasibility of Subset \(i\). The value is 1 if feasible and 0 otherwise.

4. Optimization Result and Discussion Conclusion

The result obtained through the optimization process are the combination of ships and routes that have the lowest annual operational costs. The most optimal combination is to use three ships. One unit of ship A with the route Ambon-Bombana-Kolaka Utara-Ambon and two units of ship B with the routes Ambon-Kendari-Ambon, and Ambon-Baubau-Selayar-Ambon. With all ships using LNG fuel. The minimum cost required for this scenario is $2,980,768.63. Figure 4 provides the visualization of this result. In this cluster, the use of dual fuel diesel engine instead of a conventional diesel engine for the ships can reduce the total costs by $2,434,348.97 or 44.95%.

| Subset | Route | Ship | Distance (km) | Duration | Cargo Loaded (m3) |
|--------|-------|------|---------------|----------|-------------------|
| 166    | 0-2-4-0 | A1   | 2050          | 4.88     | 790.36            |
| 187    | 0-1-0   | B1   | 1330          | 2.87     | 1552.33           |
| 200    | 0-3-5-0 | B2   | 1962          | 4.51     | 2433.22           |
|        | Ship Cap (m3) | Load Factor | Feasibility | Conventional Diesel Engine Annual Cost | Dual Fuel Diesel Engine Annual Cost |
| 3      | 1100   | 0.72 | FEASIBLE      | $1,198,464.77 | $753,510.24 |
| 5      | 2500   | 0.62 | FEASIBLE      | $1,979,648.16 | $958,185.10 |
| 11     | 2500   | 0.97 | FEASIBLE      | $2,237,004.67 | $1,269,073.29 |
| Total  |       |     |               | $5,415,117.60 | $2,980,768.63 |
5. References

[1] W. W. Purwanto, Y. Muharam, Y. W. Pratama, D. Hartono, H. Soedirman, and R. Anindhito, “Status and outlook of natural gas industry development in Indonesia,” *J. Nat. Gas Sci. Eng.*, vol. 29, pp. 55–65, 2016, doi: 10.1016/j.jngse.2015.12.053.

[2] K. B. Putra, Made Arya Satya Dharma Artana and D. Wi. Handani, “Desain Rantai Pasok Gas Alam Cair (LNG) untuk Kebutuhan Pembangkit Listrik di Indonesia Bagian Timur,” *J. Tek. ITS*, vol. 5, no. 2, 2016, doi: 10.12962/j23373539.v5i2.19120.

[3] K. B. Artana and Soegiono, *Transportasi LNG Indonesia*. Surabaya: Airlangga University Press, 2006.

[4] M. R. Garey and D. S. Johnson, “‘Strong’ NP-Completeness Results: Motivation, Examples, and Implications,” *J. ACM*, vol. 25, no. 3, pp. 499–508, 1978, doi: 10.1145/322077.322090.

[5] A. Das, C. Mathieu, and S. Mozes, “The train delivery problem - Vehicle routing meets bin packing,” *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 6534 LNCS, pp. 94–105, 2011, doi: 10.1007/978-3-642-18318-8_9.

[6] P. D. Setyorini, “Kombinasi AHP-PROMETHEE untuk Pemilihan Terminal LNG dan Optimasi Distribusi LNG dengan Metode Set Partitioning Problem A Combined AHP-PROMETHEE for LNG Terminal Selection and Optimization of LNG Distribution using Set Partitioning Problem,” Master Thesis, 2018.

[7] C. A. Kontovas, “The Green Ship Routing and Scheduling Problem (GSRSP): A conceptual approach,” *Transp. Res. Part D Transp. Environ.*, vol. 31, pp. 61–69, 2014, doi: 10.1016/j.trd.2014.03.014.

[8] R. S. J. Tol, “The marginal damage costs of carbon dioxide emissions: An assessment of the uncertainties,” *Energy Policy*, vol. 33, no. 16, pp. 2064–2074, 2005, doi: 10.1016/j.enpol.2004.04.002.

[9] A. A. B. Dinariyana, “A Study on Herterogenous Ship Routing Problem with Multiple Trip and Pickup-Delivery in a Hub-and-Spokes Environment,” University of Tokyo. Dissertation.

[10] K. Fagerholt, “Optimal fleet design in a ship routing problem,” *Int. Trans. Oper. Res.*, vol. 6, no. 5, pp. 453–464, 1999, doi: 10.1111/j.1475-3995.1999.tb00167.x.