Eduvest – Journal of Universal Studies
Volume 4 Number 08, August, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

ANALYZING OPTIMIZATION IN SHIP ROUTING FOR INDONESIA'S LIQUIFIED NATURAL GAS LOGISTICS NETWORK

Alwin Rizky[1], Dendi P. lshak[2]
[1,2] Universtias Indonesia, Jawa Barat, Indonesia
Email: alwinrizkylubis@gmail.com

ABSTRACT

This study focuses on optimizing the ship routing for Indonesia's liquefied natural gas (LNG) logistics network using Mixed Integer Linear Programming (MILP). Indonesia's pivotal role in the global LNG market underscores the need for efficient logistics, especially given the challenges of limited port capacity, infrastructure, fluctuating demand, and environmental impact. MILP techniques were applied to address these challenges by optimizing vessel routes, minimizing costs, and reducing emissions. The research identified bottlenecks within Indonesia's logistics network and proposed optimized shipping strategies that enhance cost-effectiveness and operational efficiency. The findings contribute to sustainable energy logistics and provide actionable insights for stakeholders managing Indonesia's LNG supply chain.

KEYWORDS *LNG Logistics, Ship Routing, Mixed Integer Linear Programming (MILP)*

INTRODUCTION

Indonesia is a key player in the global liquefied natural gas market (Rahmawan & Angelina, 2017), and efficient logistics networks are crucial for optimizing the transportation of LNG (Zarzuelo et al., 2019). In order to ensure Indonesia's competitiveness in the international market, it is crucial to analyze and optimize the efficiency of LNG shipping routes. Shipping NG in the form of LNG offers gas suppliers the ability to reach distant markets (Mutlu et al., 2014). This can be achieved through the implementation of a robust logistics network, including advanced technological solutions for route optimization and risk management (Zarzuelo et al., 2019). By strategically integrating cutting-edge technologies into its logistics framework and prioritizing efficient ship routing strategies, Indonesia can elevate the overall efficiency of its LNG supply chain and solidify its position as a pivotal player in the global LNG market (Budiyanto et al., 2019). Furthermore, by investing in renewable energy sources and exploring new extraction methods,

How to cite:	Alwin Rizky, Dendi P. lshak. (2024). Analyzing Optimization in Ship Routing for Indonesia's Liquified Natural Gas Logistics Network. *Journal Eduvest*. *4*(8): 6590-6599
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

Indonesia could also enhance sustainability within this vital sector. In this particular study, our main focus will be on the analysis and optimization of the ship routing for Indonesia's LNG logistics network by utilizing Mixed Integer Linear Programming techniques. By employing MILP, we aim to minimize costs and enhance the overall efficiency of LNG transportation within Indonesia's vast archipelago (Rusdianto & Siswanto, 2020).

This research holds significant potential for improving the country's LNG supply chain management and contributing to the sustainable development of Indonesia's energy sector. ## Current Challenges in the LNG Logistics Network in Indonesia The LNG logistics network in Indonesia currently faces several challenges that hinder its efficiency and effectiveness (Bittante et al., 2015).These challenges include:

1. Inadequate port capacities: Indonesia's LNG logistics network faces limitations in terms of port capacities, which affects the efficient handling and storage of LNG (Budiyanto et al., 2020).
2. Limited infrastructure: There is a lack of infrastructure, such as terminals and storage facilities, in certain areas of Indonesia, making it difficult to transport LNG to those regions (Budiyanto et al., 2019).
3. Demand-supply dynamics: The demand for LNG fluctuates, and it is essential to ensure that the supply chain can efficiently respond to these fluctuations while maintaining optimal utilization of resources and minimizing costs (Budiyanto et al., 2019).
4. Environmental impact: The LNG logistics network in Indonesia needs to address environmental concerns related to emissions and carbon footprint (Butarbutar et al., 2022).
5. Shipping costs: The cost of shipping LNG across Indonesia's archipelago can be substantial (Budiyanto et al., 2019).

Application of MILP in Ship Routing Optimization MILP techniques can be applied to optimize ship routing in Indonesia's LNG logistics network by considering various factors such as port capacities, shipping costs, demand, and supply dynamics (Rahmawan & Angelina, 2017). By formulating the problem as a MILP model, we can mathematically represent the decision variables and constraints involved in ship routing optimization (Prananda et al., 2022). The objective of the MILP model would be to maximize the efficiency and cost-effectiveness of LNG transportation by determining the optimal routes for shipping LNG from supply terminals to demand locations (Jokinen et al., 2015). To achieve this objective, the MILP model would consider variables such as vessel capacities, routing options, load factors, and transit times (Haoran et al., n.d). To solve the MILP model, various techniques such as cluster analysis, heuristic algorithms, and optimal transportation rules can be used (Papaleonidas et al., 2020). The MILP model would aim to minimize shipping costs by optimizing vessel routing, considering factors such as port capacities and demand-supply dynamics (Bittante et al., 2015). By incorporating these factors into the MILP model, it becomes possible to identify the most efficient and cost-effective routes for transporting LNG within Indonesia's archipelago(Lee et al., 2016). Additionally, the MILP model can also consider environmental objectives, such as minimizing emissions and reducing carbon footprint(Budiyanto et al., 2019). The MILP model can incorporate fuel consumption as a function of payload, fuel price, and freight rate to optimize ship routing for minimum total trip duration or minimum total cost(Dulebenets, 2018).

RESEARCH METHOD

In order to analyze and optimize ship routing for Indonesia's LNG logistics network, data on various factors such as port capacities, shipping costs, and demand-supply dynamics would need to be collected(Zarzuelo et al., 2019). A thorough analysis of the current challenges in the LNG logistics network in Indonesia will also be conducted (Zarzuelo et al., 2019). The methodology for this research paper would involve developing a mathematical model using Mixed Integer Linear Programming techniques. The mathematical model would incorporate various variables and constraints, such as vessel capacities, routing options, load factors, and transit times(Rahmawan & Angelina, 2017). To solve the MILP model, a branch and price algorithm as well as a constraint programming model can be developed. These techniques would consider factors such as fuel consumption, fuel price, and freight rate in order to optimize ship routing for minimum costs or emissions. The MILP model would be tested using real-life data and scenarios from Indonesia's LNG logistics network.

Table 1. Vessel specifications

Vessel Type	LNG Carrier	
Capacity	130,000	m^3
Loading Rate	12	knot
Discharging Rate	10,000	m^3/h
Vessel Speed	10,000	m^3/h
Total Cargo	90%	
Charter Hire	55,029	USD/day

Figure 1. Indonesian LNG Liquification & Regasification Plant

Table 2. Distance Between Port

s	LQF 1	LQF 2	LQF 3	RGF 1	RGF 2	RGF 3	RGF 4
LQF 1	-	690.61	1372.3	2516.5	1797.76	1737.34	1685.15
LQF 2	690.61	-	1011.72	2159.44	1408.19	1352.6	1301.22
LQF 3	1372.3	1011.72	-	1632.71	907.18	855.86	797.62
RGF 1	2516.5	2159.44	1632.71	-	1012.19	1027.96	1037.84
RGF 2	1797.76	1408.19	907.18	1012.19	-	62.82	121.52
RGF 3	1737.34	1352.6	855.86	1027.96	62.82	-	61.52
RGF 4	1685.15	1301.22	797.62	1037.84	121.52	61.52	-

Data Sources

To effectively analyze and optimize the ship routing for Indonesia's LNG logistics network, we will utilize real-world data on port capacities, shipping costs, LNG demand, and supply across different regions of Indonesia. This will provide us with a comprehensive understanding of the current infrastructure and operational dynamics within the country's LNG logistics network.

Methodology

Implementing Mixed Integer Linear Programming models will allow us to formulate the optimization problem for ship routing. We can effectively leverage optimization software and algorithms to solve the MILP models by mathematically representing the decision variables and constraints involved in LNG transportation. This will enable us to obtain optimal solutions for ship routing that minimize costs and enhance the efficiency of LNG transportation within Indonesia's archipelago.

Variable :

x_{ijt} A binary variable indicating whether a ship uses route i during time period t for a trip to unloading location j. $x_{ijt} = 1$ if the ship uses route i during time period t for a trip to unloading location j. $x_{ijt} = 0$ otherwise.

y_t : A binary variable indicating whether a ship is available during time period t. $y_t = 1$ if the ship is available during time period t, $y_t = 0$ otherwise

Parameters:

C_{ij} : Cost of using route i for a trip to unloading location j.

C_{it} : Production capacity at loading location i during time period t.

C_{jt} : Consumption capacity at unloading location j during time period t.

L_{it} : Inventory level at loading location i during time period t.

D_{jt} : Demand at unloading location j during time period t.

T_{ijt} : Travel time using route i during time period t.

K : Number of available ships.

M : A large value representing the cost of the shortage of available ships.

Objective Function:

$$\sum_{i} \sum_{j} \sum_{t} (C_{ij} \cdot x_{ijt}) + M \cdot \sum_{t} (1 - y_t)$$

Minimize Total Cost: The first component of the objective function is to minimize the total cost associated with LNG shipping operations. This cost includes the cost of using ship routes from loading to unloading locations, represented by $C_{ij} \cdot x_{ijt}$. In this model, we aim to find a combination of ship routes that minimizes the total cost, thereby saving operational costs for the company.

Ship Shortage Cost: The second component of the objective function accounts for the cost of ship shortages. This cost is included as an additional cost ($M \cdot \sum t(1 - yt)$) incurred if ships are unavailable during one or more specific time periods. By including this cost in the objective function, we ensure that the solution generated by the model effectively considers ship availability and does not produce solutions where ships are unavailable to meet demand.

Constraints:

1. Ships must meet demand at each unloading location:

$$\sum_{i} \sum_{t} \left(x_{ijt} \cdot P_{it}\right) \geq \sum_{i} \sum_{t} \left(x_{ijt} \cdot D_{jt}\right), \forall j, \forall t$$

2. Ships must choose one route for each trip to the unloading location:

$$\sum_{i} x_{ijt} = 1, \forall j, \forall t$$

3. Ships must consider production and consumption capacities at each location:

$$I_{it} + \sum_{j} \left(x_{ijt} \cdot P_{it}\right) = I_{jt} + \sum_{i} \left(x_{ijt} \cdot D_{jt}\right), \forall i, \forall j, \forall t$$

4. Ships must be available for use in each selected time period:

$$\sum_{t} y_t \geq 1$$

5. Ships can only be used if they are available:

$$x_{ijt} \leq y_t, \forall i, \forall j, \forall t$$

6. Limit on the number of available ships:

$$\sum_{t} y_t \leq K$$

7. Constraint on travel time:

$$\sum_{t} \left(x_{ijt} \cdot T_{ijt}\right) \leq Jadwal\ maksimum\ kapal, \forall i, \forall j$$

Findings and Contributions

Identification of Bottlenecks and Inefficiencies in the Current LNG Logistics Network in Indonesia Through an in-depth analysis of the current challenges facing Indonesia's LNG logistics network, it was determined that inadequate port capacities, limited infrastructure development, demand-supply dynamics, environmental impact considerations, and escalating shipping costs are significant impediments affecting the network's efficiency and effectiveness. Consequently, these bottlenecks obstruct the smooth transportation of LNG within Indonesia's archipelago, resulting in amplified expenses and operational inefficacies.

Development of Optimized Ship Routing Strategies

Applying Mixed Integer Linear Programming techniques has significantly contributed to developing optimized ship routing strategies for Indonesia's LNG logistics network. By formulating the problem as a MILP model and considering variables such as port capacities, shipping costs, demand, and supply dynamics, the research successfully determined the optimal routes for shipping LNG from supply terminals to demand locations. Furthermore, by incorporating environmental objectives into the MILP model, such as minimizing emissions and reducing carbon footprint, it has also made significant contributions to promoting sustainable logistics practices within the LNG transportation sector in Indonesia.

Contribution to the Existing Body of Knowledge

This research significantly contributes to the existing knowledge of logistics optimization by demonstrating the practical application of MILP techniques in the context of LNG transportation in Indonesia. By addressing the identified bottlenecks and inefficiencies in the current LNG logistics network and developing optimized ship routing strategies, this study advances the understanding of effective solutions for enhancing the overall efficiency of LNG transportation, thereby contributing to the sustainable development of Indonesia's energy sector. The findings and methodologies presented in this research provide valuable insights for stakeholders and decision-makers involved in LNG logistics network management and optimization.

RESULT AND DISCUSSION

Optimized Routes and Schedules

After applying the Mixed Integer Linear Programming model to optimize ship routing for Indonesia's LNG logistics network, the following optimized routes and schedules have been obtained. Using some previous assumptions, the results show that the LNG logistics network receives cargo from plants LQF 2 and LQF 3, and the cargo is delivered to four unloading locations: RGF 1, RGF 2, RGF 3, and RGF 4, as detailed in the following distribution table. From this table, it can be concluded that with the excess liquefaction capacity in Indonesia, the LNG produced not only meets domestic needs but the surplus can also be exported to various LNG consumer countries.

Table 3. represent number of cargo shipped from Liquification plant to Regasification plant

	RGF 1	RGF 2	RGF 3	RGF 4	DM
LQF 1	0	0	0	0	8
LQF 2	0	0	1	0	1
LQF 3	3	3	3	3	0

To obtain the optimal solution for ship route selection, a simulation of ship voyages from two loading locations to three unloading locations was conducted with various combinations of the number of ships and compared with the inventory levels at each location. If the inventory level at a liquefaction location exceeds its capacity, it will result in the location ceasing production. Conversely, if the inventory level at a regasification location falls below its minimum threshold, that location will also cease operations. These factors are key parameters for the success of this study.

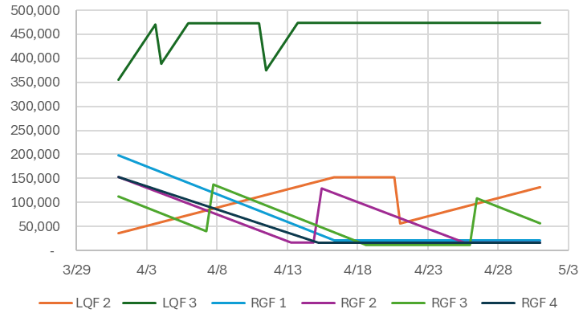

Figure 2. Scenario using 1 vessel

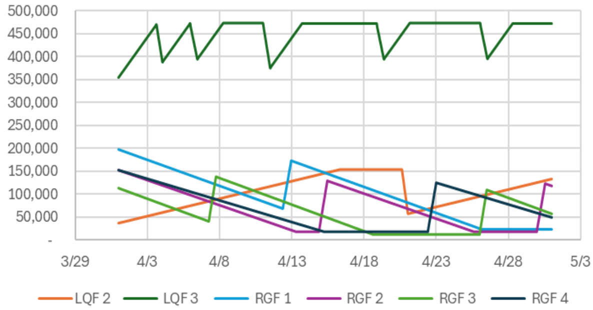

Figure 3. Scenario using 2 vessel

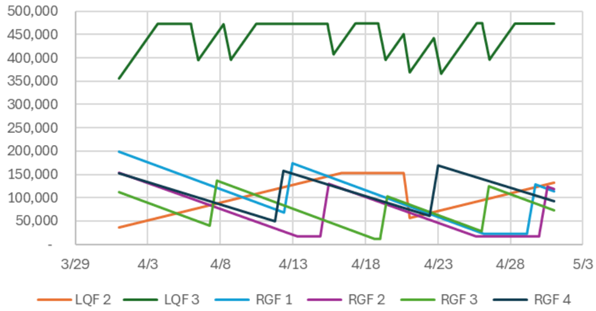

Figure 4. Scenario using 4 vessel

After simulating the inventory levels at each loading/unloading location, the following values were obtained:

Table 4. Inventory level for each plant for every scenario

SCENARIO	LQF 2	LQF 3	RGF 1	RGF 2	RGF 3	RGF 4	CHARTER HIRE
1 VESSEL	4	22	15	7	7	16	55,029
2 VESSEL	4	16	5	6	7	7	110,059
3 VESSEL	4	12	3	6	0	0	165,088

With the conclusion that inventory levels can be controlled by creating various shipping route scenarios and determining ship capacities, the study highlights the importance of strategic planning in logistics management. By simulating different routes and adjusting the number of ships, it is possible to balance supply and demand effectively, ensuring that production sites do not exceed their storage capacities and that consumption sites maintain adequate supplies. This approach not only optimizes operational efficiency but also minimizes the risk of production halts or supply shortages, thereby enhancing the overall reliability and cost-effectiveness of the LNG logistics network.

CONCLUSION

The optimized routes and schedules obtained from the MILP model offer several implications and benefits. Firstly, these routes minimize shipping costs by efficiently utilizing vessel capacities and considering factors such as port capacities and demand-supply dynamics. This leads to cost-effectiveness in LNG transportation within Indonesia's (Siahaan et al., 2020) archipelago. Moreover, the optimized schedules ensure timely delivery of LNG from supply terminals to demand locations, meeting the demand and other operational constraints effectively. This enhances the overall efficiency of LNG transportation within Indonesia and addresses the challenges identified in the current LNG logistics network. In conclusion, the optimized routes and schedules derived from the MILP model offer significant benefits in terms of cost-effectiveness, customer satisfaction, and operational efficiency for Indonesia's LNG logistics network. These findings provide valuable insights for stakeholders and decision-makers involved in LNG logistics network management and optimization (Qiu et al., 2017).

REFERENCES

Bittante, A., Jokinen, R., Pettersson, F., & Saxén, H. (2015, January 1). Optimization of LNG Supply Chain. https://doi.org/10.1016/b978-0-444-63578-5.50125-0

Budiyanto, M A., Pamitran, A S., & Yusman, T. (2019, October 1). OPTIMIZATION OF THE ROUTE OF DISTRIBUTION OF LNG USING SMALL SCALE LNG CARRIER: A CASE STUDY OF A GAS POWER PLANT IN THE SUMATRA REGION, INDONESIA. https://doi.org/10.32479/ijeep.8103

Budiyanto, M A., Riadi, A., Buana, I G N S., & Kurnia, G. (2020, July 1). Study on the LNG distribution to mobile power plants utilizing small-scale LNG carriers. https://doi.org/10.1016/j.heliyon.2020.e04538

Budiyanto, M A., Riadi, A., Buana, I G N S., & Kurnia, G. (2020, July 1). Study on the LNG distribution to mobile power plants utilizing small-scale LNG carriers. https://doi.org/10.1016/j.heliyon.2020.e04538

Butarbutar, R., Gurning, R., & Semin. (2022, January 1). LNG as marine fuel within Indonesia shipping sector, a literature review. https://doi.org/10.1088/1755-1315/972/1/012076

Coyle, D., Durr, C., & Shah, P. (2003, October 5). LNG: A Proven Stranded Gas Monetization Option. All Days. https://doi.org/10.2118/84251-ms

Dulebenets, M A. (2018, March 1). Green vessel scheduling in liner shipping: Modeling carbon dioxide emission costs in sea and at ports of call.

International journal of transportation science and technology, 7(1), 26-44. https://doi.org/10.1016/j.ijtst.2017.09.003

Haoran, Z., Yongtu, L., Qi, L., Xiaohan, Y., Yun, S., & Yabin, Z. (n.d). A three-stage stochastic programming method for LNG supply system infrastructure development and inventory routing in demanding countries. https://www.sciencedirect.com/science/article/pii/S0360544217308459

Jokinen, R., Pettersson, F., & Saxén, H. (2015, January 1). An MILP model for optimization of a small-scale LNG supply chain along a coastline. Applied energy, 138, 423-431. https://doi.org/10.1016/j.apenergy.2014.10.039

Kumar, S., Kwon, H T., Choi, K H., Lim, W., Cho, J H., Tak, K., & Moon, I. (2011, December 1). LNG: An eco-friendly cryogenic fuel for sustainable development. https://doi.org/10.1016/j.apenergy.2011.06.035

Lee, J., Ryu, J., & Chung, H. (2016, July 16). Liquefied natural gas ship-to-ship bunkering chain planning: Case studies of Busan, Singapore, and Rotterdam ports. https://doi.org/10.1177/1475090216659838

Lim, W., Choi, K., & Moon, I. (2013, January 2). Current Status and Perspectives of Liquefied Natural Gas (LNG) Plant Design. https://pubs.acs.org/doi/10.1021/ie302877g

Maxwell, D., & Zhu, Z. (2011, March 1). Natural gas prices, LNG transport costs, and the dynamics of LNG imports. https://doi.org/10.1016/j.eneco.2010.06.012

Mutlu, F., Msakni, M K., Yildiz, H., Sönmez, E., & Pokharel, S. (2014, October 25). A comprehensive annual delivery program for up stream liquefied naturalgas supply chain. European Journal of Operational Research, 120–130

Papaleonidas, C., Lyridis, D V., Papakostas, A., & Konstantinidis, D A. (2020, January 8). An innovative decision support tool for liquefied natural gas supply chain planning. https://doi.org/10.1108/mabr-09-2019-0036

Prananda, I M G., Pratiwi, E., Dinariyana, A A B., & Artana, K B. (2022, January 1). Capacitated Vehicle Routing Problem Optimization for Bali and Nusa Tenggara Natural Gas Distribution. https://doi.org/10.1088/1755-1315/972/1/012022

Qiu, R., Liang, Y., Liao, Q., Yan, X., Shen, Y., & Zhao, Y. (2017, August 1). A three-stage stochastic programming method for LNG supply system infrastructure development and inventory routing in demanding countries. https://doi.org/10.1016/j.energy.2017.05.090

Rahmawan, K A., & Angelina, N. (2017, January 1). Indonesian Maritime Logistics Network Optimization Using Mixed Integer Programming. https://doi.org/10.1051/matecconf/201710817001

Rahmawan, K A., & Angelina, N. (2017, January 1). Indonesian Maritime Logistics Network Optimization Using Mixed Integer Programming. MATEC web of conferences, 108, 17001-17001. https://doi.org/10.1051/matecconf/201710817001

Rusdianto, M., & Siswanto, N. (2020, December 1). Maritime inventory routing problem with undedicated compartments: A case study from the cement industry.

Siahaan, J J A., Pratiwi, E., & Setyorini, P D. (2020, August 1). Study of Green-

Ship Routing Problem (G-VRP) Optimization for Indonesia LNG Distribution. IOP conference series. Earth and environmental science, 557(1), 012018-012018. https://doi.org/10.1088/1755-1315/557/1/012018

Vasiliev, B U. (2017, January 5). Factors Of Environmental Safety And Environmentally Efficient Technologies Transportation Facilities Gas Transportation Industry.

Zarzuelo, I D L P., Freire-Seoane, M J., & Pais-Montes, C. (2019, January 1). Optimisation of the LNG supply chain: a literature overview. https://doi.org/10.1504/ijogct.2019.10026342

Zou, Q., Yi, C., Wang, K., Yin, X., & Zhang, Y. (2022, February 1). Global LNG market: supply-demand and economic analysis. https://doi.org/10.1088/1755-1315/983/1/012051