Quantitative Risk Assessment of LNG Terminal

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Abstract. According to the report of Agency for the Assessment and Application of Technology of Indonesia in 2019, it is stated that the demand for natural gas in Indonesia is predicted to increase from 1,516 Billions Standard Cubic Feet (BSCF) in 2017 to 4,723 BSCF or increase by an average of 3.5% per year in 2050. The most effective way in distributing natural gas nowadays is in the form of LNG. A national gas company together with a port company planned to build an LNG Terminal in a port area of Semarang, Central Java. This terminal will occupy the area based on the ultimate plan of the port which allocates the land expansion area of ± 5,200 m² as liquid bulk area. The existing terminal is already being used as fuel storage for Methanol and High Speed Diesel (HSD). The designed LNG Terminal facilities consist of storage tanks with a capacity of 10,000 m³, LNG marine loading arm, filling stations, and equipped with jetty that capable to serve 22,000 m³ LNG vessel with length up to 160m. This paper addresses on the assessment of risk that may occur on the designed LNG Terminal. The risk assessment is carried out in several stages, beginning with identifying hazards using Hazard and Operability (HAZOP) followed by analysing the frequency of hazard using Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) methods to find out the type potential hazards and its frequency. The next stage is the analysis of the consequences using fire modelling method is carried out. The level of risk is represented by mapping the result of frequency and the consequence analysis into f-N Curve according to UK-HSE. Mitigation by means of Layers of Protection Analysis (LOPA) is carried out if the risk is laid in unacceptable region.

1. Introduction

Natural gas is the third most used primary energy in the country after petroleum and coal. For this reason, natural gas holds an important role in the energy mix policy in Indonesia. The government is aggressively continuing to encourage the utilization of domestic natural gas, including through the development of natural gas infrastructure to stimulate domestic industries and maintain a cleaner environment. According to the annual report on the 2018 development achievements of the Ministry of Energy and Mineral Resources, 60.93% of Indonesia’s natural gas utilization was absorbed by domestic and 39.07% [1]. According to the report of Agency for the Assessment and Application of Technology of Indonesia in 2019, it is stated that the demand for natural gas in Indonesia is predicted to increase from 1,516 Billions Standard Cubic Feet (BSCF) in 2017 to 4,723 BSCF or increase by an average of 3.5% per year in 2050 [2]. Figure 1 shows Chart of Indonesian Natural Gas Utilization in 2014 to 2018, the graph shows value of exports every year has decreased while for domestic needs tends to increase every year.
Figure 1. Chart of Indonesian Natural Gas Utilization in 2014 to 2018

Figure 2 shows Central Java natural gas supply-demand chart, natural gas supply (supply) to the central part of Java in 2018 reached 79.98 MMSCFD with details of Existing Supply of 77.48 MMSCFD and Project Supply of 2.50 MMSCFD. To support this matter, one of the National Gas Company plans to build an LNG receiving terminal of Port in Central Java. The facility of Terminal LNG will consist of Onshore Storage Tank and Filling Station Unit. LNG will be transferred from LNG carrier to Onshore Storage Tank. LNG transferred to Onshore Storage Tank by using flexible hose through the LNG unloading line along 180m across the jetty. BOG that produced in the Storage Tank due to the presence of natural heat in the leak will be delivered to BOG compressor through BOG line which then compresses to CNG form. The capacity of Storage Tank is 10,000 m³ and will be in continuous operation to supply natural gas to Central Java gas distribution system.

The risk analysis began with hazard identification, the method used for hazard identification is HAZOP (Hazard and Operability Study). The initiating event on each existing components are acquired from DNV Failure Frequency [3]. Frequency calculations use the Fault Tree Analysis and Event Tree Analysis methods. The consequences calculations are done with Fire Modelling uses ALOHA software to know how it impacts the possible dangers. Based on the results of the mapping
using the risk matrix UK-HSE. If the resulting risks in unacceptable, therefore mitigation with LOPA (Layer of Protection Analysis) needs to be conducted. The results of the risk assessment indicate that the potential fire hazard that occurs in LNG Terminal are jet fire, flash fire, pool fire, vapor cloud explosion, and gas dispersion with each scenario of leakage bore 1 mm, 3 mm, 10 mm, 50 mm, and 150 mm

2. Method
The methodology of this research consists of several stages, starting with hazard identification, then proceed with frequency and consequence analysis where the results of the analysis will be mapped in the f-n curve. Mitigation is carried out if the risk is laid in the unacceptable region

2.1 Hazard Identification
Hazard identification starts from analyzing the function of a system and the process of a system and then identifying the potential hazards that can occur in a system and a process that can cause risk or loss. In this study, several forms of danger can occur when a gas release occurs from the system. If the release of the gas is exposed to sources of ignition, then the risk that can occur is jet fire, flash fire, and vapor cloud explosion. Meanwhile, gas releases that occur without being exposed to sources of ignition will cause gas dispersion. In this research, the HAZOP method was applied using hazard identification guidelines with BS IEC 61882: 2001 standard

2.2 Frequency and Consequence Analaysis
Frequency analysis calculations using the fault tree analysis (FTA) method to calculate the probability of failure of a system based on HAZOP references. Fault Trees is one of the most commonly used system reliability evaluation methods, especially in safety oriented systems [4]. Followed by using event tree analysis (ETA) to find out the frequency level causing the event. Event Tree is a diagram that shows all the events that might occur in the system [4]. Analysis of the consequences of each hazard is conducted using fire modeling model. An open source fire modeling software called ALOHA.

2.3 Risk Mapping
Frequency analysis and consequence analysis carried out must be related to one another. Then the merger representation is done by creating a risk mapping. In this research, the level risk represented by mapping into F-N Curve according to UK-HSE

2.4 Mitigation
Mitigation recommendations are carried out in each node's hazard scenario. Mitigation recommendations are carried out to reduce the value of the frequency of events by adding safeguards according to the IPL standard on the LOPA so that the value of the risk level from unacceptable risk or ALARP becomes an acceptable.

3. Result and Discussion
The object used as this research is the construction of the LNG receiving terminal located in Central Java. Figure 3 shows the design layout of the LNG Terminal. The LNG terminal studied is located in central Java. This terminal will occupy an area based on the final port plan which allocates an area of ± 5200m² of land expansion as a liquid bulk area. The existing terminal is already used as fuel storage for Methanol and High-Speed Diesel (HSD). The LNG terminal is also located between the unloading terminal for wheat flour and the unloading terminal for urea fertilizer.
3.1 Hazard and Operability (HAZOP)

HAZOP is a systematic way to identify possible hazards in the work process. In this approach, the process is broken down into steps, and every variation in work parameters is considered for each step, to see what could go wrong [5]. In this research used the British HAZOP BS IEC 61882: 2001 standard. Based on the HAZOP standard, the thing to do is divide the processing system into parts or nodes [6]. In this research, the system to be identified has been divided into four nodes based on the Piping and Instrument Diagram (P&ID). Node determination can be seen in Table 1 and Figure 4.

| Node | Node Description                  | Material |
|------|-----------------------------------|----------|
| 1    | LNG Carrier to Storage Tank       | LNG      |
| 2    | LNG Carrier to Storage Tank       | LNG      |
| 3    | Storage Tank to BOG Compressor    | GAS      |
| 4    | Storage Tank to Filling Station   | LNG      |

Figure 3. Design layout of LNG Terminal

Figure 4. Node determination on all existing systems
Table 2 shows the result of the hazard identification that may occur in the system using HAZOP method

Table 2. Example HAZOP Sheet for Node 1

| No | Guide Word | Deviation | Possible causes | Consequences | Safeguard | Comments | Action Required |
|----|------------|-----------|----------------|--------------|-----------|----------|----------------|
| 1  | No Flow    | Gate Valve is blocked | There is no LNG supply from LNG Carrier to Storage Tank | Add Flowmeter | Not acceptable | Check the condition of the valve and flowmeter before operating |
|    |            | Specange Flange is closed | | | | |
|    |            | Ball Valve 1 & 2 are blocked | | | | |
|    |            | Pipe is cracked | System leakage that can cause fire and explosion | None | Not acceptable | Conduct regular monitoring of pipe conditions |
| 2  | Less       | Ball Valves are opened | Low gas flow and gas release leads to fire and explosion | Pressure indicator (PI 001) and pressure transmitter (PT 001) | Not acceptable | Check valve condition and flowmeter before operating |
|    | Less Flow  |             | Gas releases which can cause fire and explosion and cannot send information to the pressure indicator | Pressure indicator (PI 001) and pressure transmitter (PT 001) | Not acceptable | Monitor and maintain equipment regularly |
| 3  | More       | External Heat | Boil off gas increased | Temperature indicator (TI 001) and Pressure indicator (PI 001) and pressure transmitter (PT 001) | Not acceptable | Monitor and maintain equipment regularly |
|    | More Pressure | Ball Valves are blocked | Causes overpressure which can caused fire and explosion | | | |
| 4  | As well as as distortion | Environment condition and age of the pipe (LNG-01-001-D-01) | Pipeline and gas release leaks | None | Not acceptable | Monitor and maintain equipment regularly |
| 5  | Other than as distortion | Cracked valves | Gas release which can caused explosion and fire | None | Not acceptable | Periksa kondisi equipment sebelum beroperasi |

3.2 Fault Tree Analysis
From result of Hazard Identification carried through using HAZOP method there are 4 nodes in this system. In analyzing the frequency of this research the beginning of the fire explosion was caused by the incident gas leak. Gas release events are caused by system leakage (system leakage) and system failure (system failure). That standard used in frequency analysis is Det Norske Veritas (DNV) Failure
Frequencies Guidelines Process Equipment Leak Frequency Data for Use in Quantity Risk Assessment (QRA). The FTA calculations was done using Relex, reliability software by giving five scenarios of leakage hole diameters; 1) hole diameter 1 mm, 2) hole diameter 3 mm, 3) hole diameter 10 mm, 4) hole diameter 50 mm, and 5) hole diameter 150 mm, Figure 5 shows an example of FTA calculation for node 1 scenario 4. Table 3 shows the summary of frequency analysis using FTA.

Table 3. Summary of frequency analysis by means of FTA for all nodes and scenario

| Node | Bore Scenario | 1 mm | 3 mm | 10 mm | 50 mm | 150 mm |
|------|---------------|------|------|-------|-------|--------|
| 1    | 1 mm          | 1,66,E-02 | 7,55,E-03 | 3,41,E-03 | 1,47,E-03 | 1,01,E-03 |
| 2    | 1 mm          | 1,66,E-02 | 7,55,E-03 | 3,41,E-03 | 1,47,E-03 | 1,01,E-03 |
| 3    | 1 mm          | 6,59,E-03 | 2,90,E-03 | 1,24,E-03 | 4,74,E-04 | 6,38,E-04 |
| 4    | 1 mm          | 1,37,E-02 | 5,85,E-03 | 2,36,E-03 | 7,93,E-04 | 4,40,E-04 |

3.3 Event Tree Analysis

ETA method in this research to calculate the modeling of events that cause fire and explosion. The fire and explosion itself starts with ignition or in this research the ETA modeling scheme starts with a gas release event which is the final result of the FTA analysis. The scenario used as the final consequence of fire and explosion in this final project is flash fire, jet fire, pool fire, VCE and gas dispersion. To find out the frequency of occurrence of ignition causes of fire and explosion used secondary data from the Chemical Process Quantitative Risk Analysis 2nd Edition. Figure 6 shows an example of ETA calculation for node 1 scenario hole 50 mm. Table 4 shows the summary of frequency analysis using ETA.
**Figure 6.** The frequency of occurrence of hazards through ETA for node 1 scenario hole 50 mm

**Table 4.** Summary of frequency analysis by means of ETA for all nodes and scenario

| Node | FREQUENCY OF EVENT / HOLE DIAMETER | Jet Fire |
|------|-----------------------------------|---------|
|      | 1mm | 3mm | 10mm | 50mm | 150mm |
| 1    | 2,50E-03 | 1,13E-03 | 5,11E-04 | 2,20E-04 | 1,52E-04 |
| 2    | 2,50E-03 | 1,13E-03 | 5,11E-04 | 2,20E-04 | 1,52E-04 |
| 3    | 9,88E-04 | 4,36E-04 | 1,86E-04 | 7,12E-05 | 9,57E-05 |
| 4    | 2,06E-03 | 8,77E-04 | 3,54E-04 | 1,19E-04 | 6,60E-05 |

| Node | FREQUENCY OF EVENT / HOLE DIAMETER | VCE |
|------|-----------------------------------|-----|
|      | 1mm | 3mm | 10mm | 50mm | 150mm |
| 1    | 9,34E-04 | 4,24E-04 | 1,91E-04 | 8,23E-05 | 5,67E-05 |
| 2    | 9,34E-04 | 4,24E-04 | 1,91E-04 | 8,23E-05 | 5,67E-05 |
| 3    | 3,70E-04 | 1,63E-04 | 6,97E-05 | 2,66E-05 | 3,58E-05 |
| 4    | 7,71E-04 | 3,28E-04 | 1,33E-04 | 4,45E-05 | 2,47E-05 |

| Node | FREQUENCY OF EVENT / HOLE DIAMETER | Flash Fire |
|------|-----------------------------------|----------|
|      | 1mm | 3mm | 10mm | 50mm | 150mm |
| 1    | 9,34E-04 | 4,24E-04 | 1,91E-04 | 8,23E-05 | 5,67E-05 |
| 2    | 9,34E-04 | 4,24E-04 | 1,91E-04 | 8,23E-05 | 5,67E-05 |
| 3    | 3,70E-04 | 1,63E-04 | 6,97E-05 | 2,66E-05 | 3,58E-05 |
| 4    | 7,71E-04 | 3,28E-04 | 1,33E-04 | 4,45E-05 | 2,47E-05 |

| Node | FREQUENCY OF EVENT / HOLE DIAMETER | Pool Fire |
|------|-----------------------------------|----------|
|      | 1mm | 3mm | 10mm | 50mm | 150mm |
| 1    | 9,34E-04 | 4,24E-04 | 1,91E-04 | 8,23E-05 | 5,67E-05 |
| 2    | 9,34E-04 | 4,24E-04 | 1,91E-04 | 8,23E-05 | 5,67E-05 |
| 3    | 3,70E-04 | 1,63E-04 | 6,97E-05 | 2,66E-05 | 3,58E-05 |
| 4    | 7,71E-04 | 3,28E-04 | 1,33E-04 | 4,45E-05 | 2,47E-05 |
3.4 Consequences Analysis

Risk assessment is the result of a combination of frequency analysis and consequence analysis. Therefore, the next step in risk assessment is to analyze the consequences. Consequence analysis starts with determining the receiver and then modeling the hazard using ALOHA fire modeling software. Hazard modeling in the form of jet fire, flash fire, pool fire, and vapor cloud explosion. Determination of the hazard location is used to analyze the consequences using fire modeling software, from the location of the receiver's point, it can be seen how much impact is generated by the hazard that occurred and the number of people exposed to the hazard. For the determination of the receiver and the number of crew can be seen in Table. 5

| Node | Receiver                                           | Number of crew |
|------|----------------------------------------------------|----------------|
| 1    | LNG Carrier Crew and Manifold Jetty Crew           | 26             |
| 2    | LNG Carrier Crew and Manifold Jetty Crew           | 26             |
| 3    | Management, operator, general worker              | 8              |
| 4    | Management, operator, general worker, security, and truck driver | 15             |

An example of one of the results of fire modeling using jet fire scenario on bore leakage (50mm) on the pipe from the LNG Carrier to the storage tank is given in Figure 7.

There are three circles in the picture with different colors where each color represents for each concentration of heat radiation, yellow with a heat concentration of 2 kW / m$^2$, blue with a heat concentration of 5 kW / m$^2$ and red color with a heat concentration of 10 kW / m$^2$. The 10 kW / m$^2$ area is an area that can cause death. Table 6 is the recapitulation of the Jetfire consequences analysis at each node and the leak scenario that has been determined using daytime conditions using fire modeling software for societal risk in the LNG Terminal.
Tabel 6. Summary of jet fire consequence analysis (50mm hole diameter)

| NODE | Hole diameter (mm) | Jet Fire Frequency | Societal Consequence |
|------|-------------------|-------------------|---------------------|
| 1    | 10                | 5,11E-04          | 6                   |
|      | 50                | 2,20E-04          | 8                   |
|      | 150               | 1,52E-04          | 10                  |
| 2    | 10                | 5,11E-04          | 6                   |
|      | 50                | 2,20E-04          | 8                   |
|      | 150               | 1,52E-04          | 10                  |
| 3    | 10                | 1,86E-04          | 4                   |
|      | 50                | 7,12E-05          | 4                   |
|      | 150               | 9,57E-05          | 6                   |
| 4    | 10                | 3,54E-04          | 4                   |
|      | 50                | 1,19E-04          | 6                   |
|      | 150               | 6,60E-05          | 8                   |

3.5 Risk Mapping

After frequency analysis and consequence analysis on a system, the next step is risk mapping. In this research the risk mapping is carried out using the UK Offshore f-N Curve standard. The consequences resulting from the f-N Curve risk mapping are in the form of societal risk. f-N Curve itself is the result of the relationship between the frequency of events (f) with the number of people (n) or known by societal risk which is the impact of an event. The risk in practical manner would be acceptable if risk in the f-N curve laid at the most in ALARP area. Figure 8 shows the f-N curve of jet fire at node 1 given hole diameter (50mm).

![F-N Curve](image_url)

Figure 8. Example of risk mapping (f-N curve) for jet fire (50 mm)

Based on the results of the mapping on the consequence analysis on all nodes and scenarios using the f-N Curve standard shows that the risk laid in acceptable and as low as reasonably practicable (ALARP) regions.
3.6 Mitigation
For example, shown of mitigation recommendations on node 1 scenario 10 mm for jet fire events in the form of the addition of gas detector, pressure alarm, and temperature alarm. The addition of these components reduces risk from unacceptable risk to transition risk or acceptable risk and available on the LOPA worksheet as follows on the Table 7.

| Scenario Number: | Node: | Scenario Title: | Risk Level: |
|------------------|-------|-----------------|-------------|
| 1 | LNG Transfer from LNGC to Storage Tank | Gas release for Jet Fire at 10 mm | ALARP |

| Date: 30-5-2020 | Description | Probability (per Year) |
|-----------------|-------------|-----------------------|
| Consequence (Description) | Fire and explosion event category Jet Fire because over pressure |
| Risk Tolerance Criteria (Frequency) | Tolerable risk of a hazard event | 1,00E-06 |
| Initiating Event (Frequency) | System leakage and failure | 3,41E-03 |
| Frequency reduction required | 1,00E-04 |
| Enabling Event | N/A | N/A |
| Ignition Probability | Immediate Ignition | 1,50E-01 |
| Frequency of Unmitigated Consequence | 5,11E-04 |
| Independent Protection Layers (IPL) & Probability of Failure on Demand (PFD) |
| IPL & PFD | Gas Detector | 1,00E-01 |
| | Pressure Alarm | 4,22E-02 |
| | Temperature Alarm | 5,22E-02 |
| Total PFD for all IPLs | 2,20E-04 |
| Frequency of Mitigated Consequence | 1,13E-07 |
| Risk Tolerance Criteria Met (Yes/No): | ACCEPTABLE |
| Action Required to Meet Risk Tolerance Criteria: | Install Gas detector, Pressure alarm and Temperature Alarm |
| Notes: | Inspection, testing and maintenance of every IPL equipment should be performed by personnel who are capable of verifying integrity and reliability of unit process equipment (e.g. Maintenance Division) |

4. Conclusion
Based on the results of the risk assessment of the LNG terminal located in Central Java, it can be concluded that the hazards that can occur are in the form of jet fire, flash fire, pool fire, and VCE events. Based on the result of the risk mapping shows that all of the risk laid in acceptable and as low as reasonably practicable (ALARP) regions, then mitigation recommendation is taken by adding safeguard components in the form of gas detectors, pressure alarms, temperature alarms to reduce risk so that it will go down to acceptable regions.
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