Distribution Route Optimization using Fleet Size and Mix Vehicle Routing Problem: A Case Study at Bali-Nusa Tenggara LNG Distribution

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Abstract

The distribution process or activities is one of the most important aspects in ensuring the energy demand fulfillment in every country. This study opts for the case of Liquified Natural Gas (LNG) distribution in supporting the sustainable energy demand fulfillment in Indonesia, especially at the Bali-Nusa Tenggara cluster. Indonesia is the biggest archipelago in the world where shipment through the ocean is the most prominent transportation mode. This study implements model fleet size and mixed vehicle routing problem (FSMVRP) combined with mixed-integer linear programming (MILP) to solve the stated problem by performing distribution route optimization. The constraints of this study consist of the fleet specification acceptance toward each terminal, and also the consideration LNG Terminal at Benoa and Makassar as only the warehousing area. Other than the distribution route, the FSMVRP and MILP model can be utilized to model the required fleet number and its utilization that has the minimum cost. This study is expected to enrich the energy distribution optimization literature and the FSMVRP and MILP combination literature in solving distributions problem that has a very strategic influence on the decision making.

Keywords
Distribution, vehicle routing problem (VRP), fleet size and mix vehicle routing problem (FSMVRP), mixed integer linear programming (MILP) and optimization.

1. Introduction
To meet the energy demand, distribution management plays a vital role in supporting the fulfillment of pre-determined energy demand. There have been many studies that aim to find the most efficient road for this case. However, those studies have already determined the fleet number and its type in determining the route. This study tries to approach the minimum distribution route by optimizing and determining the number and type of fleet to be used on that route, where the variable costs related to fuel, maintenance, labor, and other variable costs that affect distribution routes are also considered. There are several types of distribution problems and one of the most popular as a research project is Vehicle Routing Problem or VRP (Bittante, et al., 2018). Vehicle Routing Problem (VRP) itself has been developed based on the conditions and limitations faced by the researchers (Bittante & Saxén, 2020). One of them is the development of heterogeneous vehicle routing problems which are divided into two types based on the availability of the fleet, if it has a predetermined fleet number, it is usually called HF-VRP. On the other hand, if the fleet number has not been determined or not limited it is usually referred to as Fleet Size and Mix Vehicle Routing Problem (FSMVRP) (Jokinen, et al., 2015). In this paper, authors addressed a model Fleet Size and Mix Vehicle Routing

Problem (FSMVRP) to optimize the route. Because FSMVRP is heuristic, we tried to combine it with MILP to convert it to exact with the aim of providing an overall picture of the model to be studied in this study. Some researchers have combined the two models and the results of their work show that the results of the two combined models have lower costs when compared to the non-combine model. The combined model that has been communicated is expected to make minimum routing problems.

1.1 Objectives

The goal of this study is to develop, propose, and formulate an FSMVRP algorithm and mathematical model to identify the distribution scheme in the case of LNG Distribution at Bali – Nusa Tenggara, Indonesia. This study is also expected to verify the model's capability in modeling other problems within distribution-related cases.

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2. Literature Review

2.1 LNG Distribution Scheme

In general, there are several distribution schemes that often occur in the distribution process of LNG to the energy generator located in islands that are separated by waters. Nikolau (2010) stated that there are two LNG distribution schemes that often be used, such as the Hub & Spoke Method, and also the Milk-run Method. Hub & Spoke method is a network scheme where in the destinied area, one or more terminals will be chosen as the "hub" based on its location and demand. This 'hub" will act as the media or the location where the loads are mixed and then transported with the mother vessel for the inter-terminal distribution service in the region. On the other hand, the distribution service from the hub to the terminal on a smaller scale will utilize the feeder's vessel (Hsu & Hsieh, 2005). Then, the Milk-run method is a distribution system that ships or receives the load, such as materials or objects, that are distributed from one or several suppliers to one or more consumers (Nikolaou, 2010).

In the research done by Hsu & Hsieh (2005), the Hub & Spoke scheme/method is compared with the direct shipment method where the direct shipment is considered as the shipment from the origin to the destination without being sent through the consolidation terminal such as the warehouse or cross-docking facilities. The direct shipment is also based on a direct shipment/distribution between the supplier and the retailer or customer (Blumenfeld, et al., 1985). From this study, it can be derived that those two schemes/methods can be more beneficial depending on the distribution situation and the operating region. The Hub & Spoke scheme/method can be more beneficial if there is a multi-supplier with a high product variation. On the other hand, direct shipment can be more beneficial for the lower product variation (Hsu & Hsieh, 2005).

2.1 Vehicle Routing Problem & Fleet Size and Mix Vehicle Routing Problem

The Vehicle Routing Problem (VRP) is often used in operational research where a customer with a known demand is supplied by one or more depots. The goal is to find a set of shipping routes that satisfy some requirement or constraint and provide a minimal total cost (Yeun, et al., 2008). In its development, VRP has undergone many developments according to the conditions to be observed including the limitations of the fleet, capacity, time, multi depot or supply, stochastic or periodic in nature, multi-echelon and several other limitations that arise in the development of VRP (Lin, et al., 2014).

With the development of route selection in real problems, constraints in determining different fleets become a problem that often arises. So, the Heterogeneous Fleet VRP (HF-VRP) logarithm began to appear to answer this problem. Heterogeneous Fleet VRP (HF-VRP) is a variant of VRP that arises when the capacity is seen from a fleet of vehicles (limited or unlimited) of various types, characterized by different capacities and costs available for distribution activities (Koç, et al. 2016; Molina, et al. 2020).

There are two divisions of the problem depending on the available fleet. HF-VRP with unlimited fleets, known as Fleet Size and Mix VRP (FSMVRP), consists of determining the best fleet composition and routing when there is no limit to the number of vehicles available of each type. On the other hand, a variant with a limited number of vehicles called Heterogeneous VRP (HVRP) consists of optimizing routes with a fixed fleet available (Baldacci, et al., 2008; Irnich, et al., 2014; Koç, et al., 2016). Fleet Size and Mix Vehicle Routing Problem (FSMVRP) is one of the VRP developments that focuses on fleets that have different sizes/types and are mixed in 1 VRP function and seek the optimal value by minimizing the total cost function which includes components of fixed costs and variable costs (Golden, et al., 1984).

2.1 Mixed Integer Linear Programming

Generally, the model in FSMVRP is heuristic, however, since the advancement and the emergence of many studies to solve a problem, FSMVRP is often combined with a mathematical model to be exact. The reason for the exact selection is based on the researcher's desire to produce a value that directly represents the conditions in the field, so that the results obtained can help businesses to find out the cost balance if applying this route (Bittante, et al., 2018). With Mixed Integer Linear Programming (MILP) presents a new mixed-integer programming formulation based on a two-commodity network flow approach. New valid inequalities are proposed to strengthen the linear programming relaxation of the mathematical formulation. The effectiveness of the proposed cuts is extensively evaluated on benchmark instances (Baldacci, et al., 2009). With Mixed Integer Linear Programming (MILP) presents a mathematical model to aid in the supply chain design decisions by minimizing the total costs associated with fuel procurement. The use of the model is illustrated by a case study, where the optimal supply chain of LNG for covering certain parts of the energy requirements of a country is designed under different cost structures for LNG and for its land-based transportation (Jokinen, et al., 2015).

3. Model Development

From the model developed by Bittante, et-al., (2018), several developments and modifications are carried out on several objectives' functions, and constraints based on the case of this research, so that this model can represent the real condition. This model modification and development is needed to accommodate the combination between the Milk-run and direct shipment method, whereas the Bittante, et-al., (2018) model is only based on the direct shipment method/scheme. Furthermore, the model from Bittante, et-al., (2018) excludes the fleets' operation cost during the idle condition.

Formulation considers a set of port locations P, separated into two-point subsets S and J, where the former represents the supply and the latter the receiving. Different types of ship K are available for transportation. The routing of the fleet is a model using linear equations and constraints, with mixed-integer linear programming (MILP) problem to be solved. The decision of the fleet determination is the formula with variables zk. Yp,j,k, represent the number of times a ship of type k travel between ports p and j. xp,j,k, indicate the quantity of LNG in ship type k that are transported from port p to port j. vk, representing the average cruising speed, Qk the cargo capacity, Cf k the propulsion cost per kilometer traveled, and Cr k the monthly renting cost of ship k. Demands in the time horizon H for the receiving terminals j are given by Dj, while dp,m express the distances between port p and m. The price of LNG at the supply port s is CL s, while the berthing time at port p is tp. The model is defined as follows:

Minimize

$$\left[\sum_{p\in P}\sum_{m\in P}\sum_{k\in K} C_k^f d_{p.m} y_{p.m.k}\left[\frac{1}{v_k}\right]\right] + \left[H \times \sum_{k\in K} C_k^r z_k\right] + \left\{\left[H \times \sum_{k\in K} 0{,}2 C_k^f z_k\right] - \left[\sum_{p\in P}\sum_{m\in P}\sum_{k\in K} C_k^f d_{p.m} y_{p.m.k}\left[\frac{1}{v_k}\right]\right] \times 0{,}2\right\} + \sum_{m\in P}\sum_{k\in K}\sum_{k\in K} C_S^L Q_k x_{s.j.k} \quad p \neq m \quad [1]$$

The mathematical models' objection function [1] is a modified model, from Bittante, et al., (2018) model, which is expected to accommodate the lack of minimum fleet operational cost during the idle condition. The mathematical function [1] explains about four costs that include the shipping cost that is already adjusted with the speed of the fleet, vessel leasing cost, fleet operation cost during the idle state, and the LNG cost.

Subject to

$$\sum_{p\in P}\sum_{k\in K} Q_k x_{p.j.k} - \sum_{m\in P}\sum_{k\in K} Q_K x_{j.m.k} \geq D_j \quad \forall j \epsilon J \neq p, m \qquad [2]$$

The constraint function [2] describes where the demand (Dj) from the receiving terminal must be fulfilled by the distribution process that is shipped from the supplying terminal.

$$y_{p.j.k} \geq x_{p.j.k} \quad \forall p \epsilon P, j \epsilon J, k \epsilon K \qquad [3]$$

The constraint function [3] describes the integer variable y as the shipping frequency which is defined based on the continued variable x as the shipped LNG volume.

$$\sum_{p \in P} x_{p.j.k} \geq \sum_{m \in P} x_{j.m.k} \quad \forall j \epsilon J, k \epsilon K \qquad [4]$$

$$\sum_{m \in P} y_{m.p.k} = \sum_{m \in P} y_{p.m.k} \quad \forall p \epsilon P, k \epsilon K, p \neq m \qquad [5]$$

The constraint function [4] explains that the Intermediate loading function is prohibited on the receiving terminal in the model. Whereas the shipping frequency of route continuity is explained as the models' constraint [5].

$$Hz_k \geq \frac{1}{v_k} . \sum_{p \in P} \sum_{m \in P} d_{p.m} y_{p.m.k} + \sum_{p \in P} \left(t_p \sum_{m \in P} y_{p.m.k} \right) \quad \forall k \epsilon K, p \neq m \qquad [6]$$

The constraint function [6] is used to determine the fleet types' of number, where "zk" is based on time exertion in the available time horizon.

$$Q_k y_{p.j.k} \leq R_j y_{p.j.k} \quad \forall p \epsilon P, j \epsilon J, k \epsilon K \qquad [7]$$

$$\sum_{j \in J} \sum_{k \in K} Q_k x_{s.j.k} \leq V_s \quad \forall s \epsilon S \qquad [8]$$

The constraint function [7] applied terminal limitation, where "Rj" represents the terminal dimension limit "j" and is declared as the maximum vessel capacity. While the constraint function [8] "Vs" represents the maximum available LNG in the supplying terminal "s" over a period of time. The fleet subset is determined by "L".

$$\sum_{i \in J} \sum_{j \in J} x_{i.j.k} \geq 0 \quad \forall k \epsilon L, i \neq j \qquad [9]$$

The constraint function [9] is the modified model from Bittante, et al., (2018) where previously it is only used in a direct shipment scheme. Therefore, the constraint function [9] is the modified mathematical model that also applies for both milk-run or direct shipment model.

$$x_{s.j.k} \geq f y_{s.j.k} \quad \forall s \epsilon S, j \epsilon J \qquad [10]$$

The constraint function [10] limits the existence of minimum cost that is represented by fraction (f) from the total fleet capacity in performing the distribution to the receiving terminal.

$$\sum_{p \in P} D_j \leq V_s \qquad \forall j \epsilon J, s \epsilon S \qquad [11]$$

$$T_p \geq B_k \qquad \forall p \epsilon P, k \epsilon K \qquad [12]$$

The constraint function [11] limits the receiving terminal demand to not greater than the supply, while the constraint function [12] is related to the number of fleet limits that can harbor in the terminal by considering the receiving terminal dept toward the maximum fleets' draft limit (used to determine the sailing route dept).

4. Case Study: LNG Supply Chain in Bali-Nusa Tenggara

To meet the electricity demand, the demand of LNG can be used as an alternative to help to fulfill the electricity demand. According to Indonesians' Ministry of Energy and Mineral Resources on *Keputusan Menteri Energi dan Sumber Daya Mineral Nomor 13 K/13/MEM/2020*, facilities and studies, related to the LNG distribution process for electricity generation, is required. There are nine power plants at Bali and Nusa Tenggara, which are planned to be converted into LNG-based power plants such as the existing LNG terminal that already existed on the Benoa (Figure 1).

Figure 1. Power Plant and Terminal Supply Location

By considering the Benoa and Makassar terminal as the supplying terminal from Bontang and Tangguh in distributing the supply to the receiving terminal on the power plant location, six route schemes are designed which then will be applied to the developed mathematical model. Therefore, the results will be compared, and the result with the least operational cost will be chosen as the strategy. Several routes scheme that is compared are:

1. Utilize the Benoas' LNG terminal as the warehouse of the supplying terminal to support the warehousing location at the receiving terminal while using the direct shipment as the distribution scheme.
2. Utilize the Benoas' LNG terminal as the warehouse of the supplying terminal to support the warehousing location at the receiving terminal while using the milk-run shipment as the distribution scheme.
3. Utilize the Makassars' LNG terminal as the warehouse of the supplying terminal to support the warehousing location at the receiving terminal while using the direct shipment as the distribution scheme.
4. Utilize the Makassars' LNG terminal as the warehouse of the supplying terminal to support the warehousing location at the receiving terminal while using the milk-run shipment as the distribution scheme.
5. Utilize the Benoas' and/or Makassars' LNG terminal as the warehouse of the supplying terminal to support the warehousing location at the receiving terminal while using the direct shipment as the distribution scheme.
6. Utilize the Benoas' and/or Makassars' LNG terminal as the warehouse of the supplying terminal to support the warehousing location at the receiving terminal while using the milk-run shipment as the distribution scheme.

Table 1. List of Supply and Demand

No	Port	Demand Capacity (m3/year)	Terminal Capacity (m3)
1	Benoa	0	0
2	Makassar	0	0
3	Gilimanuk	82694	2266
4	Lembar	41347	1133
5	Badas	72358	1982
6	Bima	72358	1982
7	Waingapu	20674	1133
8	Labuan Bajo	31010	1699
9	Maumere	20674	1133
10	Kalabahi	31010	1699
11	Kupang	20674	1133
	Total	**392798**	**14160**

Table 2. Distance Matrix

	MKS	BNO	GIL	LBR	BDS	BIM	WGP	LBJ	MAU	KLB	KPG
MKS	0	-	345	296	232	208	301	215	296	411	495
BNO	-	0	135	53	141	228	304	297	439	570	503
GIL	345	135	0	118	184	272	373	341	485	606	568
LBR	296	53	118	0	115	198	302	269	413	536	502
BDS	232	141	184	115	0	103	304	173	318	441	502
BIM	208	228	272	198	103	0	170	100	245	371	371
WGP	301	304	373	302	304	170	0	170	314	283	204
LBJ	215	297	341	269	173	100	170	0	157	285	371
MAU	296	439	485	413	318	245	314	157	0	161	292
KLB	411	570	606	536	441	371	283	285	161	0	190
KPG	495	503	568	502	502	371	204	371	292	190	0

By considering the demand data on each receiving terminal at the power plant locations (Table 1) and the distance between the receiving and supplying terminal (Table 2), a calculation to identify the most optimal route based on the formulated scheme will be performed. Furthermore, several fleet types are also considered in this study which are the LNG Carrier (Table 3) and LNG Barge (Table 4).

Table 3. Data of Armada LNG Carrier

LNG Carrier	LNG Capacity	Draft	Vs	Fuel Consumption		Carter rate
Name	m3	m	knot	ton/day	USD / Day	USD/Day
Tangguh Towuti	145000	12,5	19	145	$196.705	$ 82.000
Ekaputra	125000	10,2	17	110	$149.225	$ 70.000
Pionner Knutsen	1100	3,5	14	7,2	$ 9.767	$ 16.500
TGE 3000	3000	4	12	7,9	$ 10.717	$ 16.500
Green Zeebrugge	5000	4,7	13	8,3	$ 11.260	$ 18.000
Coral Methane	7500	6	15	15	$ 20.349	$ 25.000

Table 4. Data Armada LNG Barge

Bunker Barge	LNG Capacity	Draft	Vs	Fuel Consumption		Carter rate
Name	m3	m	knot	ton/day	USD / Day	USD/Day
AP504	2200	2,6	8	4,1	$ 5.562	$ 6.300
Damen SYP	3000	3,8	9	4,6	$ 6.240	$ 6.900
JD 6401	5000	4,6	9	5	$ 6.783	$ 8.800
Keppel Shuttle 7,5	7500	4	9	8	$ 10.853	$ 10.500

5. Results and Discussion

5.1 Comparing and Choosing the Scheme Strategy

By implementing the model on each strategical scheme, a calculation is performed to get the utilized fleets' number and the operational cost from each scheme.

Table 5. The Fleet Choosing on each Strategy

	Strategy 1	Strategy 2	Strategy 3
AP504	1	1	1
Pionner Knutsen	3	3	3
	Strategy 4	Strategy 5	Strategy 6
AP504	1	1	1
Pionner Knutsen	3	3	3

By implementing the developed model for each strategical scheme, there is no difference found in the fleet's utilization on each scheme (Table 5) where 1 fleet of AP504 and 3 fleets of Pionner Knutsen are used.

Table 6. Cost Comparison on each Strategy

Description	**Annual Operational Cost**		
Strategi	1	2	3
Cost	$ 23.470.920	$ 23.376.170	$ 25.901.630
Strategy	4	5	6
Cost	$ 25.757.000	$ 21.714.310	$ 21.593.760

However, in Table 6 by looking at the operational cost, strategy 6 has the least operational cost compared to other strategies. The cost difference occurs because the implemented routing schemes are different. By looking at the result, it can be concluded that Strategy 6 is the chosen strategy in the case of LNG distribution at Bali-Nusa Tenggara. From strategy 6 itself, the distribution from Benoa and Makassar Terminal, Gilimanuk Terminal, Lembar, and Badas Terminal are supplied from Benoa Terminal. While the distribution scheme from Makassars' Hub has two types of milk-run schemes. In the first scheme, there is a terminal that acts as the hub to support the distribution on the other receiving terminals. This case is represented by the distribution to the Kupang Terminal, where the fleet from Makassar terminal, instead of directly traveling to the receiving terminal at Kupang, utilizes the Waingapu terminal to supply the demand at Kupang. On the other hand, for the second scheme, the fleets that originated from Maumere do not directly return to the supplying terminal in Makassar, instead, they perform LNG distribution to the Labuan Bajo terminal to load the supply shortage from Makassar. Then, they will return back to the Makassar terminal to perform distribution to other locations.

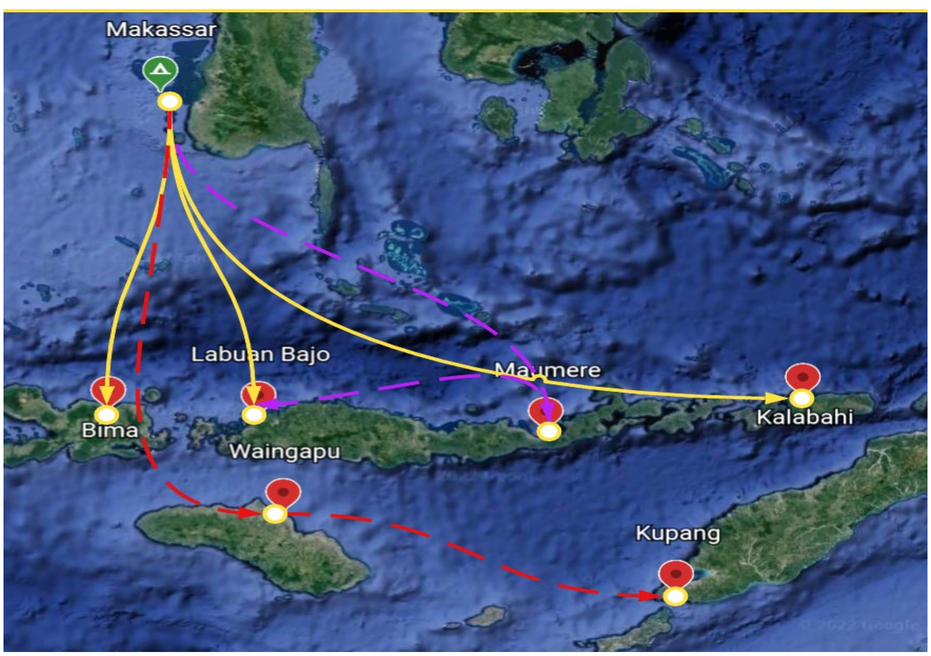

Figure 2. Strategy 6 Distribution Scheme [Makassar as the Distribution Point]

Figure 2 shows the distribution strategy 6 which originates from Makassar Terminal. The yellow lines represent the fleet operational distribution route that is started at Makassar terminal and its return to Makassar terminal again to refill the load, which then the operation can be restarted again. The purple lines refer to the occurring milk-run scheme or route, where the Labuan Bajo terminal not only receive the load from Makassar but also from the Maumere terminal. So that, the fleet, that goes from Makassar to Maumere terminal, performs the distribution process to Labuan Bajo previously, before returning to Makassar terminal. On the other hand, the red lines refer to the distribution scheme from the fleet that serves Waingapu and Kupang terminals. The Waingapu terminal will perform as the hub in supporting the distribution process at the Kupang terminal, where the fleet originating from Makassar will utilize the Waingapu terminal to load the demand at the Kupang terminal, instead of directly traveling to the receiving terminal at Kupang.

Figure 3. Strategy 6 Distribution Scheme [Benoa Distribution Point]

Figure 3 shows the distribution scheme from strategy 6 that utilize the Benoa terminal. The blue lines represent the fleet that performs the distribution from the Benoa terminal and returns back to the Benoa terminal, for reloading, before performing the distribution process again.

6. Conclusion

To answer the challenge of the case of LNG distribution scheme development in Indonesia, especially the Bali-Nusa Tenggare route, using the FSMVRP method to formulate and develop a distribution model is needed to understand which distribution route or strategy that will be implemented. By considering the Benoa terminal and Makassar hub as the supplying terminal for the Bali-Nusa Tenggara power plant as well as utilizing the direct shipment and milk-run method for the LNG distribution, the strategy 6 is considered to give a benefit from the cost generation, which by using Pioneer Knutsen and AP504 fleets it will cost about $21.593.760 as the least cost possible from the six proposed strategies.

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