Study on the LNG Distribution to Bali – Nusa Tenggara Power Plants Utilizing Mini LNG Carriers

H N Abdillah1,2, K B Artana1,2,3, A A B Dinariyana1,2, D W Handani1,2 and P W Aprilla1
1Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember, Surabaya, East Java 60111, Indonesia
2Center of Excellence for Maritime Safety and Marine Installation, Institut Teknologi Sepuluh Nopember, Surabaya, East Java 60111, Indonesia
3Corresponding author: hayyabdillah19042@mhs.its.ac.id

Abstract. LNG has proven to be a green energy source and reliable for environmentally, it’s combustion residue produces much cleaner pollutants than other fossil fuels. The Ministry of MEMR shows that the increasing demand for national electricity reaches 7.5% each year. Mini LNG carrier is an alternative solution for distribution liquid natural gas to archipelago areas with an operational cost effectiveness challenge. Power plants located in Bali and Nusa Tenggara Island are used as a case study. The aim of this study is to calculate LNG distribution using mini LNG carriers, estimate the operational cost in each power plants and risk assessment. The capacity of vessel and power plants set as the constraint, LCT non-conventional as mini LNG carrier carry out 32 ISO Tank 20ft. Hence its is need 26 mini LNG carrier to supply power plant in Bali and Nusa Tenggara as scenario 1, while 7 mini LNG carrier have to provided to supply power plant in Bali and Lombok as scenario 2. Scenario 1 is inefficient because it requires high investment and operational aspects. The final risk assessment based on hazard analysis due to hydrocarbon handling an F-N curve was found to be in ALARP compared to acceptance criteria.

Keywords. Distribution, mini LNG carrier, operational cost, risk assessment

1. Introduction

Global demand for LNG, increasing more than half by 2040, based on IEA [1]. Asia-Pasific region has a potential high demand for liquid natural gas, where this LNG supplied from the Middle East, Indonesia, Australia, and Malaysia [2]. Liquid natural gas is an alternative fuel that produces carbon dioxide and air pollutants than coal when burned to produce electricity. LNG reserves in Indonesia are abundant shown in Figure 1, it can be used for the next 230 years. LNG has proven to be a green energy source and reliable for environmentally, it’s combustion residue produces much cleaner pollutants than other fossil fuels. In the decade between 2008 and 2018, Indonesian power generation rose by 79%, from 149 TWh to 267 TWh. A coal-fired in power plant takes more time to start the engine and stop the process than a gas-fired in the power plant. This flexibility process makes liquid natural gas become an alternative fuel to renewable energy sources like solar and wave power, which are only available when the sun shines and the moving waves [3]. LNG carried by vessel is received by a principal liquid natural gas terminal facilities. Nowadays, terminal facilities are devided into two type facilities, onshore and offshore, offshore facilities set as floating storage & regasification unit called as FSRU [4]. In recent
years, many developing industries have raised their investment in LNG infrastructure facilities, however the development of LNG supply chain in many countries has not been exhaustive [5].

Characteristics of gas business in Indonesia in the last since 1963 used for industrial plant and gas price set as low price, while in 2002 use of liquid natural gas developed into export materials, power generation, petrochemical industry, fertilizer plants and industrial feedstock. The conduct of natural gas business in the future, gas priority for domestic market LNG. The ministry establish a master plant to integrate the national gas distribution plant in Indonesia. Strategy to preparing gas utilization based on among others are prepare for infrastructure upgrades and technology for natural gas process; natural gas price based on regional authority and utilization; the amount of gas provided by supply and demand of consumers throughout Indonesia; clearness of natural gas. Clearness of natural gas utilization policy is needed to coordinate between producers, operational agencies and users. However, the participation of local government is very important in gas utilization; research and development on the academic side for more efficient and effective use of fossil energy [6].

In Indonesia, many power plants that used diesel fuel as the main fuel for power plants are scattered. This trend is causes limited access to accommodate cheaper energy due to geographical aspects. Furthermore, Government subsidy on diesel fuel for power plant is too exaggerated so it needs to be considered in the future. Oil and gas industry in Indonesia still to be an important sector, where set as the main national energy, but also contributes to national incomes, including 12% of the 2014 state budget. These aspects also upgrades the national economic growth. As one of LNG exporting country, the natural gas industry in Indonesia has been experiencing significant transformation. Indonesia is known as one of the natural gas exporting countries which currently occupies the 4th position in the world, however the increasing of economic growth affects the gas consumption in the country. Indonesia should allocate a larger natural gas production drilling to occupy domestic requirement of natural gas. In the future, Indonesia is expected to switch from a gas exporter to a gas importer in order to fulfill the domestic requirement. Moreover, domestic gas utilization in Indonesia is still struggling because the sparse gas infrastructure, fragmented gas market, untransparent domestic pricing regime and uncertain law of oil and gas.

Mathematical model used to solve capacity-based transportation cases. Furthermore, the development of this model is the capacitated distribution problem, with calculate each operational cost. Even though the many research of capacitated distribution problem, not many have to applied it to the case of mini LNG carriers. Mini LNG carrier is an alternative solution for distribution natural gas to archipelago areas with an operational cost effectiveness challenge. In this study there is two alternative scenario, first scenario located in Bali-Nusa Tenggara, while second scenario located in Bali-Lombok. Lombok
Peaker, MPP Lombok, Gilimanuk and Pemaron power plants located in Bali and Lombok Island are used here as a case study (first scenario). There are Lombok Peaker, Sumbawa, Kupang Peaker, MPP Flores, Maumere, Waingapu, MPP Lombok, and Bima power plants set as second scenario, furthermore Benoa set as origin.

Some other researcher described about hazard identification and risk analysis of LNG facilities. Hazard identification arranged by LNG specific scenarios based on past events and studies [8]. Qualitative and qualitative approach used to determine risk assessment and safety aspect of mini LNG carrier. Qualitative approach identify the hydrocarbon hazard and handling system, hence quantitative and qualitative combination approach used to analyze the non-hydrocarbon hazard such as operational system and loading-unloading system. Hazard register devide into fire dan explosion hazard caused by hydrocarbon leakage. The aim of this study is to optimize LNG distribution using mini LNG carriers and calculate the operational cost in each power plants. The capacity of cargo vessel and power plants set as the constraint, LCT non-conventional as mini LNG carrier carry out 32 ISO Tank 20ft. The results of this study will describe the number of mini LNG carriers needed, operational cost and risk assessment for power plants in two scenario, Bali and Nusa Tenggara, Indonesia.

2. Case Study: LNG distribution in Bali and Nusa Tenggara, Indonesia

Power Plant in Bali and Nusa Tenggara will be supplied by LCT non-conventional as mini LNG carrier. Specification of mini LNG carriers, LOA: 50,5m; B: 11,4m; H: 3,5m; T: 2,5m design by BPPT. Recently, most mini LNG carrier networks are constructed using smaller vessels, compared to the ones used in conventional networks. Transport distance could be very short mini LNG carrier networks [4]. In archipelagos like the Indonesia region, many islands do not have adequate water depth nor piersor berths capable of handling large LNG tankers. Thus, mini LNG carrier may be used. LNG terminal project is being developed in Indonesia to supply the power plants [9]. This study focus on Bali and Nusa Tenggara Island, the data in Table 1 are shown the capacity of power plant and LNG demand. Sandards conversion used to calculated the LNG capacity in m³ and the number of ISO tank demand, while each plant consumed 0,2 MMSCFD (Million Standard Cubic Feet per Day) of natural gas per day per 1 MW power rate; 1 MMSCFD is equal to 46 m³ LNG; 1 MMSCFD equal to 1000 MMBTU; 1 ISO Tank is equivalent to 21 m³ of LNG. A preliminary study to develop LCT as mini LNG carrier was done in 2018 [10].

| Power Plant         | Capacity (MW) | MMSCFD | LNG Demands (m³/day) | ISO Tank Demand (unit/day) |
|---------------------|---------------|--------|----------------------|---------------------------|
| PLTMG Lombok Peaker | 136           | 9,07   | 417,07               | 21                        |
| MPP Lombok          | 50            | 10,00  | 460,00               | 24                        |
| PLTG Gilimanuk      | 130           | 8,70   | 398,70               | 20                        |
| PLTG Pemaron        | 80            | 5,30   | 245,30               | 13                        |
| PLTMG Sumbawa       | 50            | 10,00  | 460,00               | 24                        |
| PTLMG Bima          | 50            | 10,00  | 460,00               | 24                        |
| MPP Flores          | 20            | 4,00   | 184,00               | 10                        |
| PLTMG Maumere       | 40            | 8,00   | 368,00               | 19                        |
| PLTMG Waingapu      | 10            | 2,00   | 92,00                | 5                         |
| PLTMG Kupang Peaker | 40            | 2,67   | 122,67               | 7                         |

The draft of the mini LNG carrier are made as low as possible because it serves the coastal area, which has a restricted depth. Table 2 shows the matrix of distance at scenario 1 and Table 3 represent the matrix
of distance at scenario 2. The speed of mini LNG vessel is 5 knots. LNG distribution will be supplied by Benoa terminal as origin. The capacity of power plant in the range of 10-136 MW, which supplied by LNG in range of 92-460 m$^3$/day. Type of power plants could be divided into base load and peaker, hence base load power plants will be operated on 100% load and peaker power plants will be operated on 30% load. LNG distribution is challenging, nowadays the are only few LNG suppliers and supporting facilities have not been prepared, while cost for transformation reached 70% of the delivered natural gas price [11].

| Item | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 |
|------|----|----|----|----|----|----|----|----|----|
| X0   | -  | 65 | 62 | 614| 372| 552| 374| 191| 291|
| X1   | -  | -  | 3  | 566| 352| 448| 306| 109| 202|
| X2   | -  | -  | -  | 563| 355| 451| 302| 111| 205|
| X3   | -  | -  | -  | -  | 356| 539| 244| 588| 405|
| X4   | -  | -  | -  | -  | -  | 182| 117| 205| 93 |
| X5   | -  | -  | -  | -  | -  | -  | 296| 387| 272|
| X6   | -  | -  | -  | -  | -  | -  | -  | 350| 163|
| X7   | -  | -  | -  | -  | -  | -  | -  | -  | 127|
| X8   | -  | -  | -  | -  | -  | -  | -  | -  | -  |

Notes: X0: Benoa-Origin X2: MPP Lombok X4: MPP Flores X6: Waingapu X8: Bima X1: Lombok Peaker X3: Kupang Peaker X5: Maumere X7: Sumbawa

| Item | X0 | X1 | X2 | X9 | X10 |
|------|----|----|----|----|-----|
| X0   | -  | 65 | 62 | 137| 92  |
| X1   | -  | -  | 3  | 135| 89  |
| X2   | -  | -  | -  | 138| 92  |
| X9   | -  | -  | -  | -  | 46  |
| X10  | -  | -  | -  | -  | -   |

Notes: X0: Benoa-Origin X1: Lombok Peaker X2: MPP Lombok X9: Gilimanuk X10: Pemaron

Figure 2 and Figure 3 illustrate the distribution of LNG in scenario 1 and scenario 2. LNG distributed from Benoa Bali as origin to power plant in Lombok Peaker, MPP Lombok, Gilimanuk and Pemaron. Distribution using mini LNG carrier is considered effective and efficient to supply power plants with low gas requirements [12]. Determine on routing, sailing frequency and operational cost are important issues when planning the shipping services [13]. A simple techno-economic approach is provided in this study to determine distribution model for determine sailing frequency, the number of the mini LNG carrier and operating costs include waiting time and shipping time cost. Thomson H., et al [14] considered the parameter in their results clearly show that the cost saving in small LNG distribution strengthens the cost competitiveness of LNG as a fuel.
Frequency analysis of leakage occurrences in components is calculated based on the existing components in the P&ID system. Calculation of component leakage is carried out based on DNV Failure Frequencies Guidelines Process Equipment Leakage Data for Use in QRA. The formula in the equation (1) for calculating component leakage based on these guidelines.

\[ F(d) = C \left(1 + aD^n\right) d^m + Frup \]  \hspace{1cm} (1)

Where
- \( F \): Frequency of leaks (per valve year)
- \( C, m \): Constants representing hole size distribution
- \( a, n \): Constants representing equipment size dependency
- \( Frup \): Additional rupture frequency (per valve year)
- \( D \): Valve diameter (mm)
- \( d \): Hole diameter (mm)

The component leakage scenario is defined into three conditions, total leaks, full leaks and zero pressure. Frequency analysis of pipe leakage is also carried out which serves as the main medium for fluid transfer. Frequency results for each existing equipment refer to DNV. The calculation is used with the following formula in the equation (2)

\[ F(d) = C \left(1 + aD^n\right) d^m + Frup \]  \hspace{1cm} (2)

Where
- \( F \): Frequency of leaks (per meter year)
- \( C, m \): Constants representing hole size distribution
- \( a, n \): Constants representing equipment size dependency
- \( Frup \): Additional rupture frequency (per meter year)
- \( D \): Pipe diameter (mm)
- \( d \): Hole diameter (mm)

Frequency analysis is also carried out in the event of a pump leak which is calculated based on the components in the P&ID system. The calculation is used with the following formula in the equation (3)

\[ F(d) = Cd^m + Frup \]  \hspace{1cm} (3)

Where
- \( F \): Frequency of leaks (per valve year)
C, m : Constants representing hole size distribution
Frup : Additional rupture frequency (per valve year)
D : Pipe diameter (mm)
d : Hole diameter (mm)

The safeguard functions component as an indicator of flow, pressure and temperature. The formula in the quation (4) for calculating component leakage based on these guidelines.

\[ F(d) = C d^m + Frup \] (4)

Where
F : Frequency of leaks (per valve year)
C, m : Constants representing hole size distribution
Frup : Additional rupture frequency (per valve year)
D : Pipe diameter (mm)
d : Hole diameter (mm)

After calculating the frequency of leakage and failure of components in the system, then the identification of failures in the system is carried out using Fault Tree Analysis (FTA). Even Tree Analysis (ETA) in this study is to calculate modeling of events that cause fires and explosions. Fires and explosions occurred because of ignition or explosion. Various of worker category have been clustered into three as shown in Table 4.

| Personnel Group | Worker Category         | POB |
|-----------------|-------------------------|-----|
| LNG Carrier     | Normal operation        | 22  |
|                 | Master                  |     |
|                 | Chief Officer           |     |
|                 | Second Officer          |     |
|                 | Third Officer           |     |
|                 | Radio Operator          |     |
| Deck            | Boatwain                |     |
|                 | Quartermaster           | 3   |
|                 | Sailor                  | 2   |
|                 | Cook                    |     |
|                 | Mess Boy                | 1   |
|                 | Chief Engineer          |     |
|                 | Second Engineer         | 1   |
|                 | Third Engineer          | 1   |
| Engine          | Fourth Engineer         | 1   |
|                 | Engine Foremen          | 1   |
|                 | Oiler                   | 3   |
|                 | Wiper                   | 1   |
| Jetty           | Normal Operation        | 8   |
|                 | HSSE                    |     |
| Mooring         | Mooring Gang            | 2   |
|                 | Mooring Guard           | 2   |
| Operator        | Operator Crane          |     |
|                 | Operator Mobile Crane   | 2   |
| Office          | Normal Operation        | 18  |
|                 | Manager                 | 1   |
| Administration  | Administration Staff    | 2   |
|                 | HSSE                    | 2   |
| Technician      | Technician              | 5   |
| Misc.           | Misc. Worker            | 8   |
3. Result and Discussion

3.1. LNG distribution using mini LNG carrier

The loading and unloading process of LCT ships carrying LNG includes moving the ISO tank using a crane at the port, then LNG ISO tank carried by stacker to the stockpile to be arranged in the stockpile area. The same process applies to empty ISO tanks that will be carried by the ship to the port of origin (Benoa). Figure 4 shows the loading and unloading process, estimated the capabilities of the components were set to determine total loading unloading process such as lift velocity of the crane and stacker, times to lashing on the ship and stockpile, estimated distances. The total time for loading and unloading is 20 hours, this process is supported by the terminal facility (1 crane and 2 stacker). For loading unloading process, it is assumed that lift velocity by crane 25 m/min.; lift velocity by stacker 24 m/min.; velocity of stacker 350 m/min.; lashing process 5 min./unit.

![Figure 4. Loading-unloading LNG ISO Tank](image)

The number of mini LNG carrier to supply each route in Bali and Lombok Island find out by calculating the round trip of vessel. Table 5 represent the total of round trip which consist of loading unloading, time at sea, and slack time. The result shows ISO Tank demand and number of mini LNG carriers. Hence it is need seven mini LNG carrier to supply power plant in Bali and Lombok, five numbers of vessels were used continuously, however two others vessels were used intermittently as shown in Table 6.

| Scenario | Route | Sea Distance (Nm) | Loading-Unloading (h) | Time at Sea (h) | Round Trip (h) | Slack Time (h) | Total (h) | ISO Tank Demand (unit/round trip) | Number of Mini LNG Carrier |
|----------|-------|-------------------|-----------------------|----------------|---------------|---------------|-----------|----------------------------------|---------------------------|
| Scenario 1 | X0-X1-X0 | 130 | 20 | 26.0 | 46.0 | 4.6 | 50.6 | 44 | 1 |
| | X0-X2-X0 | 124 | 20 | 24.8 | 44.8 | 4.5 | 49.3 | 47 | 1 |
| | X0-X3-X0 | 1228 | 20 | 245.6 | 265.6 | 26.6 | 292.2 | 75 | 2 |
| | X0-X4-X6-X0 | 873 | 20 | 174.6 | 194.6 | 19.5 | 214.1 | 123 | 4 |
| | X0-X5-X0 | 1104 | 20 | 220.8 | 240.8 | 24.1 | 264.9 | 204 | 6 |
| | X0-X7-X0 | 382 | 20 | 76.4 | 96.4 | 9.6 | 106.1 | 102 | 3 |
| | X0-X8-X0 | 582 | 20 | 116.4 | 136.4 | 13.6 | 1501 | 144 | 4 |
| | X0-X9-X0 | 274 | 20 | 39.1 | 59.1 | 5.9 | 65.1 | 54 | 2 |
| | X0-X10-X0 | 184 | 20 | 26.3 | 46.3 | 4.6 | 50.9 | 26 | 1 |
| Scenario 2 | X0-X1-X0 | 130 | 20 | 26.0 | 46.0 | 4.6 | 50.6 | 44 | 1+1 |
| | X0-X2-X0 | 124 | 20 | 24.8 | 44.8 | 4.5 | 49.3 | 47 | 1+1 |
| | X0-X9-X0 | 274 | 20 | 39.1 | 59.1 | 5.9 | 65.1 | 54 | 2 |
| | X0-X10-X0 | 184 | 20 | 26.3 | 46.3 | 4.6 | 50.9 | 26 | 1 |

Scenario in Lombok Peaker and MPP Lombok power plants used vessels that operate continously and intermittently moda for each vessels. This alternative is used to minimize opeartional cost. Futhermore scenario in Gilimanuk and Pemaron power plants, each served by 1 vessel and 2 vessels that operate continously. Safety stock is provided by diesel oil in case of delays in LNG distribution to
power plan, diesel oil used for safety stock because the type of power plant could accommodate natural gas and diesel oil as a fuel. Hence its is need 26 mini LNG carrier to supply power plant in Bali and Nusa Tenggara as scenario 1, while 7 mini LNG carrier have to provided to supply power plant in Bali and Lombok as scenario 2.

| Route          | Number of Mini LNG Carrier | Total Trip/Year | Information |
|----------------|----------------------------|-----------------|-------------|
| Scenario 1     |                            |                 |             |
| X0-X1-X0       | 1                          | 180             | Continuous  |
| X0-X2-X0       | 1                          | 180             | Continuous  |
| X0-X3-X0       | 2                          | 30              | Continuous  |
| X0-X4-X6-X0    | 4                          | 45              | Continuous  |
| X0-X5-X0       | 6                          | 33              | Continuous  |
| X0-X7-X0       | 3                          | 90              | Continuous  |
| X0-X8-X0       | 4                          | 60              | Continuous  |
| X0-X9-X0       | 2                          | 53              | Continuous  |
| X0-X10-X0      | 1                          | 80              | Continuous  |

| Route          | Number of Mini LNG Carrier | Total Trip/Year | Information |
|----------------|----------------------------|-----------------|-------------|
| Scenario 2     |                            |                 |             |
| X0-X1-X0       | 1                          | 180             | Continuous  |
| X0-X2-X0       | 1                          | 180             | Intermittent|
| X0-X9-X0       | 2                          | 53              | Continuous  |
| X0-X10-X0      | 1                          | 80              | Continuous  |

### 3.2. Operational Cost

The calculation of operational costs in this study includes fuel oil (A), lubricanting (B), fresh water (C), port cost (D), ship maintenance (E), consumable (F), administration costs (G) and crew salaries (H). The cost assumptions used in this study to determine the operational costs per year of a mini LNG carrier for LNG distribution in Bali and Nusa Tenggara power plants. The assumptions used are based on latest cost reference. Port service rates are provided by Pelindo III Celukan Bawang, port charges consist of berthing service, mooring and jetty services [15], while HFO rates and lubricant rates based on previous literature studies. Maintenance of the vessels calculated by annual survey cost, futhermore each parameter to calculate the operational cost correlated with yoyal trip per year and sailing type, its continous or intermittent. Operational cost depand on total trip/year as shown in Table 7 and Table 8.

| Item | X1   | X2   | X3   | X4-X6 | X5   | X7   | X8   | X9   | X10 | Total/Year[$] |
|------|------|------|------|-------|------|------|------|------|-----|--------------|
| A    | 1.307| 1.273| 2.515| 5.529 | 7.526| 4.108| 5.167| 2.240| 877 | 30.543       |
| B    | 26   | 25   | 45   | 77    | 121  | 38   | 72   | 44   | 17  | 466          |
| C    | 4    | 4    | 4    | 4     | 4    | 6    | 5    | 5    | 3   | 38           |
| D    | 40   | 40   | 80   | 161   | 243  | 121  | 161  | 80   | 40  | 967          |
| E    | 16   | 16   | 5    | 24    | 18   | 24   | 21   | 21   | 11  | 157          |
| F    | 32   | 32   | 63   | 126   | 189  | 95   | 126  | 63   | 32  | 757          |
| G    | 100  | 100  | 201  | 401   | 602  | 301  | 401  | 201  | 100 | 2.407        |
| H    | 51   | 51   | 103  | 206   | 309  | 154  | 206  | 103  | 51  | 1.235        |

**Total** 36.570

**Grand Total (+margin 30%)** 47.541

By comparison, results of scenario 1 and scenario 2 to supply LNG typically employs different scale vessels, its indicated by total number of the vessels. Higher capacity of mini LNG vessel to be occupy
Bali-Nusatenggara power plants, however scenario 2 that supply Bali-Lombok could be selected. This cluster has power plant that are located close to each other and the capacity. LNG supply in Indonesia can run well if all of stackholder arrange and concern the weaknesses and strengths in this business process, include political will of the Government. In Indonesia, LNG price is currently approved by Ministry of Energy and Mineral Resources, so for the contractor, oil and gas company refer to regulation [16]. In another paper, more detailed economic analysis is carried out related to the capex and opex of the lng distribution business scenario.

| Item | X1  | X1-a | X2  | X2-b | X3  | X4  | Total/Year [$] |
|------|-----|------|-----|------|-----|-----|----------------|
| A    | 1.306.958 | 384.826 | 1.272.863 | 565.717 | 2.240.499 | 876.717 | 6.647.580 |
| B    | 25.896 | 25.221 | 44.394 | 17.371 | 7.625 | 11.209 | 131.717 |
| C    | 4.074 | 4.074 | 5.432 | 2.716 | 1.200 | 1.811 | 19.307 |
| D    | 40.205 | 40.205 | 80.409 | 40.205 | 17.757 | 26.803 | 245.584 |
| E    | 16.096 | 16.096 | 21.462 | 10.731 | 4.740 | 7.154 | 76.279 |
| F    | 29.104 | 29.104 | 29.104 | 29.104 | 29.104 | 29.104 | 203.731 |
| G    | 92.593 | 92.593 | 92.593 | 92.593 | 92.593 | 92.593 | 648.148 |
| H    | 47.492 | 47.492 | 47.492 | 47.492 | 47.492 | 47.492 | 332.446 |
| Total |     |     |     |     |     |     | 8.304.792 |
| Grand Total (+margin 30%) | | | | | | 10.796.229 |

3.3 Risk assessment

The risk assessment is caaried out by calculating the frequency and consequence of potential hazard during operation and loading unloading of LNG ISO tank into the stockpile which the layout as shown in Figure 6 (a).

3.3.1 Scenario and frequency analysis

The potential hazard for hydrocarbon leaks in the LNG system on the mini LNG carrier is caused by several factors. Hydrocarbon leakaged will escalate if there is heat source or spark that could create a fire or explosion hazard. The potential hazard occured when to port facilities and the vessel will be carried out by considering the follows loading-unloading from mini LNG carrier, operational system, port activity and facilities aspects. Frequency analysis is carried out to determine probability of component failure, any system failure that occurs can be dangerous. The methods used to analyze the frequency are Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). The consequences model based on three category LNG carrier, jetty and office. Distribution impact of workers in the terminal will be seen at the result of consequence modeling. Specific location of the workers distribution called by receiver, where each receiver have a number of hazard event scenario. Table 9 describe the summary of fault tree analysis which devided by four hole scenario.

| No | Hole Scenario |
|----|---------------|
|    | 3 mm | 10 mm | 50 mm | 150 mm |
| 1  | 1.242E-03 | 1.241E-03 | 1.237E-03 | 1.24E-03 |
| 2  | 1.41E-03  | 1.29E-03  | 1.23E-03  | 1.21E-03  |
| 3  | 1.34E-03  | 1.22E-03  | 1.59E-03  | 1.14E-03  |
| 4  | 4.01E-04  | 3.91E-04  | 3.81E-04  | 3.79E-04  |

Event Tree Analysis (ETA) in this study is to calculate modeling of events that cause fires and explosions. ETA modeling based on the gas release event, then find out the frequency value of Jet fire,
Flash fire, VCE and gas dispersion events. Figure 5 illustrated the example of fault tree analysis and event tree analysis for hole scenario 50 mm. Summary with same steps, Table 10 to Table 13 are recapitulation of the ETA analysis for each hazard event in jet fire, VCE, flash fire, and gas dispersion. The largest frequency value is gas dispersion event for all leak hole scenarios, while the smallest frequency value is flash fire event for all leak hole scenarios.

![Fault Tree Analysis](image1)

![Event Tree Analysis](image2)

**Figure 5.** (a) FTA for hole scenario 50 mm (b) ETA for hole scenario 50 mm

| Potential Hazards | 3 mm | 10 mm | 50 mm | 150 mm |
|-------------------|------|-------|-------|--------|
| Jet Fire          | 1.86E-04 | 1.86E-04 | 1.86E-04 | 1.86E-04 |
| VCE               | 6.34E-05 | 6.33E-05 | 6.31E-05 | 6.31E-05 |
| Flash Fire        | 1.48E-04 | 1.48E-04 | 1.47E-04 | 1.47E-04 |
| Gas Dispersion    | 8.45E-04 | 8.44E-04 | 8.41E-04 | 8.41E-04 |

### 3.3.2 Consequences analysis

The consequences analysis from potential hazards includes of fatality, partial and total asset losses, disruption of LNG supply, disruption of electricity supply from power plants. Quantitative risk analysis by analyzing the frequency and consequences of potential events that. The next step is risk mapping to determine risk level from the system, evaluation and mitigation are carried out if a scenario is considered unacceptable. The upper fatality risk for workers in the operation of the facilities has been set at 1.0E-03 per year, hence the lower tier set at 1.0E-05 per year and the risk exposure is considered acceptable region. Area between the upper and lower tiers is the intermediate tier. Risk exposures in the intermediate tier should be reduced to “As Low As Reasonably Practicable” (ALARP).

The total individual risk for each worker category is compared against the risk acceptance criteria, in order to assess whether the risks are in ALARP area, or any risk mitigation to reduction measure is required. The accumulation of fatalities in each scenario will be used as input for risk representation. Figure 5 (a) illustrated the modeling of radiation coverage due to hydrocarbon leaks located near the mini LNG carrier where the loading-unloading process occurs. Figure 5 (b) overview the F-N Curve plot for all fire and explosion scenario. Risk assessment based on hazard analysis due to hydrocarbon handling an F-N curve was found to be in as low as reasonably practicable (ALARP) compared to acceptance criteria.
4. Conclusion

This study discusses the LNG distribution and cost of shipping in four power plants (Lombok Peaker, MPP Lombok, Gilimanuk and Pemaron). The techno-economic model approached in this paper estimated the operational cost for LNG distribution in Bali and Lombok, which range from $19,307 - $6,647,580 depending on the sailing frequency for transport distance range from 62–137 Nm. As discussed in the result and discussion parts, an LNG distribution operating cost typically consists of fuel oil, lubricating, consumable, port services, maintenance, crew cost, insurance and administration. In the earlier paper, the authors informed the object of this study is LCT non-conventional as mini LNG carrier, the main dimension LOA: 50.5m; B: 11.4m; H: 3.5m; T:2.5m. Hence its is need 26 mini LNG carrier to supply power plant in Bali and Nusa Tenggara as scenario 1, while 7 mini LNG carrier have to provided to supply power plant in Bali and Lombok as scenario 2. Based on the the number of vessels from scenario 1 and scenario 2, scenario 1 is inefficient because it requires high investment and operational aspects, so the next study will focus on LNG distribution in Bali and Lombok. Scenario 2 supplied by five numbers of vessels were used continuously, however two others vessels were used intermittently. This alternative is used to minimize operational cost. The final risk assessment based on hazard analysis due to hydrocarbon handling an F-N curve was found to be in as low as reasonably practicable (ALARP) compared to acceptance criteria. Future work from this research can include the study of more advanced LNG terminal selection and the development of techno-economic models by greedy algorithm to determine optimal LNG distribution with more various destination and constrain.

Acknowledgement

The authors are grateful to the Ministry of Research and Technology/National Research and Innovation Agency (Kemenristek/BRIN/LPDP) of Republic Indonesia in publication support by 189/E1/PRN/2020, the Center of Excellence for Maritime Safety and Marine Installation, Institut Teknologi Sepuluh...
Nopember, Surabaya and our research partner Agency for the Assessment and Application of Technology (BPPT).

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