Considerations for Proponents when Conducting QRA for LNG Bunkering SIMOPS

American Petroleum Institute (API)

Report No.: PP142228-2, Rev. 3
Document No.: 1XABNXQ-2
Date: 13 June 2016

Project name:	Considerations for Proponents when Conducting QRA for LNG Bunkering SIMOPS	
Report title:	Considerations for Proponents when Conducting QRA for LNG Bunkering SIMOPS	
Customer:	American Petroleum Institute, 1220 L Street NW Washington, DC 20005-4070 United States	
Customer contact:	Amy Farrel	
Date of issue:	13 June 2016	
Project No.:	PP142228	
Organization unit:	Maritime Advisory – Americas	
Report No.:	PP142228-2, Rev. 3	
Document No.:	1XABNXQ-2	

Det Norske Veritas (U.S.A.), Inc.
Oil & Gas
Maritime Advisory – Americas
1400 Ravello Dr
Katy, TX 77449
United States
Tel: +1 281 396 1000

Applicable contract(s) governing the provision of this Report:

Objective:

Prepared by:	Verified by:	Approved by:
Hao Chen Consultant, Risk Advisory Services	Jan Hagen Andersen Senior Principal Engineer/ BDL Solutions	Bjorn-Harald Bangstein Regional Manager
Lindsay Deal Senior Consultant, Risk Advisory Services	Tone Rice Head of Section, Risk Advisory Services	

DNV GL Distribution:

☒ Unrestricted distribution (internal and external)
☐ Unrestricted distribution within DNV GL Group
☐ Unrestricted distribution within DNV GL contracting party
☐ No distribution (confidential)

Keywords:
LNG, Bunkering, QRA, SIMOPS

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	7 December 2015	Draft issue	HCHEN	JAND	BBANG
1	21 December 2015	Revised Draft	HCHEN	JAND	BBANG
2	25 April 2016	Final	LDEAL	JAND	BBANG
3	13 June 2016	Final	LDEAL	TRICE	BBANG

Table of contents

List of Abbreviations

Acronym	Meaning
ALARP	As Low As Reasonably Practicable
ANGA	America's Natural Gas Alliance
API	American Petroleum Institute
CTAC	USCG Chemical Transportation Advisory Committee
DOE	U.S. Department of Energy
DWT	Deadweight Tonnage
HAZID	Hazard Identification
HP	Horse Power
IR	Individual Risk
ISO	International Organization for Standardization
LFL	Lower Flammability Limit. LFL is the lower end of the concentration at which a flammable gas in air can ignite under ambient conditions.
LNG	Liquefied Natural Gas. LNG is produced in large liquefaction plants as an ambient pressure cryogenic fluid at about -161°C (-258°F). However when used as a transport fuel it is usually warmed a little and at 4 to 8 bar pressure (60 to 120 psig).
LSIR	Location-Specific Individual Risk
PLL	Potential Loss of Life
PPE	Personal Protective Equipment
PSV	Platform Supply Vessel
QRA	Quantitative Risk Assessment
QRC	Quick Release Coupling
RORO	Roll-on/roll-off Ferries
RP	Recommended Practice
SGMF	Society of Gas as a Marine Fuel
SIMOPS	Simultaneous Operations
TEU	Twenty-foot Equivalent Units
UFL	Upper Flammability Limit. UFL is the highest concentration at which a flammable mixture of gas or vapor can ignite at a given temperature and pressure.
ULCS	Ultra Large Container Ship
USCG	U.S. Department of Homeland Security United States Coast Guard
VLCS	Very Large Container Ship

1 INTRODUCTION

Interest in bunkering with LNG has grown significantly but is not without its challenges. To cost-effectively implement LNG bunkering, it is critical to minimize the time spent at berth. As a result, it is desirable to perform LNG bunkering while performing other tasks at berth, known as simultaneous operations or SIMOPS. Minimizing time spent at the berth reduces operational costs and maximizes usage of available port infrastructure for more vessels in the span of time. SIMOPS are desirable for industry because it wants to maintain as much similarity between diesel and LNG bunkering, while regulators remain diligent because it has the potential to increase the risk to individuals both onboard and nearby.

While it is well understood that SIMOPS changes the risk, the degree (magnitude) of change in risk is not. As a result, the US Coast Guard (1) references ISO/TS 18683:2015 (2) and DNVGL-RP-0006:2014 (3) with regards to allowing SIMOPS activity. Both documents require a Quantitative Risk Analysis (QRA) prior to allowing SIMOPS during LNG bunkering. The US shipping industry currently lacks a standard for performing a LNG bunkering SIMOPS QRA. Consequently, project feasibility is in question because of uncertainty in the approval process due to insufficient understanding of the requirements to conduct a SIMOPS QRA by all stakeholders.

There is a lack of agreed methodology and understanding of the risk introduced with SIMOPS between the different players of the industry. In order to establish a common methodology and better understand the risks introduced by SIMOPS activities, America's Natural Gas Alliance (ANGA[1]), over 20 industry partners and DNV GL have collaborated to organize a workshop and conduct a series of analyses resulting in this report. As a result of this work, DNV GL has

- Expanded on the QRA methodologies currently applied and based on internationally recognized standards (2), (3) and (4) to document an LNG Bunkering SIMOPS methodology.
- Analyzed over 100 identified generic SIMOPS activities to identify those with the most potential to increase risk.

This document is not intended to serve as the QRA for any single, specific project, but rather to facilitate robust, project-specific SIMOPS QRA studies. It aims to show the difference in risk between the SIMOPS in order to guide the proponents on what SIMOPS should be assessed in a project-specific QRA. It does not attempt to identify the SIMOPS which introduce unacceptable risk.

This document and work are also intended to complement and assist the efforts in regards to SIMOPS risk assessment carried out by the Society of Gas as a Marine Fuel (SGMF) and the USCG Chemical Transportation Advisory Committee (CTAC).

[1] ANGA and API were combined into a single trade association effective, January 1, 2016. The combined association continues ANGA's mission under API.

1.1 How to Read this Report

The structure of this report is shown in Figure 1-1. The report describes in Section 2.1 the following seven types of vessels modeled in this study:

- River Push Boat
- Passenger Ferry
- Platform Supply Vessel
- Large Cruise Ship
- Large Container Vessel
- Feeder Container Vessel
- Bulk Carrier (Bulker)

The four bunkering modes are described in Section 2.2:

- Truck to Ship
- Shore to Ship
- Ship to Ship
- Midstreaming

Following the description of vessels and bunkering modes, Section 3 of the report introduces the risk assessment methodology applied in this study.

The results are described and discussed in Section 4. Since Section 4 is the major section in this report, the detailed structure of Section 4 is described and illustrated separately in Figure 1.2.

Based on the obtained results, the summarized conclusions are given in Section 5 and the recommendations for future LNG bunkering SIMOPS risk assessment are provided in Section 6.

The above mentioned sections together with the Reference Section constitute the main report.

This report has two appendices:

- Study Basis for each type of vessel (Appendix A)

  In the Study Basis, the assumptions of conducting a SIMOP QRA for each type of vessel are described in detail.

- Checklist and Guideline for use of SIMOP risk assessment (Appendix B)

  The checklist and guideline assist regulators to review a QRA for LNG bunkering operations with proposed SIMOPS activities, and help other stakeholders to facilitate and guide the process of conducting a QRA for an LNG bunkering facility.

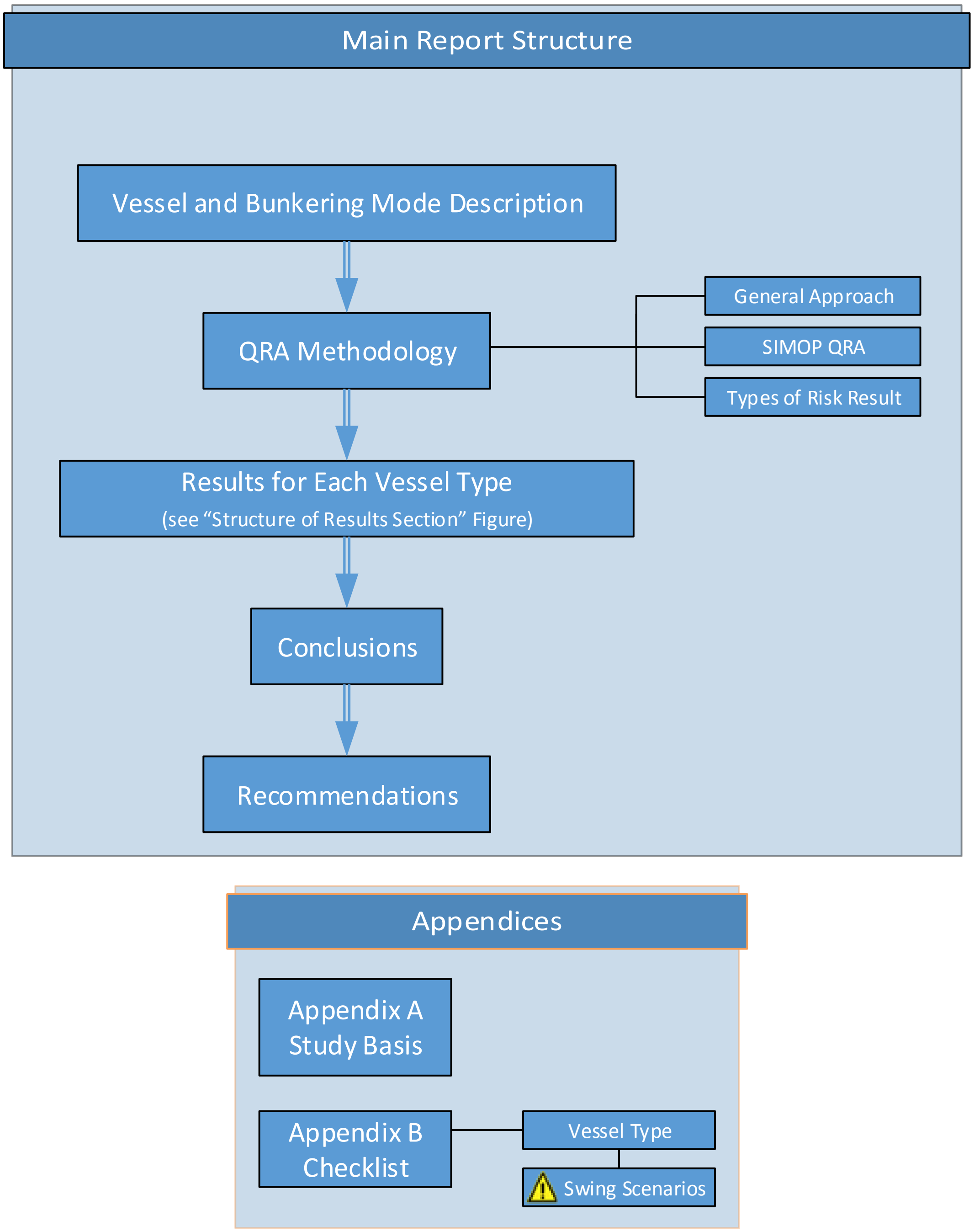
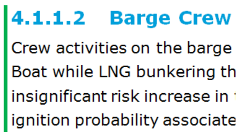


Figure 1-1 Overall Structure of Report

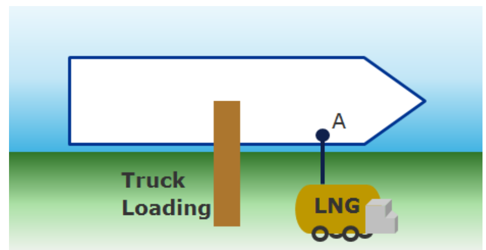
The result section (Section 4) is divided into seven subsections, one for each vessel type assessed. All subsections present and discuss the QRA results.

In the beginning of each subsection, one graph summarizing the risk changes for all applied SIMOPS is shown with color codes corresponding to different risk levels (see Figure 1-2).



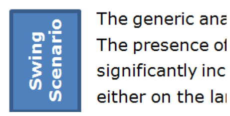
Risk results discussion includes all assessed vessel types, bunkering modes and SIMOPS activities. The discussions for each SIMOPS activity include a colored bar in the left margin which matches change in risk depicted in the figure at the beginning of each new vessel subsection.

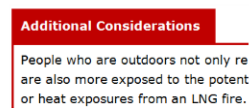
SIMOPS activities with the same level of delta risk for multiple bunkering modes are only discussed for the first vessel where the SIMOPS activity is considered. Mitigation measures are only discussed for the SIMOPS activities increasing risk to more than 2 times the Base Case risk.



For each SIMOPS activity under each bunkering mode for every vessel, one diagram is shown to indicate the location of LNG bunkering and the SIMOPS activity modeled in the study.

For certain SIMOPS, "swing scenarios" are identified which could change the risk category to a higher significance (e.g., from a Category A to a Category B). Red text boxes labelled "Additional Consideration" are used to draw attention to important issues. These text boxes are only utilized in sections for Passenger Ferry and Large Cruise Ship.





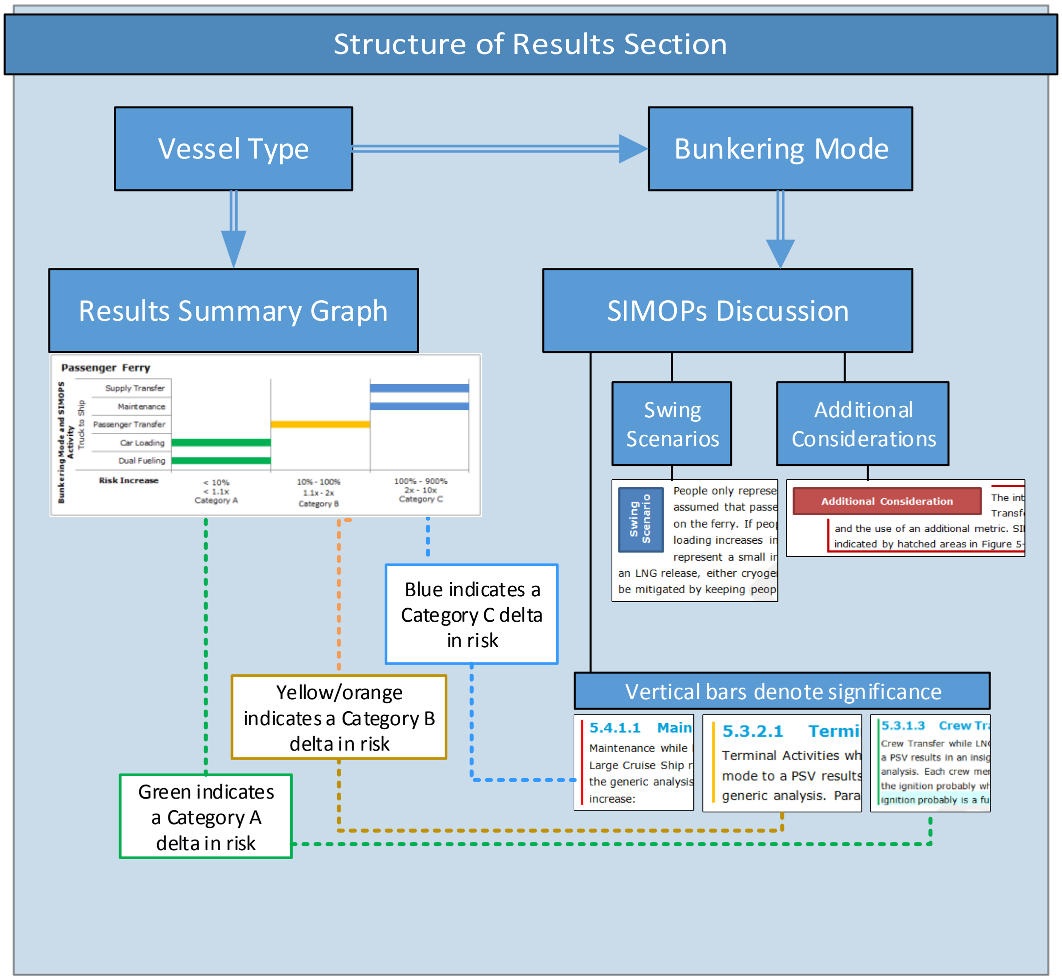


Figure 1-2 Detailed Structure of Results Section

1.2 How to Use this Study

This report can be utilized in several different ways and below is a brief description of who may find it useful.

- Checklists and key scenarios can be
  - Used by **regulators** to ensure the SIMOPS QRA fullfills basic QRA standards
  - Used by **risk assessors** to ensure identified scenarios adequately address the full scope of risks/hazards posed from the LNG bunkering operations & SIMOPS activities
- Results of the generic study can be
  - Used by **operators** to identify what key parameters affect their operation and how to influence their decision-making accordingly
  - Used by **regulators** to identify hazardous SIMOPS and ensure risks are reduced to an acceptable level with mitigation measures.
- The Study Basis combined with key parameters identified in this study for each vessel can

- Inform **ship owners** how differences in their potential LNG bunkering operations and SIMOPS may increase or decrease risk
- Help **regulators** ask informed questions about how proponents will manage risks which may differ from this study

- Swing scenarios can help **regulators** and **operators** to identify areas for more detailed focus in project-specific studies.

2 VESSEL AND BUNKERING MODE DESCRIPTION

2.1 Vessel Type Description

The following is a short description of the vessel types that are selected for the study. The vessel types are chosen based on the most relevance for SIMOPS and also the most likely early adopters of LNG as a fuel. The details of each vessel used in the generic SIMOPS QRA were discussed in a workshop, and the final study basis and specification are enclosed in Appendix A.

2.1.1 River Push Boat

A pusher, pusher craft, pusher boat, pusher tug, or towboat, is a boat designed for pushing barges or other floating objects. These vessels are characterized by a square bow, a shallow draft, and typically have knees, which are large plates mounted to the bow for pushing barges of various heights. These boats usually operate on rivers and inland waterways. Multiple barges lashed together, or a boat and any barges lashed to it, are referred to as a "tow" and can have dozens of barges. Many of these vessels, especially the long distances, or long haul boats, include living quarters for the crew.

Towboats engine output range from less than 600 hp up to 12,000 hp. Most push boats are from 35 to 200 feet (11 to 61 m) long, and 21 to 56 feet (6.4 to 17.1 m) wide. Smaller boats are typically used in port and harbors, while larger boats operate in "line-haul" operations over long distances and between ports.

2.1.2 Passenger Ferry

A ferry is a ship used to carry passengers, and sometimes vehicles and cargo as well, across a body of water. Most ferries operate on regular, frequent, return services. Ferries form a part of the public transport systems in many areas, allowing direct transit between points at a capital cost much lower than bridges or tunnels. However, ship connections of much larger distances (such as over long distances in water bodies) may also be called ferry services, especially if they carry vehicles.

Ferry designs depend on the length of the route, the passenger or vehicle capacity required, speed requirements, and the sea and weather conditions on the route.

- Double-ended ferries have interchangeable bows and sterns, allowing them to shuttle back and forth between two terminals without having to turn around. Well-known double-ended ferry systems include the Staten Island Ferry and Washington State Ferries.
- Catamarans are normally associated with high-speed ferry services.
- Roll-on/roll-off ferries (RORO) are large conventional ferries named for the ease by which vehicles can board and leave.
- A cruise ferry is a ship that combines the features of a cruise ship with a roll-on/roll-off ferry.

Ferries have been one the early adopters of LNG as a fuel, especially in Northern Europe. However, there are also ferries operating on LNG in North America (STQ in Quebec, Canada) and more on order and planned (BC Ferries, Washington State Ferries, Staten Island Ferry).

2.1.3 Platform Supply Vessel (PSV)

A Platform Supply Vessel (often abbreviated as PSV) is a ship specially designed to supply offshore oil platforms. These ships range from 150 to over 300 ft in length and accomplish a variety of tasks. The term

Platform Service Vessels (PSV) is also commonly used for this segment, and especially for the larger of these vessels. The function for most of these vessels is logistic support and transportation of goods, tools, equipment and personnel to and from offshore oil platforms and other offshore structures.

The vessels will return parts and other cargoes to shore. Cargo tanks for drilling mud, pulverized cement, diesel fuel, potable and non-potable water, and chemicals used in the drilling process comprise the bulk of the cargo spaces. Fuel, water, and chemicals are almost always required by oil platforms.

These vessels have been the early adopters of LNG as a fuel. Early adoption was driven by the company that charters the vessel, which is typically the oil company that operates the offshore installation. The first vessels in the US operating on LNG as fuel, were the Harvey Gulf PSVs operating out of Port Fourchon, LA, and chartered by Shell.

2.1.4 Large Cruise Ship

A cruise ship or cruise liner is a passenger ship used for pleasure voyages, where the voyage itself and the ship's amenities are a part of the experience, as well as the different destinations along the way. Transportation is not the prime purpose, as cruise ships operate mostly on routes that return passengers to their originating port, so the ports of call are usually in a specified region of a continent.

They vary in size and passenger capacity, from small ships about 400 ft in length and less than 200 passengers, to large cruise ships with over 7000 passengers and crew, and a length of over 1100 ft. The world's largest cruise ship is currently Royal Caribbean International's Allure of the Seas with a length of 1181 ft, a capacity of 5400 passengers and 2100 crews.

Because the high power requirement from both propulsion and hotel loads, large cruise ships typically used 4-6 very large diesel engines to generate electric power. Installed power for a large cruise ship can be from 40 MW–100 MW.

The large power requirement, space constraint, SIMOPS, and the perception of higher risk because of the large number of passengers, have been seen as a challenge for the use of LNG as a fuel for the large cruise vessel.

However, this year Carnival Corporation ordered four new ships using LNG as fuel for their AIDA and Costas brand. It is expected that these ships will enter service around 2020. Other cruise lines are also planning new ships using LNG as a fuel.

2.1.5 Container Ship

Container ships are cargo ships that carry their entire load in truck-size intermodal containers. They are a common means of commercial intermodal freight transport and now carry most sea-going non-bulk cargo. Container ship capacity is measured in twenty-foot equivalent units (TEU).

<u>Feeder:</u>
Container ships under 3,000 TEU are typically called feeders. In some areas of the world, they might be outfitted with cargo cranes.

<u>Panamax:</u>
Container ships between 3000-5100 TEU, this size is restricted by the original Panama Canal's lock chambers.

New Panamax:
Container ships between 5100-10000 TEU. This size is restricted by the new Panama Canal's lock chambers.

VLCS:
Container ships between 10000-14500 TEU, very Large Container Ship, these vessels are typically 300-350 meters in length

ULCS:
Container ships larger than 14500, ultra Large Container Ship, 350+ meter long. New generation of containership, only a few built.

2.1.6 Bulk Carrier (Bulker)

Bulk Carriers are vessels designed to carry bulk solids such as cereals, coal, ore and cement. Bulk carriers make up more than a third of the entire merchant fleet in the world. Bulk carriers have to be carefully designed and maintained because they may carry cargo that is very dense, corrosive or abrasive.

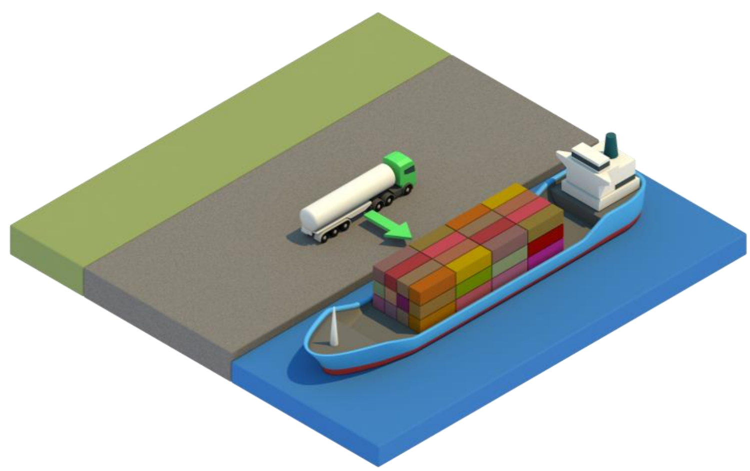
- Handysize: 10-30,000 DWT, these smaller vessels are the workhorses of the dry bulk market
- Supramax: 45-60,000 DWT,-these vessels are typically 150 – 200 (500 – 650 ft) meters in length
- Panamax: 60-80,000 DWT, this size is restricted by the Panama Canal’s lock chambers
- Capesize: 120,000+ DWT, these ships are too large to traverse the Suez or Panama Canals. Because of their size they can only dock at small number of ports.

2.2 Bunkering Modes

The study reviewed four bunkering modes

1. Truck-to-Ship
2. Shore-to-Ship
3. Ship-to-Ship
4. Midstreaming

2.2.1 Truck-to-Ship



Truck-to-Ship bunkering is the transfer of LNG from a truck’s storage tank to a vessel moored to the dock or jetty. Typically, this is completed by connecting a flexible hose designed for cryogenic LNG service. Alternatively, a flexible connection arm can be used. A typical LNG tank truck can carry 13,000 gallons of LNG and transfer a complete load in approximately one hour.

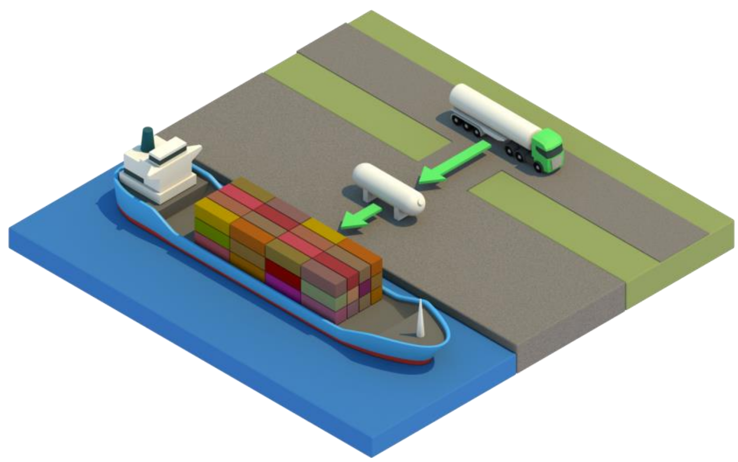
This bunkering option offers great flexibility to vessel owners, operators, and to bunkering site; in practice any jetty may be used. This may complicate the process to demonstrate the safety (not one distinct location; new neighbors; etc.); however, capacity and supply security can be limited. For vessels with small volume LNG fuel tanks, it can be used as a start-up solution to probe the bunkering market before making a large capital investment in LNG bunkering infrastructure.

Truck-to-Ship bunkering has many potential applications & will be an important part of the bunkering infrastructure in the North America to promote a transition to LNG as a marine fuel.

This bunkering option is attractive now and in the future because of its portability, low capital investment, and capability to transport LNG to remote locations on short notice. However, it is not without its drawbacks. The feasibility of transferring LNG under this option for very large volume transfers is limited by transfer rate and the number of trucks required. The rate is driven primarily by the rate at which the receiving vessel can bunker LNG, the connecting pipework/hoses, any truck-installed transfer pump, and the difference in pressure of the supply and fuel tanks.

In this bunkering option, a key operator will be the truck driver who might not be a permanent member of the bunkering operation. As a result, the truck driver may not be as familiar with the safety requirements as a permanent operator of a fixed installation. Furthermore, safety risks associated with on-road transport and possibility of LNG-related traffic accidents do also exist and should be included in a project-specific QRA.

2.2.2 Shore-to-Ship



In the Shore-to-Ship bunkering option, LNG is transferred from a fixed storage tank on land through a cryogenic pipeline with a flexible end piece or hose to a vessel moored to a nearby dock or jetty. This is referred to as pipeline-to-ship as well.

These facilities have scalable onsite storage such that designs could be capable of performing bunkering of larger volumes than Truck-to-Ship or with portable tanks.

LNG may be transported to the facility by truck, rail, or floating tankers, and may be transported from a remote liquefaction facility. LNG may be produced (i.e., converted from gas to liquid) at a small-scale production facility known as a liquefaction facility. In principle, small-scale LNG liquefaction facilities may provide LNG bunkering onsite in the future.

This set-up has good design flexibility that can meet the needs of specific or many customers. Such bunkering option can potentially supply much higher flow rates than Truck-to-Ship bunkering. In addition, In addition, Shore-to-Ship bunkering that takes place in ports has the benefits of an established security program with trained facility personnel and a more consistent law enforcement presence.

Although the Shore-to-Ship option has great flexibility in the design for transfer rate and volume, it is the least flexible with respect to geography. It must be sited at a fixed location, relatively close to the dock or jetty. Heat loss from long sections of pipeline and costs of cryogenic-service pipelines necessitate this proximity constraint.

In addition, as a fixed installation, vessels must make the necessary arrangements to be at the loading berth for transfers. For vessels with other activities (i.e., cargo transfers) in the port, bunkering could occur at the same time as the other activities to reduce the time spent in port (SIMOPS).

2.2.3 Ship-to-Ship

Ship-to-Ship bunkering is the transfer from one ship or barge with LNG as cargo to another vessel for use as fuel. This bunkering option offers a wide range of flexibility on quantity and transfer rate. Bunker ships and barges also have the greatest flexibility in location of bunkering. There are two modes of Ship-to-Ship bunkering operations: one is performed at the port, and the other is carried out at sea.

In the Port of Stockholm, the first Ship-to-Ship bunkering of LNG began operation between the bunker vessel Seagas and the ferry Viking Grace. The Seagas bunkers approximately 40,000 gallons of LNG an hour to the Viking Grace on a daily basis.

While transfer rates are not quite as high as Shore-to-Ship bunkering, the transfer capabilities exceed Truck-to-Ship bunkering rates and volumes.

Ship-to-Ship transfers have additional potential threats (e.g., excess movement between vessels, sea state, ship collision) compared to shore-based transfers. These risks can be mitigated if they are identified and addressed in the design and operation.

This bunkering option can enable additional logistical flexibility by conducting bunkering with other activities while docked. These activities include cargo transfers and embarkation/disembarkation. Ship-to-Ship bunkering can also enable passing vessels to refuel without entering the port.

2.2.4 Midstreaming

Midstreaming is one of the Ship-to-Ship bunkering ways facilitating the bunkering of vessels operating in shallow waters, as the water depth does not allow for Shore-to-Ship or Truck-to-Ship bunkering options.

3 QRA METHODOLOGY

The methodology used in this study is consistent with relevant standards and meets the USCG requirements for SIMOPS risk assessment. The SIMOPS risk assessment is part of a more comprehensive LNG bunkering risk assessment outlined in Figure 3-1 which is taken from ISO Technical Specification 18683:2015 (2). Where the SIMOPS QRA fits into the overall risk assessment is highlighted in the **orange** box below.

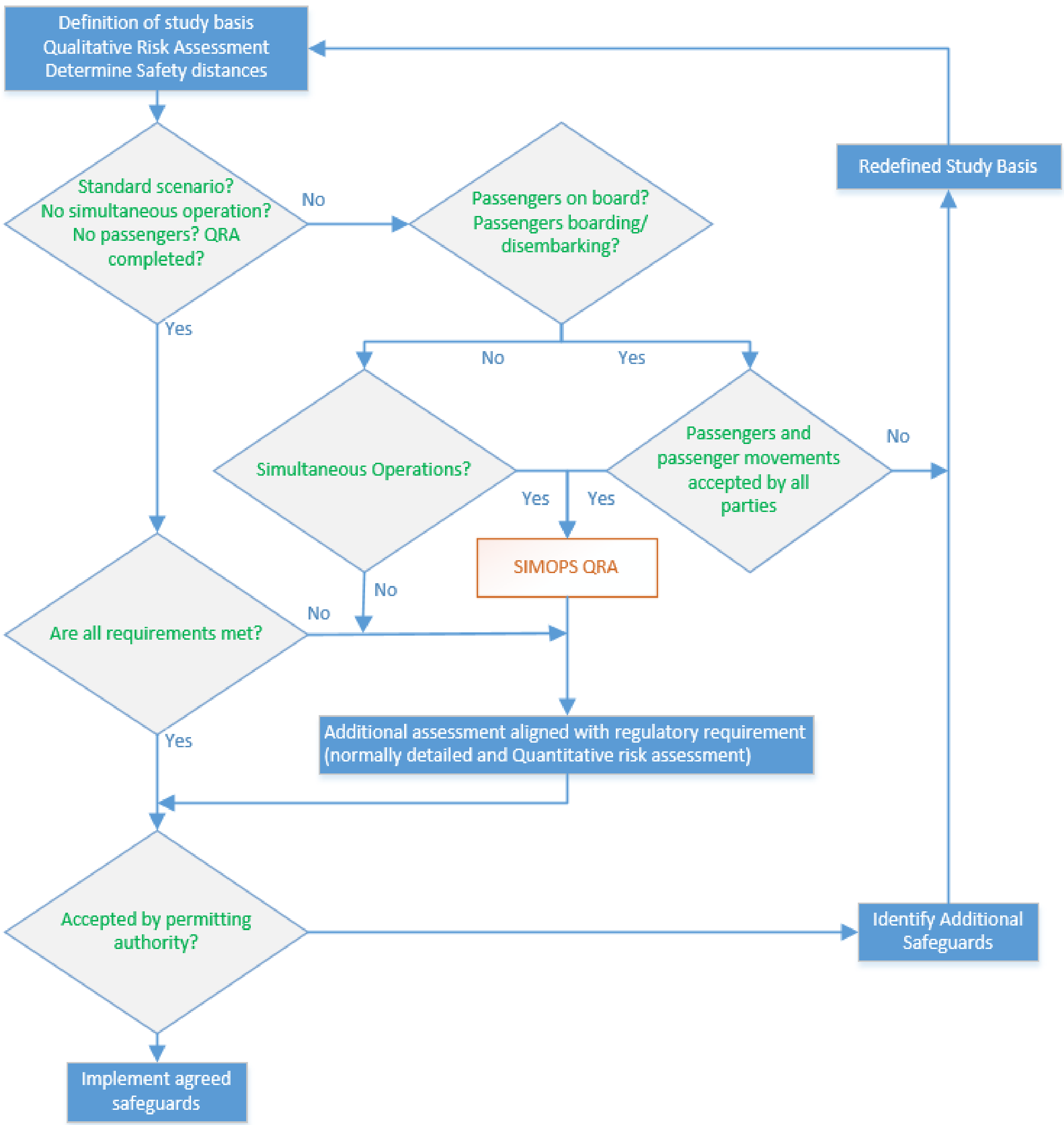


Figure 3-1 ISO Schematic Approach for Bunkering Risk Assessment

Figure 3-2 zooms in on the **orange** box from Figure 3-1 and shows how this generic, comparative study assists in a project-specific SIMOPS QRA.

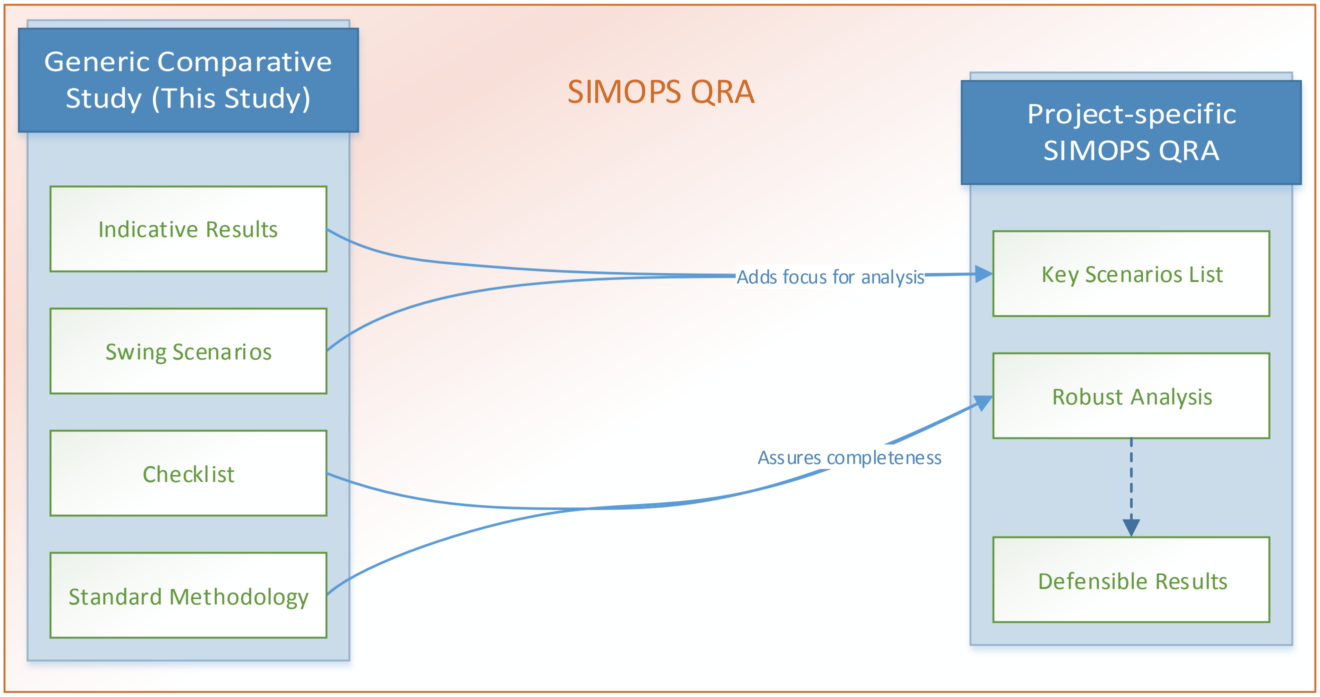


Figure 3-2 SIMOPS QRA

This section discusses, in general terms, the methodology and key considerations of a project or project-specific SIMOPS QRA and the specifics of the methodology applied in this generic study. Figure 3-2 shows how this study is related to a project-specific SIMOPS QRA. This assessment compares risk for many potential bunkering operations in order to provide the most comprehensive review of bunkering options to date and inform stakeholders about potential changes in risks due to SIMOPS activities. In Section 4, potential swing situations are identified which could increase the risk. In addition, potential safeguards are discussed which could assist in mitigating the risks.

Further specifics of the modeling details for this generic study are provided in Appendix A.

An overview of the industry accepted QRA methodology is presented in Figure 3-3 (4). Each of the steps is detailed in Appendix D of DNVGL-RP-G105 (4). A copy of DNVGL-RP-G105 is available for free at http://www.dnvgl.com.

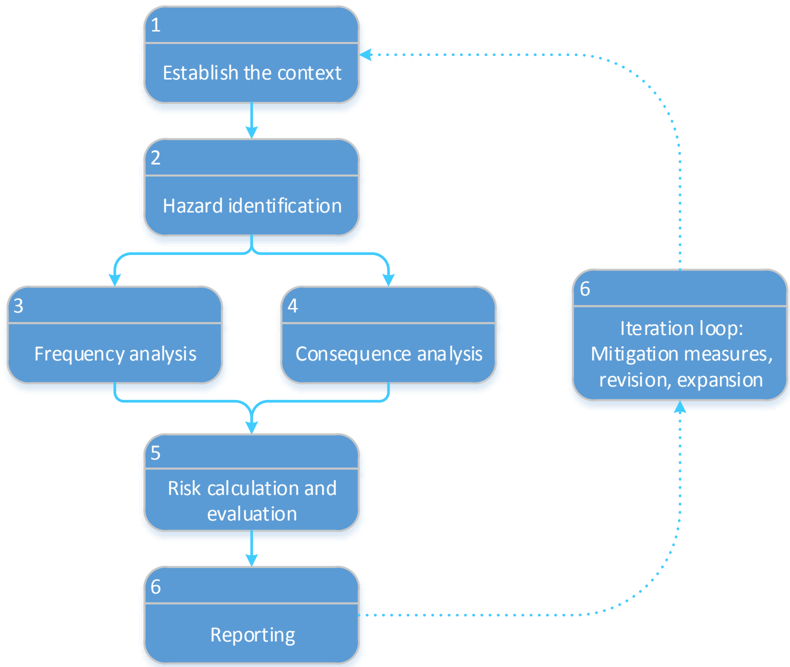


Figure 3-3 QRA Methodology

The methodology outlined in Figure 3-3 can be applied directly to a project-specific SIMOPS QRA, but is slightly modified for this assessment due to its generic nature. The iteration loop with specific mitigation measure is not included for each SIMOPS activity.

Throughout this section, the methodology and key considerations are discussed in three ways

1. General application of the methodology outlined in Figure 3-3. The general application discussion is included to provide context for LNG QRA studies but is not specific to bunkering or SIMOPS.
2. Application to a project-specific SIMOPS QRA
3. Application to this generic comparative study

In many aspects, the methodology used for this generic study is the same as for a project-specific QRA. However, any deviations in methodology or key assumptions used for this particular study are highlighted in the report as text between bold blue lines.

3.1 Establish the Context

The context for any QRA starts with the question that needs to be answered. For a project-specific SIMOPS QRA the question is, “Are the risks associated with these activities acceptable?” For this generic comparative study that question is, “What is the difference in risk between LNG Bunkering only and LNG Bunkering with various SIMOPS activities?” The difference in the question changes the scope of the Hazard Identification. The comparative nature of this study allows us to focus on only the hazards that differ due to the SIMOPS activities whereas the project-specific SIMOPS QRA needs to identify and assess all of the hazards associated with the operations.

Application to this Study

In this study, about 100 individual scenarios are modeled by selecting several combinations of vessel type, bunkering mode and potential SIMOPS activities. This study systematically compares all of the scenarios to identify any trends and assess the change in risk between the Base Case (LNG Bunkering only) and the SIMOPS cases.

Swing Scenario

Since this study did not investigate any specific operation, potential swing scenarios are also identified in order to understand what potential circumstances might increase the risk for a particular SIMOPS when compared with the Base Case (LNG Bunkering only). Swing scenarios can be found throughout the report by looking for the blue box, "Swing Scenario."

3.2 Hazard Identification

Hazards are identified for equipment and piping segments, classifying the risk by hazardous material and operating conditions. The development of potential hazardous releases ranging from small leaks to catastrophic leaks is necessary to fully understand the overall risks. The approach taken in a QRA is to systematically identify the hazards and quantify release parameters based on operational conditions.

A project-specific SIMOPS QRA requires a systematic review of technical and operational conditions which may influence the risk. As applicable to the level of detail of the analysis and the installation in question the review may include

Physical structure of equipment	Evacuation philosophy and procedures
Layout and spacing	Permit to Work systems
Process design	External impacts from dropped objects or collisions
Utility systems	External fires
Environmental data	Accidents related to loss of electrical power
Phases of operation	Loss of buoyancy
Emergency preparedness	Excess weight
Displaced ballast	Earthquake
Extreme weather	

3.3 Scenario Definition

The result of the Hazard Identification forms the basis for development of a comprehensive set of scenarios to be included in a QRA. Activities or systems with the potential to change the release frequency, the extent of a consequence or the probability of failure of a control system have the potential to affect the scenario definition.

Application to this Study

The comparative SIMOPS QRA follows Figure 3-3 for all cases. In Step 1, the Base Case is defined and the potential SIMOPS cases are identified for analysis. Variations of each are clearly identified by vessel type, LNG bunkering mode and a single activity performed as a SIMOPS with LNG bunkering.

Industry partners participating in the workshop identified 17 different SIMOPS activities with the potential to affect the risk profile, applied to 15 different combinations of ship type and bunkering mode. Figure 3-4 shows the ship type-bunkering mode combinations considered.

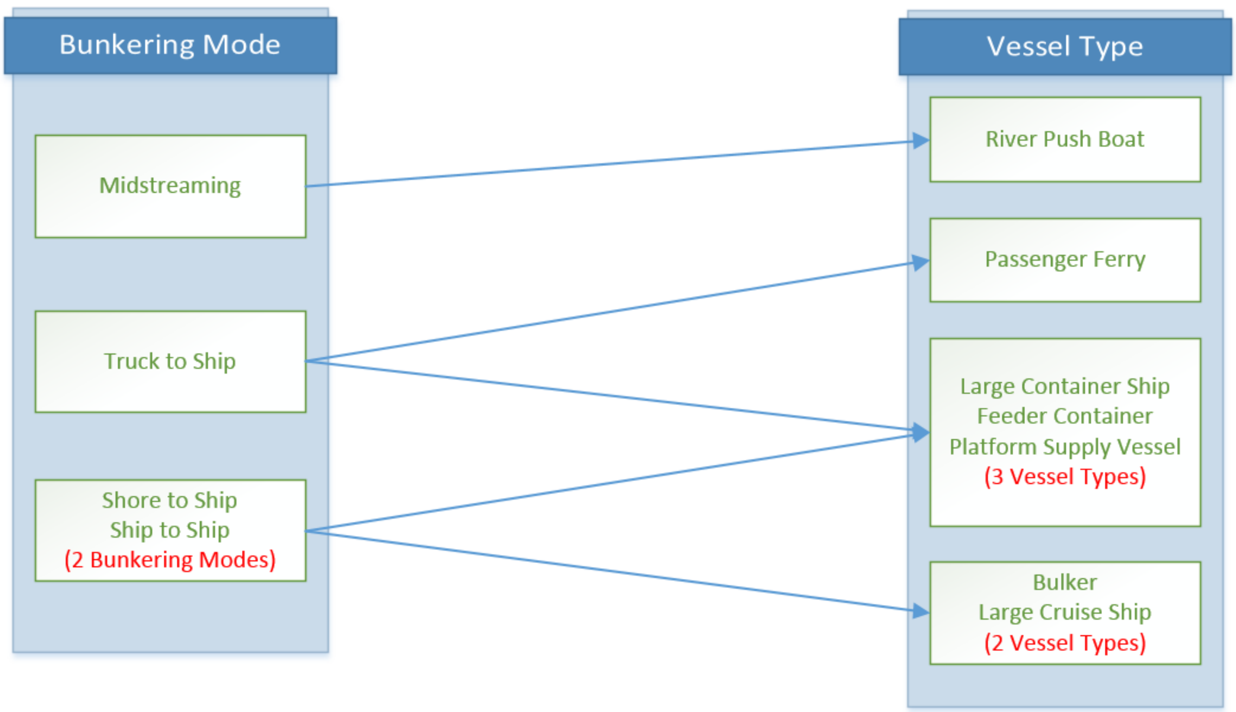


Figure 3-4 Bunkering Mode / Vessel Type Combinations Analyzed

Since the goal of this study is to compare the LNG Bunkering only (Base Case) with the various SIMOPS cases, only releases from loading equipment are included in the analysis in this report.

Appendix A details all of the SIMOPS activities considered for each of these combinations. There are no SIMOPS analyzed which combine multiple activities. Each is treated independently to determine the independent effect of each SIMOPS activity on the Base Case.

Each of the 17 SIMOPS activities changes either the release frequency or one of the key parameters of the Base Case. Table 3-1 maps the key parameters identified in the workshop for each SIMOPS activity in this generic analysis. The introduction of additional ignition sources close to the bunkering station and modifications to the release frequencies are the most common changes made to Base Case assumptions.

Table 3-1 Key Parameters Associated with SIMOPS Activities

SIMOPS Activities	Release Frequency (see 3.4)	Ignition Probability	Areas Available to Confine LNG Vapor	Escalation Effect
Ballasting	x			
Barge Crew Activity		x		
Cargo Loading	x	x		
Car Loading	x	x		
Crew Transfer		x		
Drills		x		
Dual Fueling		x		X
Crane Operations	x	x		
Inspection		x		
Maintenance	x	x	x	
Passenger Transfer		x		
Stores Loading	x	x		
Supply Transfer	x	x		
Cargo Hold Cleaning		x	x	X
Terminal Activity		x		
Pushing/Towing Activity	x			
Truck Loading	x	x		

Key parameters for the generic study include:

- Ignition sources/probability

  Different SIMOPS activities may introduce new ignition sources such as human activity, hot work, and motor vehicles. The ignition probably is a function of three factors:

  - The strength of the ignition source - an open flame provides a stronger ignition source than a hot surface, and a running car provides a stronger ignition source than a person.
  - The number of ignition sources - the ignition probability of ten running cars is greater than one running car.
  - The exposure time of an ignition source to the flammable gas cloud – the ignition probability increases with the duration that the flammable cloud is exposed to the ignition source.

- Presence of confined/congested area

  The confined space or congested area will impede the free dispersion of released LNG, resulting in a potential for explosion. Some SIMOP activities could introduce confined/congested areas. For example, maintenance work may open hatches to the interior of the vessel. An explosion would occur if a gas cloud were drawn into an open hatch and ignited. The jetty or terminal infrastructure may act as congested areas.

- Potential for escalating events

  Prolonged exposure to LNG may cause cryogenic embrittlement to the ship structure and other infrastructure (e.g., the bunkering line of diesel for dual fueling SIMOPS). A release of LNG might result in cascading failures from cryogenic embrittlement, as discussed in Section 3.5.2.

- Release frequency

  Section 3.4 describes factors that can influence the leak frequencies and how the frequencies are applied in this generic study.

A project-specific QRA may have different key parameters associated with each SIMOPS, and will likely have a more complex structure accounting for both variation in release condition and mitigations:

- Isolation status and failure probability
- Shutdown timing on ignition sources
- Effect and failure probability of firefighting systems
- Effect and reliability of gas detection systems
- Location and effect of passive fire protection
- Probability of successful manual intervention
- Probabilities of various weather and wind conditions

These are not accounted for in the generic comparative study because, in general, they do not vary between the LNG Bunkering only case (Base Case) and the SIMOPS cases.

3.4 Frequency Analysis

Frequencies for hydrocarbon releases are key inputs to a Quantitative Risk Assessment, and in any safety assessment the likelihood of the events have to be taken into account. The release frequency is related to material properties, equipment design, operational stress and strain, and external damage. A release of LNG during bunkering may result from inadequately designed equipment, excessive motion of the ship or dropping objects onto LNG infrastructure while using lifting equipment.

Leak frequencies used in QRAs are typically taken from historical databases which include a compilation of equipment failure data collected from facilities across the industry for decades. This requires systematic data collection, covering not only leaks but also the exposed equipment population, over many plants for many years. However, there is no such database for LNG specific equipment or equipment in LNG services and establishing credible leak frequencies for LNG specific operations is therefore difficult.

When experience data for specific equipment is lacking, historical data can still be used. However, an important aspect for the use of historical frequencies in a QRA is to understand the basis of the data - to enable it to be applied effectively to the specific study.

Application to this Study

Failure of loading arms and hoses comprise the vast majority of the release frequencies. Release frequencies for loading arms and hoses are taken from the Dutch Purple Book (5). The total frequency for failure of a loading arm is 7.7 x 10^{-7}/hour/arm. The total frequency for failure of a hose is 4.4 x 10^{-5}/hose/hour. The Purple Book assumes that these failure rates do not account for any mitigation measures. Also, these failure frequencies are generic and based on transfer of all kinds of fluids (e.g. conventional fuels, cryogenic fluids such as LPG), which implies that no credit is taken for the more stringent safety procedures that should apply to a LNG facility.

The breakdown by failure mechanism is taken from Advisory Committee on Dangerous Substances (ACDS) and used to account for SIMOPS activities that increase a specific failure mechanism but should not affect other failure mechanism (6). For example, ranging failures account for 1.2% of all historical failures. Activities affecting the relative movement of the ship being fueled (such as ballasting) affect only the 1.2% of the release frequency attributed to ranging failures.

Cause / Type of Failure		**Fraction of Failures**
Connection Failures	Failure of arm	75.0%
	Failure of quick release connection	7.5%
	Failure of ship's pipework	8.0%
	Operator error	8.0%
Ranging Failures	Mooring fault	0.9%
	Passing ships	0.3%

Frequencies from other piping and equipment are derived from the UK HSE Hydrocarbon Release Database (HCRD). According to DNV GL's knowledge there exist no publicly available data source for releases from LNG facilities that combine break down on failure modes, equipment units and exposure time. Limited analysis of leaks from LNG terminals in Japan, indicate that HCRD data may be overestimating the leak frequency by up to a factor of 10. No adjustment factor for LNG service is applied in this study.

Initial release frequencies have significant uncertainty when applied to LNG service. The effect of these uncertainties is limited in this generic study due to the comparative nature of the analysis. This study compares the Base Case using historical release frequencies with various SIMOPS cases. SIMOPS activities are evaluated based on whether they could increase the frequency of a particular failure mechanism or likelihood of a hazardous outcome.

Alternative methods such as fault tree analysis are possible for project-specific applications and are normally used in combination with generic frequencies, rather than as an independent alternative. These supplemental methods are particularly appropriate where there are new and novel technologies and can be used to calibrate either the initial release frequency or the failure probability.

3.5 Consequence Analysis

Once the hazards are identified and the frequencies are determined for the range of potential release sizes, the magnitude of the range of potential consequences is modeled. There is a range of modeling tools available from simple-empirical models increasing in complexity to computational fluid dynamics code.

Application to this Study

In this study, the consequence modeling was conducted using DNV GL’s proprietary software package Phast v6.7. Phast is a comprehensive hazard analysis tool applicable to all stages of design and operation across a wide range of process industries. Its theory and performance have been independently reviewed as part of the European Commission (EC) funded project – Scientific Model Evaluation of Dense Gas Dispersion Models (SMEDIS), and it has excelled in both areas. Phast’s dispersion model (UDM) is also one of a few models which are approved by PHMSA for use in LNG siting applications.

The consequence results are used as input to the risk model within Phast Risk to calculate risk to personnel as further detailed in the Risk Assessment step.

3.5.1 Physical Phenomena and Modeling of LNG Hazards

The model chosen should be able to account for the physical phenomena of LNG upon

- Liquid pool formation
- Vapor cloud dispersion
- Flash fire
- Jet fire
- Pool fire
- Vapor cloud explosion

Rapid Phase Transition (RPT) is a physical phenomenon that occurs when LNG is rapidly converted to methane vapor after LNG is submersed in water. Small pockets of LNG that evaporate instantaneously when superheated in water, create pressure pulse which will travel at the speed of sound and decay as any other pressure pulse. This pressure pulse is unlikely to damage large structural elements of a ship or the port. Therefore, no specific modeling is recommended as it is not likely to produce hazard zones greater than those generated by the physical phenomena listed above.

3.5.1.1 Liquid Pool Formation

Spilled LNG will simultaneously undergo several physical processes such as pool formation, spread, and boil-off. Pool formation for cryogenic boiling liquids is a dynamic process balancing the LNG input rate, gravitational spread, surface tension effects, heat transfer, and gas boil-off.

3.5.1.2 Vapor Cloud Dispersion

Methane gas and other associated heavier hydrocarbons, if present, that boil off from the pool will form a dense gas cloud due to its very cold temperature (initially -162°C) and condensation of atmospheric temperature. As the cloud disperses with the wind, it will spread, mix with air, and eventually reach its neutral density. Depending on circumstances, the cloud may eventually become buoyant because methane is much lighter than air at ambient conditions. However, the presence of heavier hydrocarbons and colder ambient temperature may reduce the buoyancy. The cloud may also be so diluted with air before it becomes buoyant that it may not affect the flammable hazards.

3.5.1.3 Flash Fire

A flash fire is the non-explosive combustion of a flammable vapor cloud resulting from a release of LNG into the open air. A dispersed cloud of methane, and any other hydrocarbons present, can be ignited anywhere where the concentration is above the Lower Flammable Limit (LFL) (i.e., the lower end of the concentration at which a flammable gas in air can ignite under ambient conditions) and below Upper Flammable Limit (UFL). Once the cloud reaches an ignition source (e.g. open flame, combustion engine, spark) and ignites, the cloud will “flash back” across all its flammable mass (i.e., parts of the cloud between the UFL and LFL) and will burn at the UFL boundary until all hydrocarbons are burned. Then, the rest of the cloud will flash back to the source, ignite the pool and cause a pool fire. The flame initially propagates slowly, often 10m/s or less; however, where congestion or confinement exist, flame speeds can accelerate to hundreds of m/s and overpressure effects could occur. A flash fire is typically only harmful to people and equipment within the flame envelope. Flame duration and intensity for most flammable clouds are insufficient to cause a significant thermal radiation hazard outside the flame envelope and rarely cause equipment damage.

Application to this Study

The gas dispersion model within Phast requires as inputs: material, phase, release rate, duration, and velocity. Where the cloud is ignited without being in contact with any area of congestion or confinement, a *flash fire* is assumed to occur. The flammable cloud envelope defining the flash fire envelope is taken as the distance to lower flammable limit (LFL), i.e. is equivalent to the cloud dimensions.

3.5.1.4 Jet Fire

Jet fires can occur upon immediate ignition of the LNG release. If ignition is delayed, a flash fire will occur. This flash fire will typically flash back to the source forming a residual jet fire.

Application to this Study

The widely used Cone (Shell) model is applied as the basis for the jet fire modeling within Phast, which describes the shape of a jet flame as a frustum of a cone. The parameters describing the frustum, accounting for choked flow, have been derived from comparisons with experimental data from laboratory and field tests. The key input parameters in defining jet fires are release rate, velocity, material, and release elevation. For the purpose of the risk calculations, immediate fatality is assumed for all personnel within the 35 kW/m^2 radiation contour of a jet fire or a pool fire.

3.5.1.5 Pool Fire

A pool fire may take place when an LNG spill is ignited on a horizontal, solid surface in open areas, within enclosures, or on sea surfaces. If an LNG spill is located near an ignition source, the ratio of gas and air is large enough to create a pool fire. When an LNG pool is ignited, it generates significant amounts of thermal radiation. The thermal radiation decreases as the distance from the pool increases.

When an LNG spill is ignited, it creates heavy smoke that reduces the thermal radiation. Once a pool forms, its size is limited by the evaporation (before ignition) and evaporation and combustion (after ignition). Open air and on-sea pool fires rarely cause fatalities as the time between when the fire starts until the time when the fire is fully developed is usually sufficient for people to escape. If there are fatalities, these tend to be people caught within the pool.

Application to this Study

The pool fire model in Phast calculates the shape and intensity of the flame, and a wide range of radiation results. A pool fire flame is modeled as a cylinder sheared in the direction of the wind, with diameter, height, and tilt angle (measured from the vertical). The flame shape gives input to the radiation calculations. The surface area of a pool is a critical parameter for fire radiation calculations.

3.5.1.6 Vapor Cloud Explosion

A vapor cloud explosion (VCE) can occur when a large flammable vaporous mass is ignited in a confined, partially confined situation or congested region. In an open space or outdoor environment, with limited confinement and congestion, experimental results show that methane gas mixed with air will burn relatively slow, in the order of 10 m/s, and will rise due to combustion. Previous ignition trials have also confirmed that no significant overpressures (>1 mbar) are developed in open space or water because sufficient flame acceleration (i.e., >100 m/s) cannot be achieved where there is low congestion. There is slow flame propagation and also the flame can be extinguished prematurely and not be sustained through the whole cloud.

Where the vapor cloud is enclosed in confined areas, such as an open hatch-way, or is exposed to congested areas, the fuel-air is unable to expand as it combusts and develops overpressure. The predicted overpressure caused by a VCE is associated with the volume (mass) of the flammable cloud confined within the obstructed region(s), which needs to be differentiated from the entire volume of the vapor cloud or the total released inventory.

Application to this Study

The amount of the flammable cloud confined within the congested/confined region(s) with the concentration between LFL and UFL is used for the overpressure calculation.

3.5.2 Cascading Failures and Escalation

In addition to the initial hazards, consequence modeling includes cascading failures and escalation effects. Escalation effects result from cascading failures of equipment where the failure of one system results in the failure of another. Escalation intensifies the consequences of an initial release event resulting in an increase in risk.

Cascading failures are a concern where cryogenic embrittlement may impact adjacent equipment not suitable for cryogenic service. If equipment is affected by cryogenic embrittlement, a failure of this equipment could result in the release of other hydrocarbons (e.g., diesel). Similarly, a pool fire from a diesel leak may result in thermal degradation and subsequent loss of containment from LNG infrastructure.

Cascading consequences can occur when an inventory of LNG is exposed to prolonged radiation from an ongoing fire resulting in a Boiling Liquid Expanding Vapor Explosion (BLEVE). The heat causes the pressure of the inventory to build up until the vessel can no longer hold it and bursts. When pressurized liquids are rapidly released, LNG flashes almost instantly and creates a large fireball. The fireball will burn from the outside in because there is no air inside the expanded hydrocarbon. While burning, it will rise simultaneously due to thermal buoyancy effects. Fireballs can generate large amounts of thermal radiation over a period of 20-40 seconds and pose a hazard to any unprotected people nearby.

Application to this Study

Cascading effects from one inventory to another, BLEVE effects and cryogenic cracking are all considered as possible scenarios in this study. The risk model is initially run with only consequences from the initial release events. The radiation, overpressure and temperatures from each event are then screened at the location of adjacent inventories. Cascading events are included in a second run of the model if damaging conditions are seen as a result of the initial screening.

A similar process is required for a project-specific SIMOPS QRA.

3.6 Meteorology

Each of these physical phenomena is influenced by the meteorological conditions. The dispersion of a gas cloud is governed by the wind speed, wind direction and the atmospheric stability. In the event of a release, a high wind speed will dilute the release, however (depending on release scenario) may also transport the released material far downwind before it has sufficient time to diffuse to a safe concentration. The effect of wind direction is obvious in that mostly those downwind of a release face an immediate risk of exposure.

While not as readily apparent as the effect of wind speed and direction, atmospheric stability has a substantial impact on the vapor cloud dispersion. An unstable atmosphere, such as found on a sunny day, is highly turbulent, which acts to quickly dilute the cloud. In contrast, a stable atmosphere, as frequently found during the night, has little turbulence. A release into a stable atmosphere can therefore travel a great distance before it becomes diluted to a safe level.

The selection of atmospheric temperature could have a significant effect on the pool vaporization rate and thus the amount of vapor dispersed from a given release.

When performing a project-specific study, probabilities of experiencing a range of meteorological conditions should be identified and included in the risk assessment.

Application to this Study

For the use in comparative studies, the selection of meteorology data is not critical and can be generic in nature. Comparative studies do require that selected meteorological data are consistent for both the base case and the compared (SIMOPS) case, since the ultimate goal of a comparative study is to identify the delta in risk between the two cases.

3.7 Risk Calculation

Once the risk model structure is set and the frequencies and consequences are estimated, probabilities of each of the key parameters of the model should be determined. These probabilities are often where a SIMOPS activity or risk mitigation affects the overall risk.

Application to this Study

This study applies an event tree risk model.

The initial release frequency is multiplied by each of the key parameter probabilities until there is a final frequency associated with each consequence. Those consequence, frequency pairs are combined with the populations (also a factor often changed by SIMOPS activities) and vulnerability of populations to radiation, overpressure or toxic thresholds to estimate the fatality risk.

3.8 Types of Risk Results to Compare

There are several types of results that can be compared. Each measure provides different insight and may be appropriate for different situations.

Location-Specific Individual Risk (LSIR)

LSIR is a measure of the average annual risk (typically fatality risk) for a single individual if one were permanently stay at a single location. For example, an LSIR of 1×10^{-6} per year represents a probability of 1 in 1,000,000 that a person at the specified location becomes a casualty during the course of a year if present all the time. The LSIR is estimated as the product of the frequency of the hazardous event(s) occurring (such as flammable releases) and the consequences (impact on the person) from each hazardous event. The LSIR can be summed across multiple events to give the risk from a particular hazardous operation or site.

Societal Risk - Potential Loss of Life (PLL)

PLL is a measure of risk where the average number of fatalities per year due to a hazardous activity is estimated. Unlike the LSIR, PLL accounts for the number of individuals impacted by a hazardous event, however, PLL does not indicate the risk to each individual.

PLL is the sum of the frequency of all expected accidental outcomes (such as flammable releases) multiplied by their corresponding number of fatalities. The PLL can be estimated for a specific event or for an entire operation. This gives a single number that can be used to easily compare societal risks from different operations or for different design options.

Application to this Study

In this study, risks are compared between the Base Case and SIMOPS cases using Location-Specific Individual Risk (LSIR), also referred to throughout the report as Individual Risk. LSIR represents the risk to a hypothetical person who is present and unprotected at a location 24 hours per day, 7 days per week for the entire year. DNV GL's RP suggests an individual risk increase of <10% as acceptable for this generic QRA (4).

When a SIMOPS activity introduces large number of people, societal risk in the form of Potential Loss of Life (PLL) is used to compare the risk between the Base Case and the SIMOPS case. PLL accounts for exposure level and number of individuals exposed.

3.9 Estimating the Change in Risk from Mitigations

This is an iterative step in the QRA process with the purpose of assessing the benefit of risk reduction measures. The risk reduction measures can be directed towards reducing the likelihood of a release (frequency based) or reducing the impact of a release (consequence based). Examples of such changes are:

- Reducing the leak frequency of the equipment by applying welded piping instead of flanged
- Introducing a rigorous control and maintenance scheme to reduce the likelihood of leaks
- Reduce the likelihood of a fire or explosion by reducing the number of potential ignition sources nearby

- Introducing spacing between equipment and avoiding creating confined spaces to reduce the likelihood of an explosion once a leak has occurred
- Limit the consequences of a fire or explosion by implementing protective structures such as fire or blast walls
- Limit the number of people working near the hazardous material

Application to this Study

Mitigation efforts are generally very specific to an operation. Given the generic nature of the comparison study, the iterative step of quantifying the effect of possible mitigation measures is not included in the analysis.

Evaluating the impact of possible mitigation measures that could be put in place to reduce the risks is, however, a key step in a project-specific SIMOPS QRA. A cost benefit analysis is a method that can be used to evaluate the trade-off between managing the increased risk of SIMOPS activities and the cost saved by minimizing time at the dock by performing SIMOPS.

4 RESULTS AND CONCLUSIONS OF GENERIC SIMOPS SCENARIOS

In this study, four potential LNG bunkering modes (Ship-to-Ship, Shore-to-Ship, Truck-to-Ship and Midstreaming) are considered and analyzed in order to compare risks between the broadest set of potentially feasible operations. The analysis began with a workshop held by ANGA on September 30, 2015. During the workshop, the participants including ship owners, operators, USCG, marine engineers and industry experts identified and agreed on the representative SIMOP operations for each type of ship. A comparative SIMOPS QRA was performed for each operation using the proposed methodology. The risk increases for each SIMOPS case are summarized and compiled into this report.

The important information from a comparative QRA is the change in risk (delta risk) from the Base Case (LNG Bunkering only) posed by introducing each of the SIMOPS activities. Introducing more activities has an unavoidable and wide-ranging increase on risk. It aims to show the difference in risk between the SIMOPS in order to guide the proponents on what SIMOPS should be assessed in a project-specific QRA. It does not attempt to identify the SIMOPS which introduce unacceptable risk.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. Since this study is generic and assesses a proximate average case for LNG bunkering in all scenarios, the study provides further evidence that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

The remainder of this section presents these changes in individual risk and discusses the patterns and conclusions from the results.

4.1 River Push Boat Results

Generic analysis for the River Push Boat includes a single bunkering mode, Midstreaming, and three SIMOPS activities. The results indicate that when compared with the Base Case (LNG bunkering only) all three SIMOPs activities; Transfer of People and Supplies, Pushing/Towing activity and Barge Crew activities, cause an increase in the risk of less than 10%. The results are shown in Figure 4-1.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

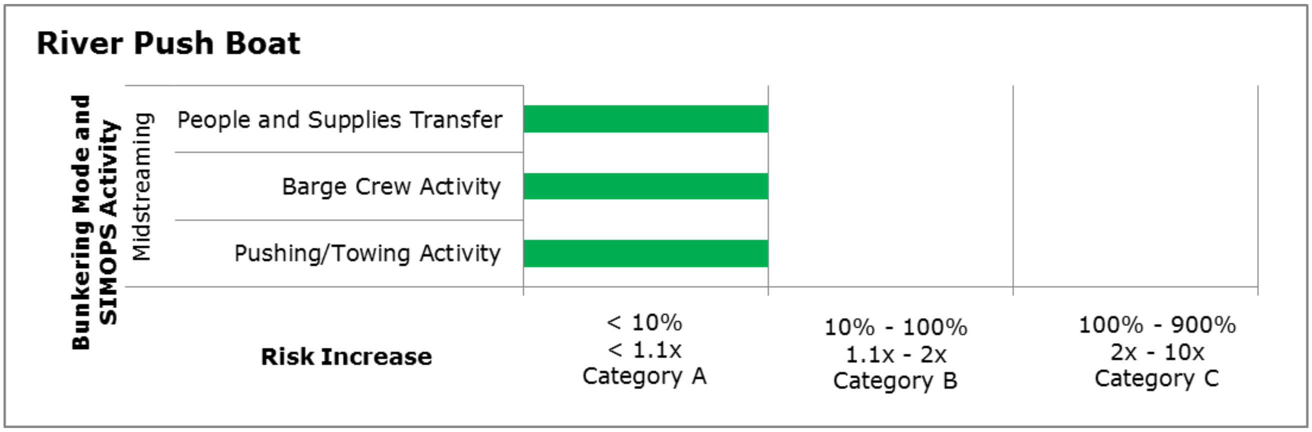
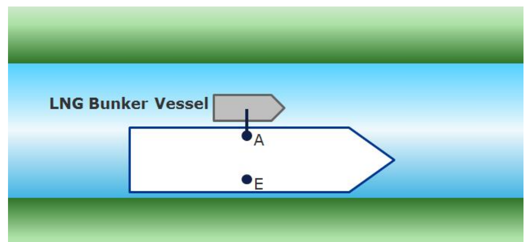


Figure 4-1 River Push Boat Change in Average Individual Risk by SIMOPS Activity

4.1.1 Midstreaming of River Push Boats



In this section, the results from the three SIMOPS activities included in the generic analysis; People and Supplies Transfer, Towing Activities and Barge Transfers are discussed.

4.1.1.1 People and Supplies Transfer

People and Supplies transfer while LNG bunkering in a Midstreaming mode to a River Push Boat results in a risk increase of less than 10% from the Base Case in the generic analysis. Parameters causing the small risk increase include:

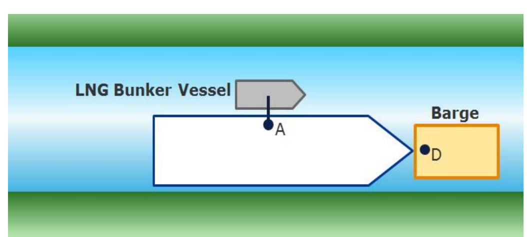
- Increased ignition probability from the introduction of people in the transfer process

  Given the small size of a River Push Boat, the number of people involved in the transfer process (at Point E) is small compared to other vessels with more complex operations going on while bunkering (and with SIMOPS activities). The generic analysis assumes an average of 2 people are involved during transfer. This low number of people results in a very small increase of the total ignition probability, hence, the increase in risk is insignificant.

- The excess motion of the River Push Boat

Again, given the small size of a River Push Boat, the people and supplies transfer process might affect the stability of the ship and cause certain ship motions. The ship motion may shear/stretch off the LNG loading hose from the fuel tank, leading to an LNG release. However, since this mode only accounts for a small fraction of the LNG hose failures, the induced risk increase is less than 10% of the Base Case.

4.1.1.2 Crew Activity

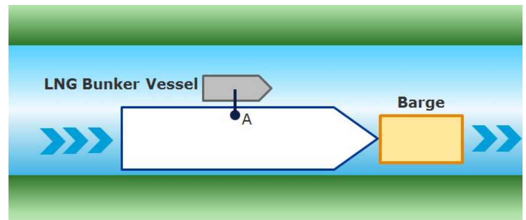


Crew activities associated with the barge being pushed/towed by the River Push Boat while LNG bunkering the River Push Boat, result in a risk increase of less than 10% in the generic analysis. Due to the low ignition probability associated with the small number of people involved and the physical separation between the crew and the LNG bunkering location, the overall ignition probability does not significantly increase.

Swing Scenario

The generic analysis assumes that only a small number of crew members are present on the River Push Boat (Point D in the Figure) without conducting activities generating open flame, electric sparks or other hot surfaces, which could act as strong ignition sources. A project-specific QRA should include both the anticipated distribution of the crew members and the full range of allowed activities conducted. Activities generating open flames, electric sparks, exposing hot surfaces or with the potential to ignite a release, should be evaluated with the most detail.

4.1.1.3 Pushing/Towing Activity



The activities associated with pushing/towing barges by a River Push Boat while LNG bunkering for the Midstreaming bunkering mode to the River Push Boat results in a risk increase of less than 10% in the generic analysis. The motion of the River Push Boat may cause the dislocation of the LNG loading hose, leading to LNG release. However, the hose failure due to excessive motion only accounts for a very small fraction of the total hose failures limiting, the increase in risk from the Base Case.

4.2 Passenger Ferry Results

The generic analysis for the passenger ferries includes a single bunkering mode, Truck-to-Ship, and five SIMOPS activities. The results indicate that when compared with LNG bunkering the risk increase from the various SIMOPS activities range from less than 0.01% up to 10 times the Base Case risk. The results are shown in Figure 4-2.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

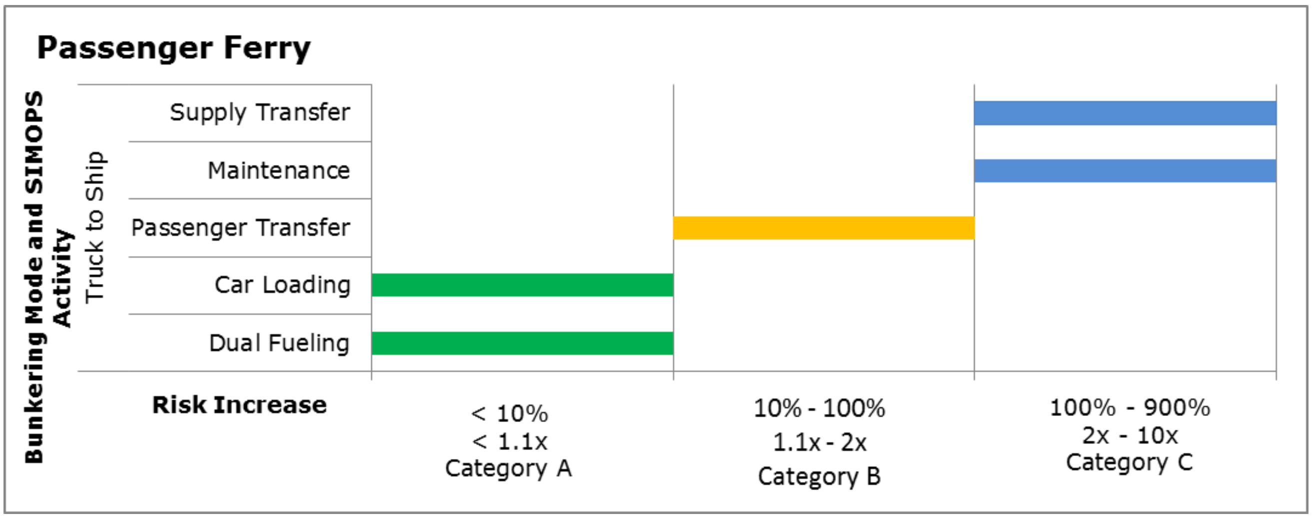


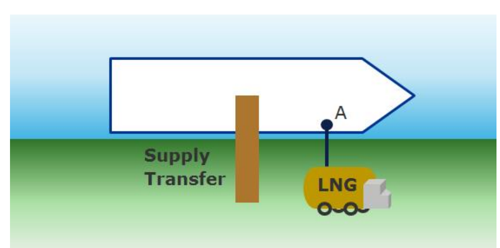
Figure 4-2 Passenger Ferry Change in Average Individual Risk by SIMOPS Activity

4.2.1 Truck-to-Ship Bunkering of Passenger Ferry

Supply Transfer and Maintenance increase the risk to more than 2 times the Base Case. Car Loading and Dual Fueling activities cause an increase in the risk of less than 10%.

4.2.1.1 Supply Transfer

Supply transfer while LNG bunkering in a Truck-to-Ship mode to a Passenger Ferry results in a risk increase to more than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase



- Increased ignition probability from the introduction of both people and vehicles

  The generic analysis introduces 10 people and 3 running vehicles for the entire duration of bunkering resulting in a substantial increase in ignition probability.

- Potential for a dropped object

Supplies are loaded with and without mechanical aids in the generic analysis at midship (as shown in the Figure). Potentially dropping supplies near the LNG bunkering location (point A) results in a small increase of the release frequency.

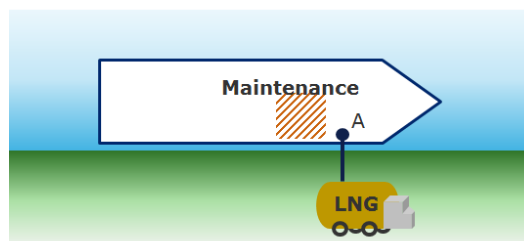
- Proximity of activity to the LNG bunkering location

  Loading is assumed to occur at midship in the generic analysis. Both dropped objects and increased ignition probability due to the lifting activities are assumed to occur at midship.

Several mitigations are available to manage the risk from supplies loading:

- The use of mechanical lifting aids increases the weight of a load lifted and thus the impact if the load is dropped. Some mechanical lifting aids also increase the ignition probability. Limiting the use of mechanical lifting aids reduces risk.
- Supplies are loaded into and out of vehicles. Making sure those vehicles are not running during LNG bunkering reduces the ignition probability.
- Proving sufficient distance, as determined by a project-specific SIMOPS QRA is the most robust mitigation to limit the effects of dropped object potential.
- Physical or structural barriers designed to prevent damage to the LNG bunkering equipment given a dropped object can serve as a mitigation if sufficient distance cannot be achieved.

4.2.1.2 Maintenance



Maintenance while LNG bunkering in a Truck-to-Ship mode to a Passenger Ferry results in a risk increase to more than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase

- Introduction of the confined space
- Introduction of ignition source associated with confined space due to grinding
- Power outage combined with failure to disconnect the LNG bunkering line (either through a failure of the Quick Disconnect System or communication of power loss)

Swing Scenario

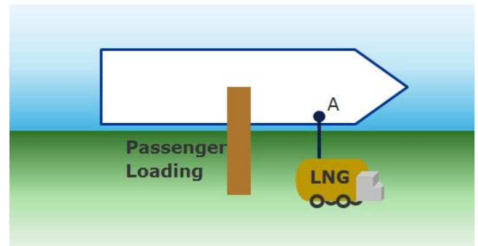
The generic analysis modeled the risk increase due to Maintenance in a conservative way. More precise definitions of which maintenance activities are allowed in which areas of the ship are likely to limit the increases in risk. Some maintenance activities, like painting, do not introduce the same risk as activities that involve grinding or hot work. Operators of individual projects should define each allowed maintenance activity as specifically as possible in terms of both tasks and permissible locations. A project-specific SIMOPS QRA can be used to demonstrate that the more restricted maintenance activity does not significantly increase the risk.

Mitigations of risk from maintenance activities are as varied as the range of tasks included in the activity and should be selected to mitigate each task included in the restricted definition. Mitigations for the generic case include:

- Restricting the area where strong ignition sources such as grinding and hot work, are introduced
- Restricting the area where hatches are opened

- Supplying back up power to the LNG loading system to allow for a safe disconnect given a power failure due to maintenance

4.2.1.3 Passenger Transfer



Passenger Transfer while LNG bunkering in a Truck-to-Ship mode to a Passenger Ferry results in a risk increase of less than 2 times the Base Case risk in the generic analysis when comparing individual risk. Passenger loading is assumed to occur at a constant rate of 200 people per hour at midship (as shown in the figure). Passenger Transfer introduces multiple weak ignition sources, people, present at any point during bunkering and, thus, increases risk.

Additional Considerations

The comparison in Figure 4-2 and the categorization of A, B and C risk use individual risk as the metric. Individual risk is a measure of risk experienced by a single person and is independent of the number of people exposed to the risk. One person or each of 100,000 people in similar locations with similar ongoing activities for a similar amount of time experience similar levels of individual risk. This metric alone is sufficient to compare most of the identified SIMOPS activities, since most SIMOPS activities introduce relatively few people who are exposed in similar ways as personnel aboard the vessel during the Base Case.

A second metric is useful to account for the number of people potentially exposed to the risk. Potential Loss of Life (PLL) is a single measure of societal risk used for comparison. PLL is typically expressed as number of fatalities per year. For example, if 100 people are each exposed to a risk level of 1 fatality per hundred thousand years, the PLL is (100) x (1/100,000) = 0.001 fatalities per year.

Introducing passengers requires the use of the PLL metric because:

1. The passengers are often exposed to the risk only a fraction of the time that employees are exposed, resulting in lower individual risk.
2. Greater care is taken when more people are at risk.

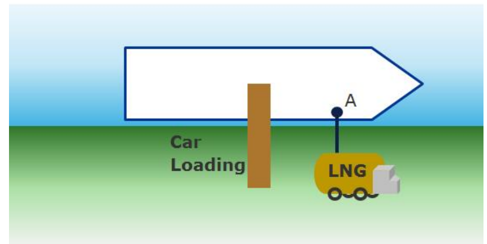
A project-specific SIMOPS QRA should consider both the individual risk and a societal risk metric. In particular when SIMOPS include large populations or populations with varying exposure to the risks, a societal risk metric can identify impacts to specific populations which can inform the development of risk mitigation strategies.

Swing Scenario

People (passengers and crew) only represent increases in ignition probability when outdoors. In the generic analysis, it is assumed that passengers are only outdoors while loading. They wait indoors on the landing and on the ferry. If passengers wait outdoors either on the landing or on the ferry, the risk from passenger loading increases in terms of both individual risk and PLL. People who are outdoors not only represent a small increase in ignition probability, but they are also more exposed to the consequences of an LNG release, either cryogenic exposures or heat exposures from an LNG fire. Passenger loading risk can be mitigated by keeping passengers indoors and thus reducing the ignition probability.

4.2.1.4 Car Loading

Car Loading while LNG bunkering in a Truck-to-Ship mode to a Passenger Ferry results in a risk increase of less than 10% in the generic analysis. An increase in ignition probability drives the risk increase similar to Passenger Loading. Even though a vehicle is a stronger ignition source than people, the increase in ignition probability is smaller than with passenger loading because



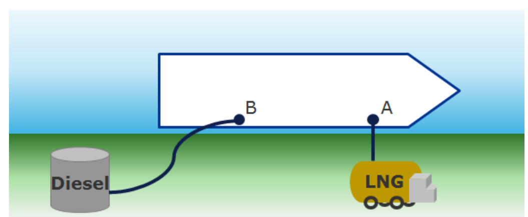
- Fewer cars are loaded, 120 in the generic analysis.
- Cars are loaded more quickly than people, so the duration of exposure to the ignition source is shorter.

Swing Scenario

The generic analysis assumes that cars drive directly onto the ferry and then turn the ignition off. The presence of stationary, running vehicles outdoors either on the landing or on the ferry significantly increases the ignition probability. Requirements to turn off the ignition while waiting either on the landing or the ferry limits the increase in ignition probability. A project-specific SIMOPS QRA should account for both the actual requirements regarding car ignitions and some anticipated deviation from such requirements.

4.2.1.5 Dual Fueling

Dual Fueling while LNG bunkering in a Truck-to-Ship mode to a Passenger Ferry results in a risk increase of less than 10% in the generic analysis. In the generic analysis, Dual Fueling increases the number of people at the fuel oil bunkering stations by ten. Each person is associated with a small increase in the ignition probability. Dual fueling also has the potential to introduce escalation effects. The separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) in the generic case (33 meters) is sufficient to prevent escalation in the generic case.



Swing Scenario

A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to an LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that may occur concurrently into a SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.3 Platform Supply Vessel (PSV) Results

The generic analysis for the Platform Supply Vessel (PSV) includes three bunkering modes, Ship-to-Ship, Shore-to-Ship and Truck-to-Ship. The Ship-to-Ship bunkering mode includes four SIMOPS activities. The Shore-to-Ship and Truck-to-Ship bunkering modes include one additional SIMOPS activity, Terminal Vehicle Traffic, for a total of five SIMOPS activities. Depending on the bunkering mode the results indicate that when compared with LNG Bunkering Only (Base Case) the risk increase from the various SIMOPS activities range from less than 0.01% up to 10 times the Base Case risk. The results are shown in Figure 4-3.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

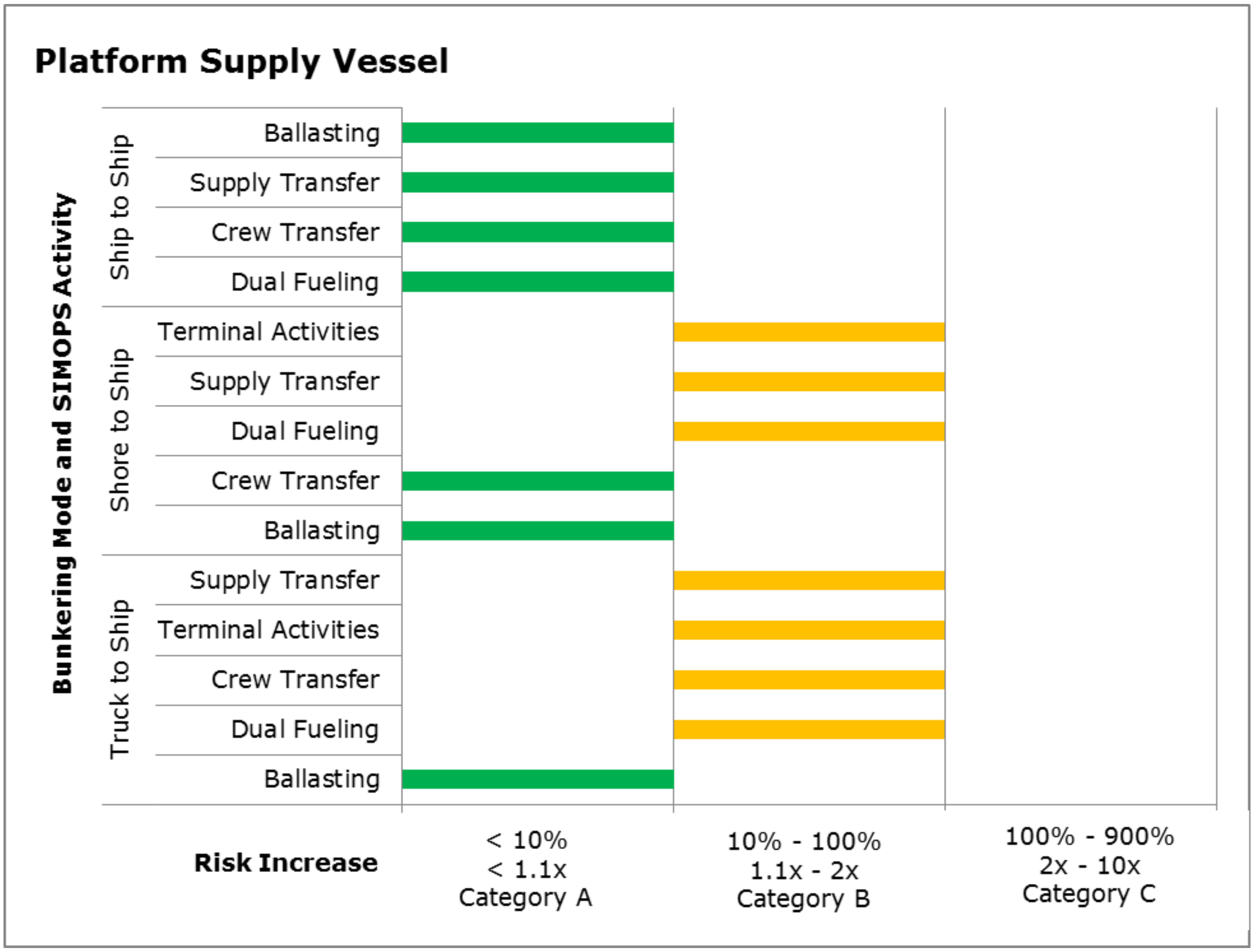
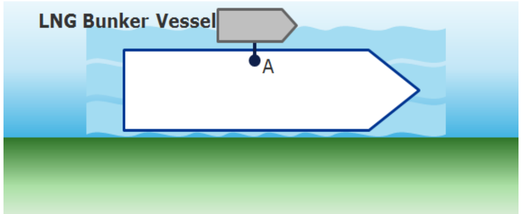


Figure 4-3 Passenger Ferry Change in Average Individual Risk by SIMOPS Activity

4.3.1 Ship-to-Ship Bunkering of Platform Supply Vessel (PSV)

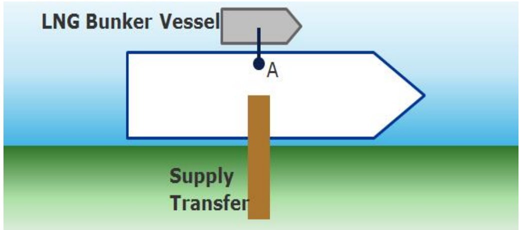
The generic analysis of Ship-to-Ship bunkering of PSV includes four SIMOPS activities; Ballasting, Supply Transfer, Crew Transfer and Dual Fueling. Each of the four SIMOPS activities cause an increase in risk of less than 10% compared with the Base Case.

4.3.1.1 Ballasting



Ballasting while LNG bunkering in a Ship-to-Ship mode to a PSV results in a risk increase of less than 10% in the generic analysis. Ballasting is assumed to potentially affect the stability of the vessel, increasing the LNG release frequency. Ballasting has the potential to increase the relative motion between the bunkering vessel and the PSV which can cause the LNG loading hose to shear or cause a misalignment in the quick release coupling. Historical loading failure frequencies include ranging failures as a potential failure mechanism. However, failures due to excessive motion of the ship only account for a small fraction of the total LNG hose failure limiting the increase in the risk due to ballasting operations.

4.3.1.2 Supply Transfer

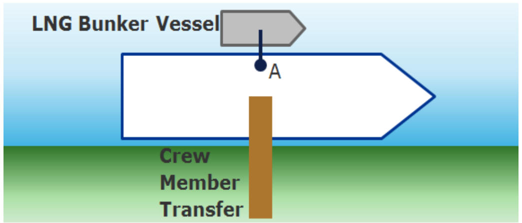


Supply Transfer while LNG bunkering in a Ship-to-Ship mode to a PSV results in a risk increase of less than 10% in the generic analysis. Parameters driving the risk increase:

- Small increase in ignition probability from the introduction of both people and vehicles
- Potential for a dropped object - supplies (e.g. fuel tanks, containers, pipe sections etc.) are loaded with mechanical aids in the generic analysis at midship (as shown in the Figure). Potentially dropping supplies near the LNG bunkering location (point A) results in a small increase of the release frequency.

The bulk of the Supply Transfer activity occurs on the shore-side of the vessel limiting the potential for a dropped object to impact the bunkering infrastructure in the Ship-to-Ship bunkering mode.

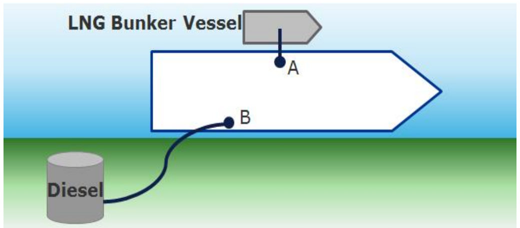
4.3.1.3 Crew Transfer



Crew Transfer while LNG bunkering in a Ship-to-Ship mode to a PSV results in a risk increase of less than 10% in the generic analysis. Each crew member represents a small increase in the ignition probably while they are outdoors.

The overall increase in ignition probability is small since few people are present and each person is a weak ignition source.

4.3.1.4 Dual Fueling



Dual Fueling while LNG bunkering in a Ship-to-Ship mode to a PSV results in a risk increase of less than 10% in the generic analysis. In the analysis, Dual Fueling increases the number of persons aboard by ten. Each person is associated with a small increase in the ignition probability. Dual fueling also has the potential to introduce escalation effects. The separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) is sufficient to prevent escalation in the generic case.

Swing Scenario

A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.3.2 Shore-to-Ship Bunkering of Platform Supply Vessel (PSV)

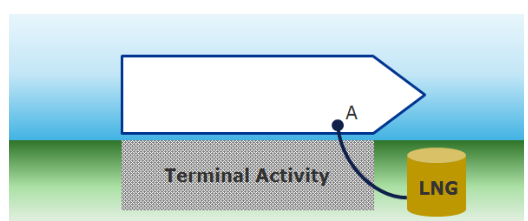
Generic analysis of Shore-to-Ship bunkering of PSV includes the same four SIMOPS activities as the Ship-to-Ship bunkering mode. An additional SIMOPS introduced to the Shore-to-Ship bunkering mode is Terminal Vehicle Traffic. As with the Ship-to-Ship bunkering mode, Ballasting and Crew Transfer cause an increase in risk of less than 10% compared to the Base Case.

Unlike the Ship-to-Ship mode Supply Transfer, Dual Fueling and Terminal Vehicle Traffic increase the risk to less than 2 times the Base Case risk.

Each of these SIMOPS activities involves transferring supplies or fuel oil from the shore to the vessel. The bulk of these SIMOPS activities occur on the shore and the shore-side of the vessel. A Shore-to-Ship bunkering mode puts the LNG bunkering station closer to these activities and results in a larger increase to the risk.

4.3.2.1 Terminal Activities

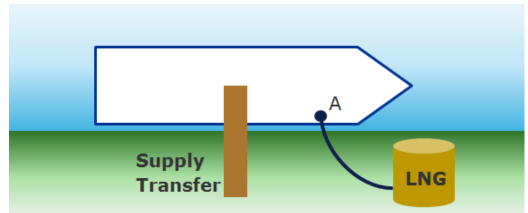
Terminal Activities while LNG bunkering in a Shore-to-Ship mode to a PSV results in a risk increase to less than 2 times the Base Case risk in the generic analysis. Parameters increasing the risk:



- Increased ignition probability from the introduction of vehicles associated with terminal activities
- Introduction of a congested area near the loading area (point A). LNG vapor is flammable in the concentrations between 5% and 15%. If a flammable cloud enters and ignites within a congested region, overpressure develops.

Limiting congestion near the LNG bunkering area mitigates the risk in the generic analysis.

4.3.2.2 Supply Transfer



Supply Transfer while LNG bunkering in a Shore-to-Ship mode to a PSV results in a risk increase to less than 2 times the Base Case risk in the generic analysis. Parameters leading to the risk increase include:

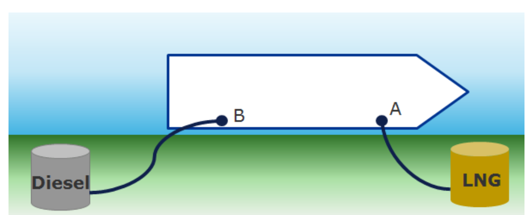
- Small increased ignition probability from the introduction of both people and vehicles
- Potential for a dropped object - Supplies are loaded with and without mechanical aids in the generic analysis at midship (as shown in the Figure). Potentially dropping supplies near the LNG bunkering location (point A) results in an increase of the release frequency.

The risk from Supply Transfer in a Shore-to-Ship bunkering mode is higher than the risk from Supply Transfer in a Ship-to-Ship bunkering mode. This increase is caused by the location of LNG bunkering relative to where Supply Transfers occur. In a Shore-to-Ship bunkering mode LNG bunkering is more prone to impact from supply transfers since both activities occur on the same side of the PSV. This increases the failure frequency.

Several mitigations are available to manage the risk from supplies loading:

- The use of mechanical lifting aids increases the weight of a load lifted and thus the impact if the load is dropped. Some mechanical lifting aids also increase the ignition probability. Limiting the use of mechanical lifting aids reduces risk.
- Supplies are loaded into and out of vehicles. Making sure those vehicles are not running during LNG bunkering reduces the ignition probability.
- Providing sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to limit the effects dropped object potential.
- Physical or structural barriers designed to prevent damage to the LNG bunkering equipment given a dropped object can serve as mitigation if sufficient distance cannot be achieved.

4.3.2.3 Dual Fueling



Dual Fueling while LNG bunkering in a Shore-to-Ship mode to a PSV results in a risk increase to less than 2 times the Base Case risk in the generic analysis. In the analysis, Dual Fueling increases the number of persons at the fuel oil bunkering station by ten. Each person is associated with a small increase in the ignition probability. Dual fueling also has the potential to introduce escalation effects, but the separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) in the generic case (27 meters) is sufficient to prevent escalation.

Given that for the Shore-to-Ship Dual Fueling activity, both the location of LNG bunkering and the location of diesel bunkering are on the same side of the PSV, the risk increase will be more significant compared to Dual Fueling in a Ship-to-Ship bunkering mode.

Swing Scenario

A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

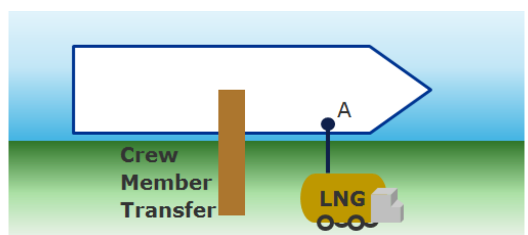
Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect independent SIMOPS have on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.3.3 Truck-to-Ship Bunkering of PSV

Generic analysis of Truck-to-Ship bunkering of PSV includes the same five SIMOPS activities as the Shore-to-Ship bunkering mode. Supply Transfer, Terminal Vehicle Traffic and Dual fueling increase the risk to less than 2 times the Base Case risk; and Ballasting causes increases in risk less than 10% like the Shore-to-Ship bunkering mode.

4.3.3.1 Crew Transfers

Unlike the other bunker modes, Crew Transfer increases the risk to less than 2 times the Base Case risk in the Truck-to-Ship bunkering mode. Crew Transfer is in a similar location in the Truck-to-Ship and Shore-to-Ship mode, however, the increase in risk is more significant in the Truck-to-Ship mode than in the Shore-to-Ship mode.



In the generic analysis, the Truck-to-Ship mode employs a manifold to allow multiple trucks to bunker. The use of the manifold increases the overall frequency of an LNG release causing a small increase in ignition probability introduced by the presence of the crew members.

The increase in risk from Crew Transfer in the Truck-to-Ship mode is just above the 10% threshold. The increase in risk from the Shore-to-Ship mode is within 2 percentage points of the Truck-to-Ship mode. Both modes would be mitigated similarly.

Swing Scenario

People only represent increases in ignition probability when outdoors. In the generic analysis, it is assumed that crew members are only outdoors while loading. They wait indoors on the landing and on the PSV. If people wait outdoors, the risk from crew transfer increases. People who are outdoors not only represent a small increase in ignition probability, but they are also more exposed to the consequences of an LNG release, either cryogenic exposures or heat exposures from an LNG fire. Crew transfer risk can be mitigated by keeping people indoors and thus reducing the ignition probability and exposure. A project-specific SIMOPS QRA should account for prescribed crew behavior and anticipated deviations from prescribed behavior.

4.4 Large Cruise Ship Results

The generic analysis for the Large Cruise Ship includes two bunkering modes, Ship-to-Ship and Shore-to-Ship. The Ship-to-Ship bunkering mode includes six SIMOPS activities. The Shore-to-Ship bunkering mode includes one additional activity for a total of seven SIMOPS activities. The results indicate that when compared with the Base Case (LNG bunkering only) the risk increase from the various SIMOPS activities range from less than 0.01% to up to 10 times the Base Case risk. The results are shown in Figure 4-4.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

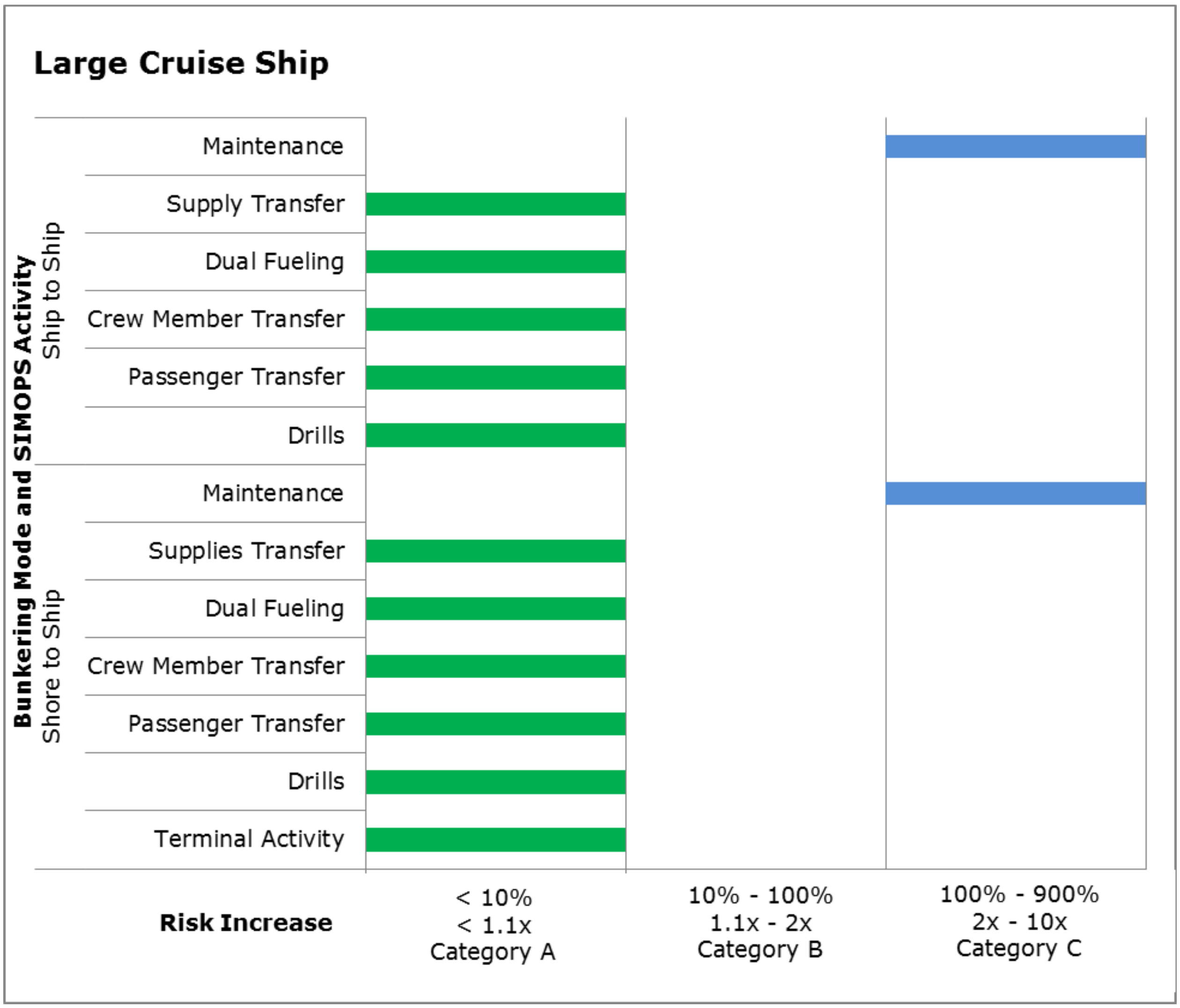
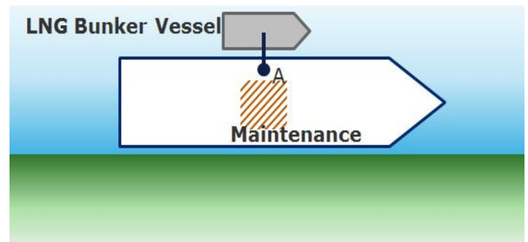


Figure 4-4 Large Cruise Ship Change in Average Individual Risk by SIMOPS Activity

4.4.1 Ship-to-Ship Bunkering of Large Cruise Ships

Generic analysis of Ship-to-Ship bunkering of Large Cruise Ships includes six SIMOPS activities. Maintenance increases the risk to more than 2 times the Base Case risk. Supplies Transfer, Dual Fueling and Crew Member Transfer activities cause an increase in the risk of less than 10% when compared with the Base Case. Passenger Transfer and Drill activities also cause an increase in the individual risk of less than 10% but they also introduce a significant population, so they require a more complex look at the risk (see Additional Considerations under 4.4.1.5 Passenger Transfer and 4.4.1.6 Drills).

4.4.1.1 Maintenance



Maintenance while LNG bunkering in a Ship-to-Ship mode to a Large Cruise Ship results in a risk increase to more than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase:

- Introduction of confined space
- Introduction of ignition sources associated with confined space due to grinding
- Power outage combined with failure to disconnect the LNG bunkering line (either through a failure of the Quick Disconnect System or communication of power loss)

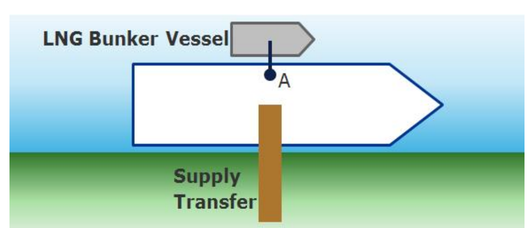
Swing Scenario

The generic analysis modeled the risk increase due to Maintenance in a conservative way. More precise definitions of which maintenance activities are allowed in which areas of the ship are likely to limit the increase in risk. Some maintenance activities, like painting, do not introduce the same risk as activities that involve grinding or hot work. Operators of individual projects should define each allowed maintenance activity as specifically as possible in terms of both tasks and permissible locations. A project-specific SIMOPS QRA can be used to demonstrate that the more restricted maintenance activity does not significantly increase the risk.

Mitigations of risk from maintenance activities are as varied as the range of tasks included in the activity and should be selected to mitigate each task included in the restricted definition. Mitigations for the generic case include:

- Restricting the area where strong ignition sources such as grinding and hot work, are introduced.
- Restricting the area where hatches are opened.
- Supplying back up power to the LNG loading system to allow for a safe disconnect given a power failure due to maintenance

4.4.1.2 Supply Transfer

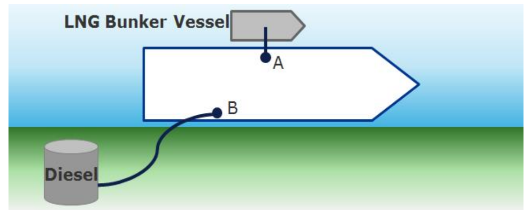


Supply transfer while LNG bunkering in a Ship-to-Ship mode to a Large Cruise Ship results in a risk increase of less than 10% in the generic analysis. Parameters driving the small risk increase include:

- Small increased ignition probability from the introduction of both people and vehicles
- Potential for a dropped object - Supplies are loaded with and without mechanical aids in the generic

analysis at midship (as shown in the Figure). Potentially dropping supplies near the LNG bunkering location (point A) results in only a small increase of the release frequency.

4.4.1.3 Dual Fueling



Dual Fueling while LNG bunkering in a Ship-to-Ship mode to a Large Cruise Ship results in a risk increase of less than 10% in the generic analysis. In the analysis, Dual Fueling increases the number of persons at the fuel oil bunkering stations by ten. Each person is associated with a small increase in the ignition probability. Dual Fueling also has the potential to introduce escalation effects. The separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) is sufficient to prevent escalation in the generic case.

Swing Scenario

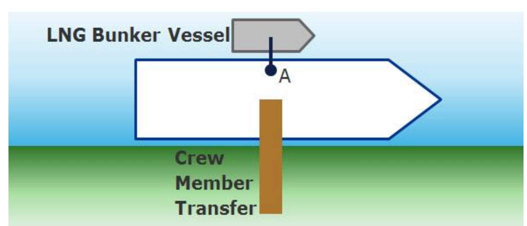
A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.4.1.4 Crew Member Transfer



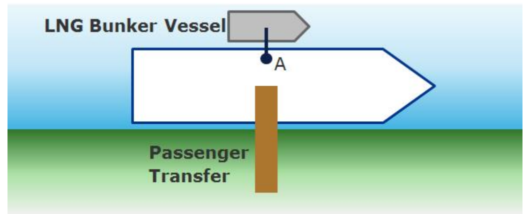
Crew Member Transfer while LNG bunkering in a Ship-to-Ship mode to a Large Cruise Ship results in a risk increase of less than 10% in the generic analysis. The generic analysis assumes a crew transfer of 350 people. Each of those people represents a small increase in the ignition probability while they are outdoors.

Even though the size of the crew population is large, the overall increase in ignition probability is small since a person is a weak ignition source and each person is assumed to spend only a small amount of time outdoors during the transfer period.

Swing Scenario

People only represent increases in ignition probability when outdoors. In the generic analysis, it is assumed that crew members are only outdoors while loading. They wait indoors on the landing and are indoors after they board the cruise vessel. If people wait outdoors either on the landing or on the vessel, the risk from crew member transfer increases. Crew member transfer risk can be mitigated by keeping people indoors, thus, reducing the ignition probability. A project-specific SIMOPS QRA should account for prescribed crew behavior and anticipated deviations from prescribed behavior.

4.4.1.5 Passenger Transfer



Passenger Transfer while LNG bunkering in a Ship-to-Ship mode to a Large Cruise Ship results in a risk increase of less than 10% in the generic analysis when comparing individual risk. The generic analysis assumes 6000 passengers. Each of those people represents a small increase in the ignition probability while they are outdoors. Even though the size of the population is large, the overall increase in ignition probability is small since a person is a weak ignition source and each person is assumed to spend only a small amount of time outdoors during the transfer period.

Additional Considerations

The comparison in Figure 4-4 and the categorization of A, B and C risk use individual risk as the metric. Individual risk is a measure of risk experienced by a single person and is independent of the number of people exposed to the risk. One person or each of 100,000 people in similar locations with similar ongoing activities for a similar amount of time experience similar levels of individual risk. This metric alone is sufficient to compare most of the identified SIMOPS activities, since most SIMOPS activities introduce relatively few people who are exposed in similar ways as personnel aboard the vessel during the Base Case.

A second metric is useful to account for the number of people potentially exposed to the risk. Potential Loss of Life (PLL) is a single measure of societal risk used for comparison. PLL is typically expressed as number of fatalities per year. For example, if 100 people are each exposed to a risk level of 1 fatality per hundred thousand years, the PLL is (100) x (1/100,000) = 0.001 fatalities per year.

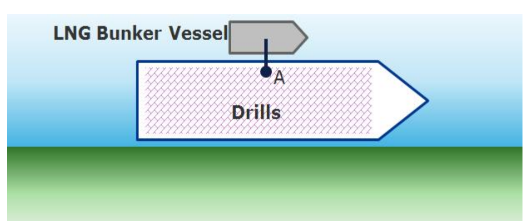
Introducing passengers requires the use of the PLL metric because:

2. The passengers are often exposed to the risk only a fraction of the time that employees are exposed, resulting in lower individual risk.

1. Greater care is taken when more people are at risk.

A project-specific SIMOPS QRA should consider both the individual risk and a societal risk metric. In particular when SIMOPS include large populations or populations with varying exposure to the risks, a societal risk metric can identify impacts to specific populations which can inform the development of risk mitigation strategies.

4.4.1.6 Drills



Drills while LNG bunkering in a Ship-to-Ship mode to a Large Cruise Ship results in a risk increase of less than 10% in the generic analysis when comparing individual risk. The generic analysis assumes that all 2400 crew members congregate outdoors to participate in drills. Each of those people represent a small increase in the ignition probability for the period of time that they are outdoors and, thus, a small individual risk increase.

Additional Considerations

This generic analysis assumed that only the crew members are participating in the drill. However, sometimes also the passengers are participating which could significantly change the ignition probability.

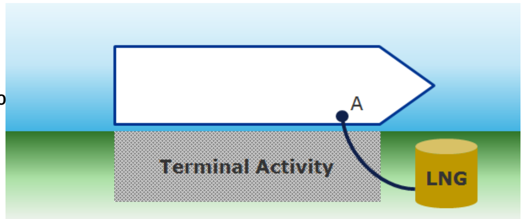
People who are outdoors not only represent a small increase in ignition probability, but they are also more exposed to the potential impact of an LNG release, either cryogenic exposures or heat exposures from an LNG fire.

Drills introduce a large outdoor population wearing no personal protective equipment against LNG or LNG fire exposure. A project-specific SIMOPS QRA should consider both the individual risk and a societal risk metric. In particular when SIMOPS include large populations or populations with varying exposure to the risks, a societal risk metric can identify impacts to specific populations which can inform the development of risk mitigation strategies.

4.4.2 Shore-to-Ship Bunkering of Large Cruise Ships

Generic analysis of Shore-to-Ship bunkering of Large Cruise Ships includes the same six SIMOPS activities as the Ship-to-Ship bunkering mode and one additional SIMOPS activity, Terminal Activity. All of the six shared SIMOPS activities result in similar changes to the Base Case for both bunkering modes. Terminal Activity causes an increase in the risk of less than 10% in the Shore-to-Ship bunkering mode.

4.4.2.1 Terminal Activity



Terminal Activity while LNG bunkering in a Shore-to-Ship mode to a Large Cruise Ship results in a risk increase of less than 10% in the generic analysis. A small number of passing and parking vehicles result in a slight increase in ignition probability and some congestion in the terminal. LNG vapor is flammable in the concentrations between 4% and 17%. If a flammable cloud enters and ignites within a congested region, overpressure develops. The series of events leading to overpressure occur at extremely low frequencies in the generic analysis, so the increase in risk is insignificant.

4.5 Large Container Vessel Results

Generic analysis for the Large Container Vessels includes three bunkering modes, Ship-to-Ship, Shore-to-Ship and Truck-to-Ship. Each bunkering mode includes seven SIMOPS activities. The results indicate that when compared with LNG bunkering the risk increase from the various SIMOPS activities range from less than 0.01% up to 10 times the Base Case risk. The results are shown in Figure 4-5.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

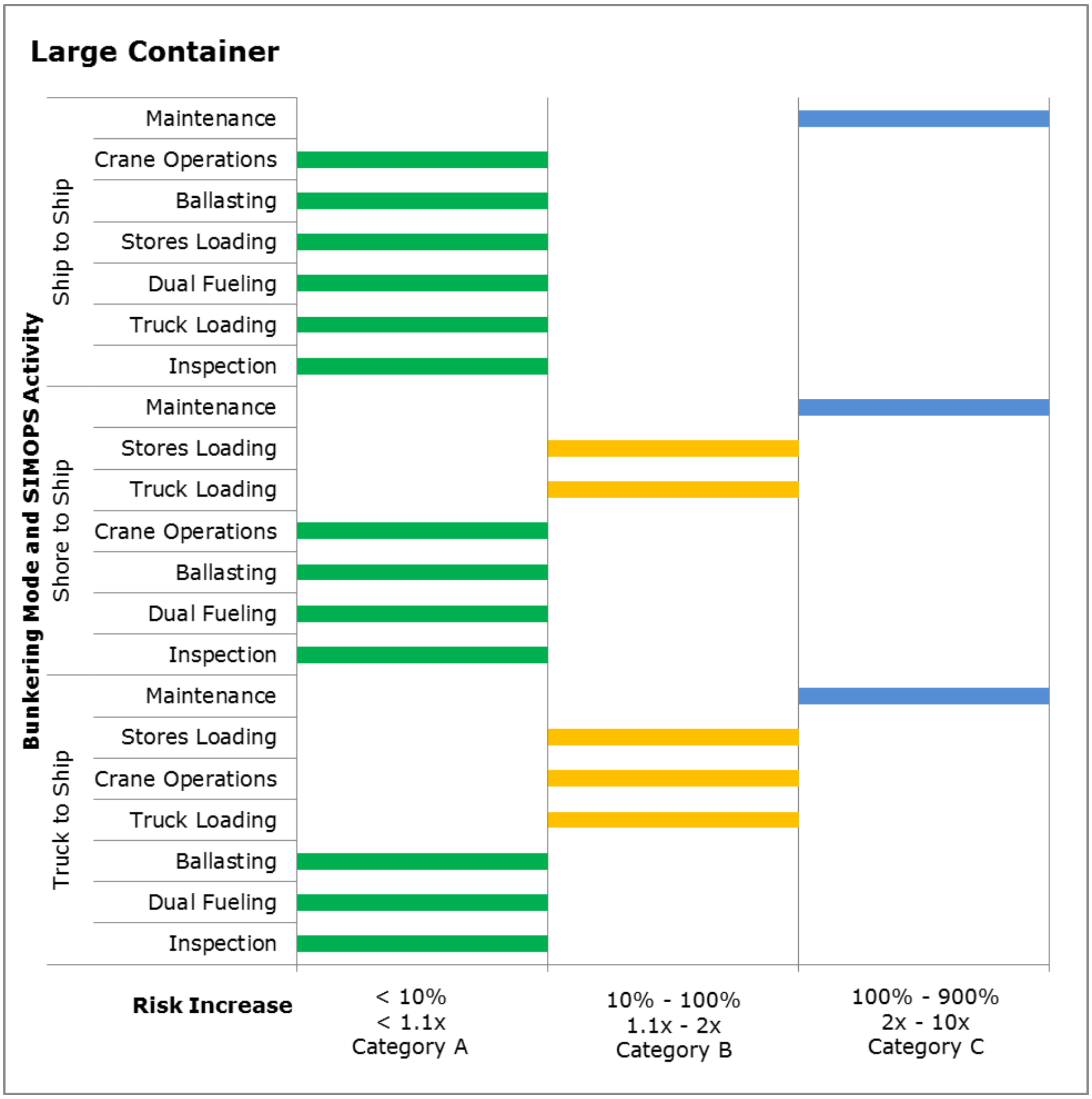
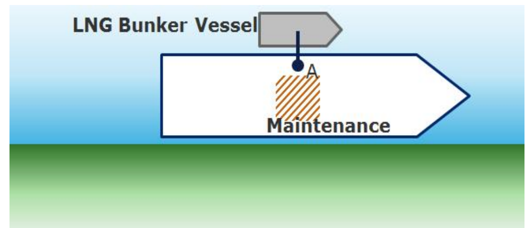


Figure 4-5 Large Container Change in Average Individual Risk by SIMOPS Activity

4.5.1 Ship-to-Ship Bunkering of Large Container Vessels

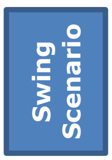
Generic analysis of Ship-to-Ship bunkering of Large Container Vessels includes seven SIMOPS activities. Maintenance increases the risk to more than 2 times the Base Case risk. Crane Operations, Ballasting, Stores Loading, Dual Fueling, Truck Loading and Inspection activities cause an increase in the risk of less than 10% when compared with the Base Case.

4.5.1.1 Maintenance



Maintenance while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase to more than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase

- Introduction of confined space
- Introduction of ignition source associated with confined space due to grinding
- Power outage combined with failure to disconnect the LNG bunkering line (either through a failure of the Quick Disconnect System or communication of power loss)

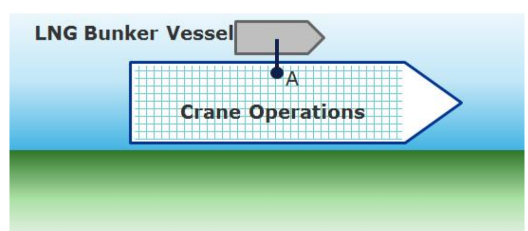


The generic analysis modeled the risk increase due to Maintenance in a conservative way. More precise definitions of which maintenance activities are allowed in which areas of the ship are likely to limit the increases in risk. Some maintenance activities, like painting, do not introduce the same risk as activities that involve grinding or hot work. Operators of individual projects should define each allowed maintenance activity as specifically as possible in terms of both tasks and permissible locations. A SIMOPS QRA can be used to demonstrate that the more restricted maintenance activity does not significantly increase the risk.

Mitigations of risk from maintenance activities are as varied as the range of tasks included in the activity and should be selected to mitigate each task included in the restricted definition. Mitigations for the generic case include

- Restricting the area where strong ignition sources such as grinding and hot work are introduced
- Restricting the area where hatches are opened
- Supplying back up power to the LNG loading system to allow for a safe disconnect given a power failure due to maintenance

4.5.1.2 Crane Operations



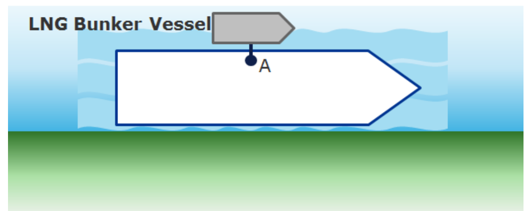
Crane Operations while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase of less than 10% in the generic analysis. Loading cargo by crane is assumed to occur during the entire bunkering duration. Several parameters drive the risk increase:

- Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment in the bunkering area.
- Mechanical failure of the lifting equipment could result in dropping a load on the vessel resulting in enough relative motion to induce the LNG loading hose to shear or stretch off the connection point or cause a misalignment in the quick release coupling.
- Introduction of ignition source associated with the lifting equipment

A dropped object either on the bunkering equipment or on the vessel accounts for the majority of the risk increase. The controls in place during Crane Operations make a dropped object a rare event. Additionally, the bulk of the Crane Operations activity in the Ship-to-Ship bunkering mode occurs on the shore-side of the vessel limiting the potential for a dropped object to directly impact the bunkering equipment. A dropped object anywhere on the vessel could lead to an increase in relative motion and a resulting leak. Historical loading failure rates include ranging failures as a potential failure mechanism. However, failures due to the excessive motion of the ship only account for a small fraction of the total LNG hose failure.

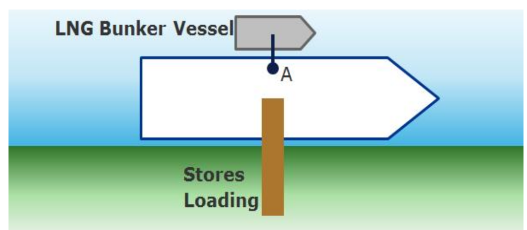
The generic analysis introduces ignition sources to account for the crane activity. The increase in the overall ignition probability and, thus, the risk is limited.

4.5.1.3 Ballasting



Ballasting while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase of less than 10% in the generic analysis. Ballasting is assumed to affect the stability of the entire vessel, increasing the LNG release frequency. Ballasting has the potential to increase the relative motion between the bunkering vessel and the Large Container Vessel and induce the LNG loading hose to shear or stretch off the connection point or cause a misalignment in the quick release coupling. Historical loading failure rates include ranging failures as a potential failure mechanism. However, failures due to the excessive motion of the ship only account for a small fraction of the total LNG hose failure limiting the increase in the risk due to ballasting operations.

4.5.1.4 Stores Loading



Stores Loading while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase of less than 10% in the generic analysis. Several parameters drive the risk increase

- Increased ignition probability from the introduction of both people and vehicles

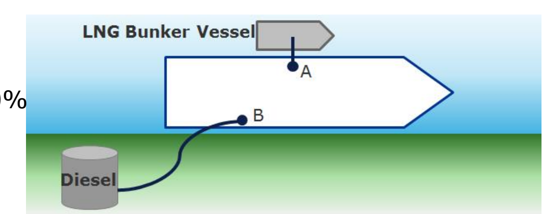
  The generic analysis introduces 10 people and 3 running vehicles for the entire duration of bunkering resulting in a substantial increase in ignition probability.

- Potential for a dropped object

  Supplies are loaded with mechanical aids in the generic analysis at midship (as shown in the Figure). Potentially dropping supplies near the LNG bunkering location (point A) results in a small increase of the release frequency.

The bulk of the Stores Loading activity occurs on the shore-side of the vessel limiting the potential for a dropped object to impact the bunkering infrastructure in the Ship-to-Ship bunkering mode.

4.5.1.5 Dual Fueling



Dual Fueling while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase of less than 10% in the generic analysis. In the analysis, Dual Fueling increases the number of persons at the fuel oil bunkering station by ten. Each person is associated with a small increase in the ignition probability. Dual fueling also has the potential to introduce escalation effects. The separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) in the generic case (58 meters) is sufficient to prevent escalation.

Swing Scenario

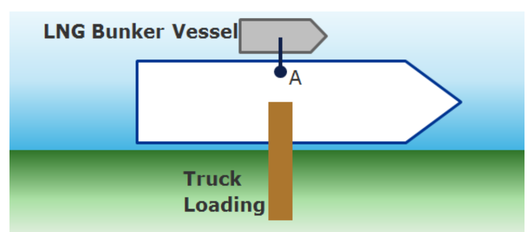
A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to an LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the LNG Bunkering Only (Base Case). A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.5.1.6 Truck Loading

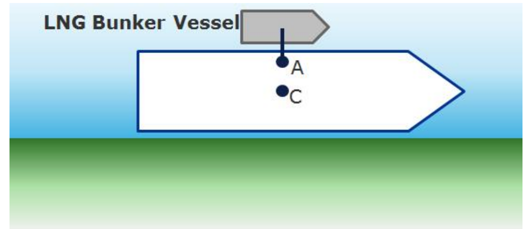


Truck Loading while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase of less than 10% in the generic analysis. The generic analysis assumes 5 trucks are loading cargo onto the ship continuously over the bunkering period. The trucks and additional personnel associated with cargo loading increase the ignition probability. Additionally, the movement of vehicles on board the vessel introduces the potential for a collision with the bunkering infrastructure. The increase in the overall ignition probability, and thus the risk, is small due to the limited number of vehicles. The bulk of the Truck Loading activity occurs on the shore-side of the vessel limiting the potential for a vehicle impact with the bunkering infrastructure in the Ship-to-Ship bunkering mode.

Swing Scenario

Truck Loading and Crane Operations are likely activities to be performed concurrently. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.5.1.7 Inspection



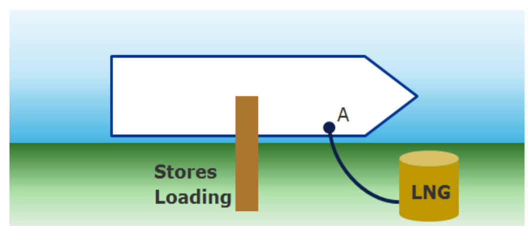
Inspection while LNG bunkering in a Ship-to-Ship mode to a Large Container Vessel results in a risk increase of less than 10% in the generic analysis. Inspection introduces several inspectors, each of which slightly increases the ignition probability, are assumed to be involved in the inspection activity (point C). Since there are few inspectors, the increase in total ignition probability and the resulting increase in the risk, is limited.

4.5.2 Shore-to-Ship Bunkering of Large Container Vessels

Generic analysis of Shore-to-Ship bunkering of Large Container Vessels includes the same seven SIMOPS activities as the Ship-to-Ship bunkering mode. As with the Ship-to-Ship bunkering mode, Maintenance increases the risk to more than 2 times the Base Case risk. Crane Operations, Ballasting, Dual Fueling and Inspection cause increases in the risk of less than 10% compared to the Base Case.

Unlike in a Ship-to-Ship bunkering mode, Stores Loading and Truck Loading increase the risk to less than 2 times the Base Case risk in the Shore-to-Ship bunkering mode. Each of these SIMOPS activities involves transferring stores or cargo from the shore to the vessel. The bulk of these SIMOPS activities occur on the shore and the shore-side of the vessel. A Shore-to-Ship bunkering mode puts the LNG bunkering station closer to these activities and results in a larger increase to the risk.

4.5.2.1 Stores Loading



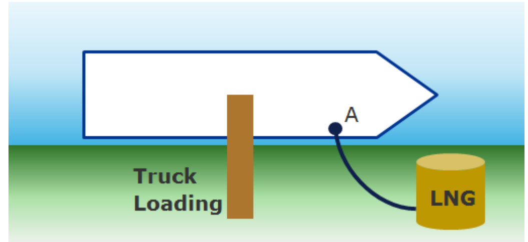
Stores Loading while LNG bunkering in a Shore-to-Ship mode to a Large Container Vessel results in a risk increase to less than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase

- Increased ignition probability from the introduction of both people and vehicles
- Potential for a dropped object
- Proximity of activity to the LNG bunkering location (Point A) – Stores Loading is assumed to occur at midship (as shown in the Figure) in the generic analysis. Both the source of the dropped objects and the increased ignition probability occur at midship (as shown in the Figure).

Several mitigations are available to manage the risk from Stores Loading:

- Supplies are loaded into and out of vehicles. Making sure those vehicles are not running during LNG bunkering reduces the ignition probability.
- Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to limit the effects of the dropped object potential.
- Physical or structural barriers designed to prevent damage to the LNG bunkering equipment given a dropped object can serve as a mitigation if sufficient distance cannot be achieved.

4.5.2.2 Truck Loading



Truck Loading while LNG bunkering in a Shore-to-Ship mode to a Large Container Vessel results in a risk increase to less than 2 times the Base Case risk in the generic analysis. The generic analysis assumes 5 trucks are loading cargo on board the vessel over the bunkering period. The trucks and additional personnel associated with cargo loading increase the ignition probability. Additionally, the movement of vehicles on board the vessel introduces the potential for a collision with the bunkering infrastructure. The increase in the overall ignition probability' and thus, the risk, is small due to the limited number of vessels. Trucks are assumed to board the vessel at midship (as shown in the Figure) increasing the proximity of the activity to LNG bunkering location (point A) relative to the Ship-to-Ship mode.

Vehicle impacts are most effectively mitigated by proving sufficient distance, as determined by a project-specific SIMOPS QRA. Physical or structural barriers designed to prevent damage to the LNG bunkering equipment can serve as mitigation if sufficient distance cannot be achieved.

Swing Scenario

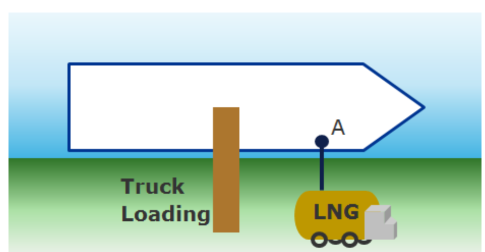
Truck Loading and Crane Operations are likely activities to be performed concurrently. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.5.3 Truck-to-Ship Bunkering of Large Container Vessels

Generic analysis of Truck-to-Ship bunkering of Large Container Vessels includes the same seven SIMOPS activities as the Ship-to-Ship and Shore-to-Ship bunkering modes. As with the other modes, Maintenance increases the risk to more than 2 times the Base Case risk. Ballasting, Dual Fueling and Inspection cause increases in the risk of less than 10% when compared with the Base Case.

Stores Loading and Truck Loading increase the risk to less than 2 times the Base Case risk in the Truck-to-Ship bunkering mode similar to the Shore-to-Ship bunkering mode since the LNG bunkering activity occurs on the shore-side of the vessel.

4.5.3.1 Truck Loading



Unlike the other bunker modes, Crane Operations increase the risk to less than 2 times the Base Case risk in the Truck-to-Ship bunkering mode. Truck Loading is in a similar location in the Truck-to-Ship and Shore-to-Ship mode. However, the increase in risk is more significant in the Truck-to-Ship mode than in the Shore-to-Ship mode for two reasons:

- The Truck-to-Ship mode bunkers at a slower rate than Shore-to-Ship modes and requires more bunkering time to fill the same tank size. Since Crane Operations occur during the entire bunkering duration for both cases, the LNG bunkering infrastructure is exposed to more dropped objects when bunkering in a Truck-to-Ship mode than in a Shore-to-Ship mode.

- In the generic analysis, the Truck-to-Ship mode employs a manifold to allow multiple trucks to bunker. The use of the manifold increases the amount of the infrastructure exposed to dropped objects compared to the Shore-to-Ship mode.

4.6 Feeder Container Vessel Results

Generic analysis for the Feeder Container Vessels includes three bunkering modes, Ship-to-Ship, Shore-to-Ship and Truck-to-Ship. Each bunkering mode includes seven SIMOPS activities. The results indicate that when compared with LNG bunkering only (Base Case) the risk increase from the various SIMOPS activities range from less than 0.01% up to 10 times the Base Case risk. The results are shown in Figure 4-6.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

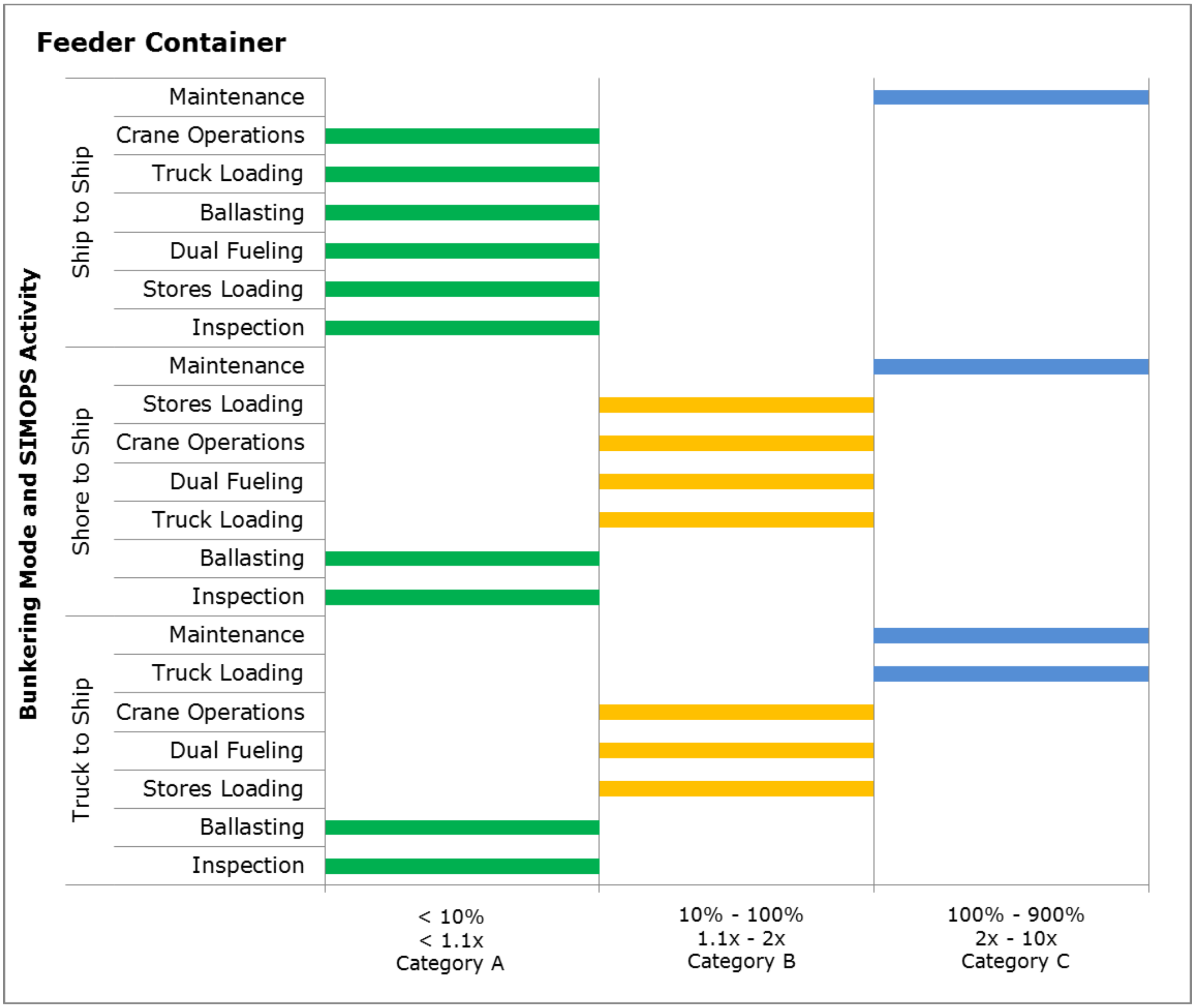
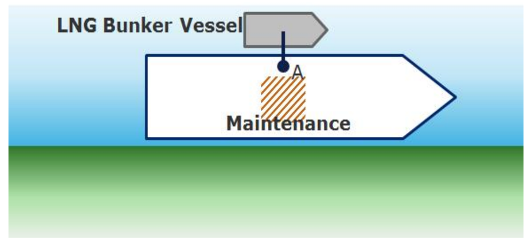


Figure 4-6 Feeder Container Change in Average Individual Risk by SIMOPS Activity

4.6.1 Ship-to-Ship Bunkering of Feeder Container Vessels

Generic analysis of Ship-to-Ship bunkering of Feeder Container Vessels includes seven SIMOPS activities. Maintenance increases the risk to more than 2 times the Base Case risk. Crane Operations, Truck Loading, Ballasting, Dual Fueling, Stores Loading and Inspection activities cause an increase in the risk of less than 10% when compared with the Base Case.

4.6.1.1 Maintenance



Maintenance while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in a risk increase to more than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase

- Introduction of confined space
- Introduction of ignition source associated with confined space due to grinding
- Power outage combined with failure to disconnect the LNG bunkering line (either through a failure of the Quick Disconnect System or communication of power loss)

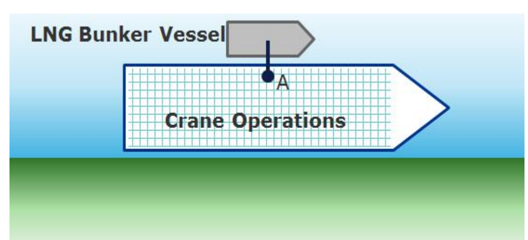
Swing Scenario

The generic analysis modeled the risk increase due to Maintenance in a conservative way. More precise definitions of which maintenance activities are allowed in which areas of the ship are likely to limit the increases in risk. Some maintenance activities, like painting, do not introduce the same risk as activities that involve grinding or hot work. Operators of individual projects should define each allowed maintenance activity as specifically as possible in terms of both tasks and permissible locations. A SIMOPS QRA can be used to demonstrate that the more restricted maintenance activity does not significantly increase the risk.

Mitigations of risk from maintenance activities are as varied as the range of tasks included in the activity and should be selected to mitigate each task included in the restricted definition. Mitigations for the generic case include

- Restricting the area where strong ignition sources, such as grinding and hot work, are introduced
- Restricting the area where hatches are opened
- Supplying back up power to the LNG loading system to allow for a safe disconnect given a power failure due to maintenance

4.6.1.2 Crane Operations



Crane Operations while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in a risk increase of less than 10% in the generic analysis. Crane Operations loading cargo are assumed to occur during the entire bunkering duration. Several parameters drive the risk increase:

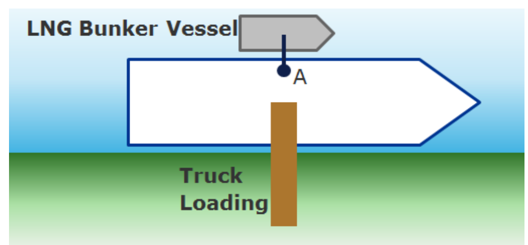
- Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment in the bunkering area.

- Mechanical failure of the lifting equipment could result in dropping a load on the vessel resulting in enough relative motion to induce the LNG loading hose to shear or stretch off the connection point or cause a misalignment in the quick release coupling.
- Introduction of ignition source associated with the lifting equipment

A dropped object either on the bunkering equipment or on the vessel accounts for the majority of the risk increase. The controls in place during Crane Operations make a dropped object a rare event. Additionally, the bulk of the Crane Operations activity in the Ship-to-Ship bunkering mode occurs on the shore-side of the vessel limiting the potential for a dropped object to directly impact the bunkering equipment. A dropped object anywhere on the vessel could lead to an increase in relative motion and a resulting leak. Historical loading failure rates include ranging failures as a potential failure mechanism. However, failures due to the excessive motion of the ship only account for a small fraction of the total LNG hose failure.

The generic analysis introduces ignition sources to account for the crane activity. The increase in the overall ignition probability and, thus, the risk is limited.

4.6.1.3 Truck Loading

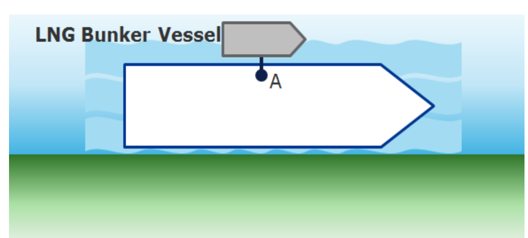


Truck Loading while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in a risk increase of less than 10% in the generic analysis. The Truck Loading activity accounts for the potential to load cargo via truck. The generic analysis assumes 5 trucks working continuously over the bunkering period. The trucks and additional personnel associated with cargo loading increase the ignition probability. Additionally, the movement of vehicles on board the vessel introduces the potential for a collision with the bunkering infrastructure. The increase in the overall ignition probability and, thus, the risk is small due to the limited number of vessels. The bulk of the Truck Loading activity occurs on the shore-side of the vessel limiting the potential for a vehicle impact with the bunkering infrastructure in the Ship-to-Ship bunkering mode.

Swing Scenario

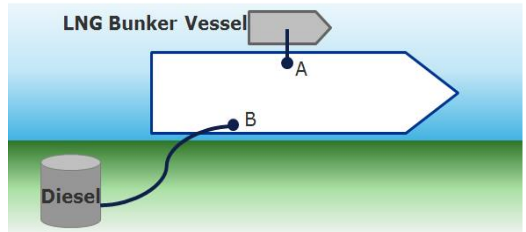
Truck Loading and Crane Operations are likely activities to be performed concurrently. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.6.1.4 Ballasting



Ballasting while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in risk increase of less than 10% in the generic analysis. Ballasting is assumed to affect the stability of the entire vessel, increasing the LNG release frequency. Ballasting has the potential to increase the relative motion between the bunkering vessel and the Feeder Container vessel and induce the LNG loading hose to shear or stretch off the connection point or cause a misalignment in the quick release coupling. Historical loading failure rates include ranging failures as a potential failure mechanism. However, failures due to the excessive motion of the ship only account for a small fraction of the total LNG hose failure, hence, the increase in the risk due to ballasting operation is limited.

4.6.1.5 Dual Fueling



Dual Fueling while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in a risk increase of less than 10% in the generic analysis. In the analysis, Dual Fueling increases the number of persons near the fuel oil bunkering station by ten. Each person is associated with a small increase in the ignition probability. Dual Fueling also has the potential to introduce escalation effects. The separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) in the generic case (57 m) is sufficient to prevent escalation.

Swing Scenario

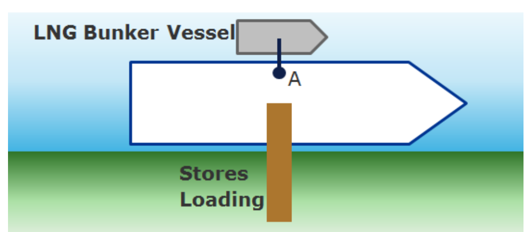
A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.6.1.6 Stores Loading

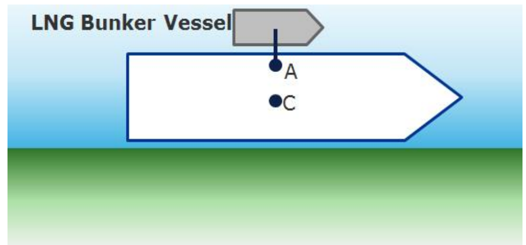


Stores Loading while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in a risk increase of less than 10% in the generic analysis. Parameters driving the risk increase are:

- Increased ignition probability from the introduction of both people and vehicles
- The generic analysis introduces 10 people and 3 running vehicles for the entire duration of bunkering resulting in a substantial increase in ignition probability.
- Potential for a dropped object
- Supplies are loaded with mechanical aids in the generic analysis at midship (path X). Potentially dropping supplies near the LNG bunkering location (point X), results in a small increase of the release frequency.

The bulk of the Stores Loading activity occurs on the shore-side of the vessel limiting the potential for a dropped object to impact the bunkering infrastructure in the Ship-to-Ship bunkering mode.

4.6.1.7 Inspection



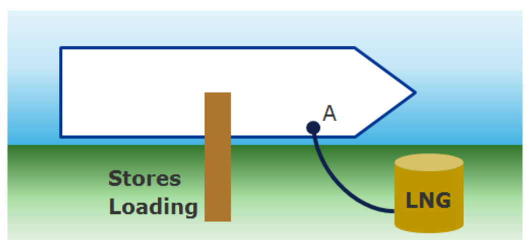
Inspection while LNG bunkering in a Ship-to-Ship mode to a Feeder Container Vessel results in a risk increase less than 10% in the generic analysis. Inspection introduces several inspectors, each of which slightly increases the ignition probability, are assumed to be involved in the inspection activity (Point C). Since there are few inspectors, the increase in total ignition probability and the resulting increase in the risk is limited.

4.6.2 Shore-to-Ship Bunkering of Feeder Container Vessels

Generic analysis of Shore-to-Ship bunkering of Feeder Container Vessels includes the same seven SIMOPS activities as the Ship-to-Ship bunkering mode. As with the Ship-to-Ship bunkering mode, Maintenance increases the risk to more than 2 times the Base Case risk, while both Ballasting and Inspection cause increases in the risk of less than 10% when compared with the Base Case.

Unlike in a Ship-to-Ship bunkering mode, Stores Loading, Crane Operations, Dual Fueling and Truck Loading increase the risk to less than 2 times the Base Case risk in the Shore-to-Ship bunkering mode. Each of these SIMOPS activities involves transferring stores or cargo from the shore to the vessel. The bulk of these SIMOPS activities occur on the shore and the shore-side of the vessel. A Shore-to-Ship bunkering mode puts the LNG bunkering station closer to these activities and results in a larger increase to the risk.

4.6.2.1 Stores Loading



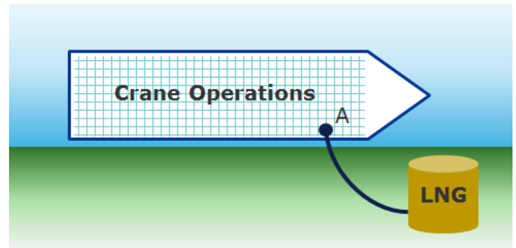
Stores Loading while LNG bunkering in a Shore-to-Ship mode to a Feeder Container Vessel results in a risk increase to less than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase:

- Increased ignition probability from the introduction of both people and vehicles
- Potential for a dropped object
- Proximity of activity to the LNG bunkering location - Loading is assumed to occur at midship (as shown in the Figure) in the generic analysis. Both the source of the dropped objects and the increased ignition probability occur at midship (as shown in the Figure).

Several mitigations are available to manage the risk from Stores Loading:

- Supplies are loaded into and out of vehicles. Making sure those vehicles are not running during LNG bunkering reduces the ignition probability.
- Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to limit the effects of the dropped object potential.
- Physical or structural barriers designed to prevent damage to the LNG bunkering equipment given a dropped object can serve as mitigation if sufficient distance cannot be achieved.

4.6.2.2 Crane Operations



Crane Operations while LNG bunkering in a Shore-to-Ship mode to a Feeder Container Vessel results in a risk increase to less than 2 times the Base Case risk in the generic analysis. Loading cargo by crane is assumed to occur during the entire bunkering duration. Several parameters drive the risk increase:

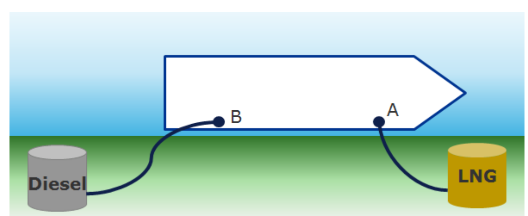
- Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment in the bunkering area.
- Mechanical failure of the lifting equipment could result in dropping a load on the vessel resulting in enough relative motion to induce the LNG loading hose to shear or stretch off the connection point or cause a misalignment in the quick release coupling.
- Introduction of ignition source associated with the lifting equipment
- Proximity of activity to the LNG bunkering location - Cranes are assumed to pick up loads from the shore. Loads are placed over the entire deck of the vessel in the generic analysis. Both the source of the dropped objects and the increased ignition probability occur across the ship but are more likely at the Shore-to-Ship interface.

A dropped object either on the bunkering equipment or on the vessel accounts for the majority of the risk increase. The controls in place during Crane Operations make a dropped object a rare event.

Several mitigations are available to manage the risk from Crane Operations:

- Avoiding dropped objects limits the increase in the risk. Proper operational controls for lifting including operator training and equipment inspection programs decrease the change for a dropped object.
- Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to limit the effects dropped objects impacting the bunkering infrastructure.
- Physical or structural barriers designed to prevent damage to the LNG bunkering equipment given a dropped object can serve as a mitigation if sufficient distance cannot be achieved.

4.6.2.3 Dual Fueling



Dual Fueling while LNG bunkering in a Shore-to-Ship mode to a Feeder Container Vessel results in a risk increase to less than 2 times the Base Case risk in the generic analysis. In the analysis, Dual Fueling increases the number of persons at the oil fuel bunkering station by ten. Each person is associated with a small increase in the ignition probability. Dual fueling also has the potential to introduce escalation effects.

Escalation effects are most effectively mitigated by proving sufficient distance, as determined by a project-specific SIMOPS QRA. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

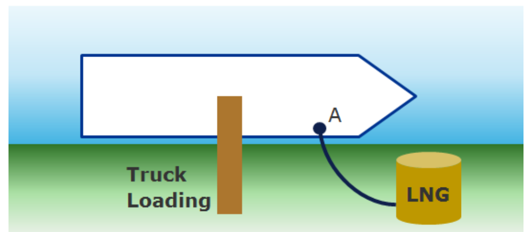
Swing Scenario

A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.6.2.4 Truck Loading



Truck Loading while LNG bunkering in a Shore-to-Ship mode to a Feeder Container Vessel results in a risk increase to less than 2 times the Base Case risk in the generic analysis. The generic analysis assumes 5 trucks are loading cargo on board the vessel over the bunkering period. The trucks and additional personnel associated with cargo loading increase the ignition probability. Additionally, the movement of vehicles on board the vessel introduces the potential for a collision with the bunkering infrastructure. The increase in the overall ignition probability, and thus the risk, is small due to the limited number of vessels. Trucks are assumed to board the vessel at midship (as shown in the Figure) increasing the proximity of the activity to LNG bunkering location relative to the Ship-to-Ship mode.

Vehicle impacts are most effectively mitigated by proving sufficient distance, as determined by a project-specific SIMOPS QRA. Physical or structural barriers designed to prevent damage to the LNG bunkering equipment can serve as mitigation if sufficient distance cannot be achieved.

Swing Scenario

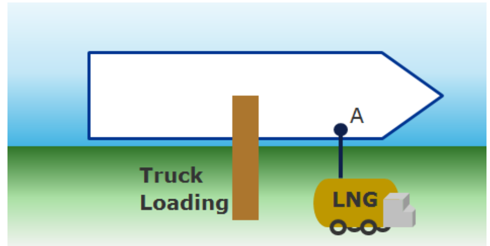
Truck Loading and Crane Operations are likely activities to be performed concurrently. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.6.3 Truck-to-Ship Bunkering of Feeder Container Vessels

Generic analysis of Truck-to-Ship bunkering of Feeder Container Vessels includes the same seven SIMOPS activities as the Ship-to-Ship and Shore-to-Ship bunkering modes. As with the other modes, Maintenance increases the to more than 2 times the Base Case risk, while both Ballasting and Inspection cause increases in the risk of less than 10% compared with the Base Case.

Stores Loading, Crane Operations and Dual Fueling increase the risk to less than 2 times the Base Case risk in the Truck-to-Ship bunkering mode similar to the Shore-to-Ship bunkering mode since the LNG bunkering activity occurs on the shore-side of the vessel.

4.6.3.1 Truck Loading



Unlike the other bunker modes, Truck Loading increases the risk to more than 2 times the Base Case risk in the Truck-to-Ship bunkering mode. Truck Loading is in a similar location in the Truck-to-Ship and Shore-to-Ship mode, however, the increase in risk is greater in the Truck-to-Ship mode than in the Shore-to-Ship mode for two reasons:

1. The Truck-to-Ship mode bunkers at a slower rate than Shore-to-Ship modes and requires more bunkering time to fill the same tank size. Since truck loading occurs during the entire bunkering duration for both cases, the LNG bunkering infrastructure is exposed to more truck movements when bunkering in a Truck-to-Ship mode than in a Shore-to-Ship mode.
2. In the generic analysis, the Truck-to-Ship mode employs a manifold to allow multiple trucks to bunker. The use of the manifold increases the amount of the infrastructure exposed to vehicle impact compared to the Shore-to-Ship mode.

4.7 Bulker Results

The generic analysis for Bulkers includes three bunkering modes, Ship-to-Ship, Shore-to-Ship and Truck-to-Ship. Each bunkering mode includes six SIMOPS activities. The results indicate that, when compared with LNG bunkering, the risk increase from the various SIMOPS activities range from less than 0.01% up to 10 times the Base Case risk. The results are shown in Figure 4-7.

It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. This study is generic and assesses a proximate average case for LNG bunkering in all scenarios. The range in delta risk seen across the SIMOPS operations indicates that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

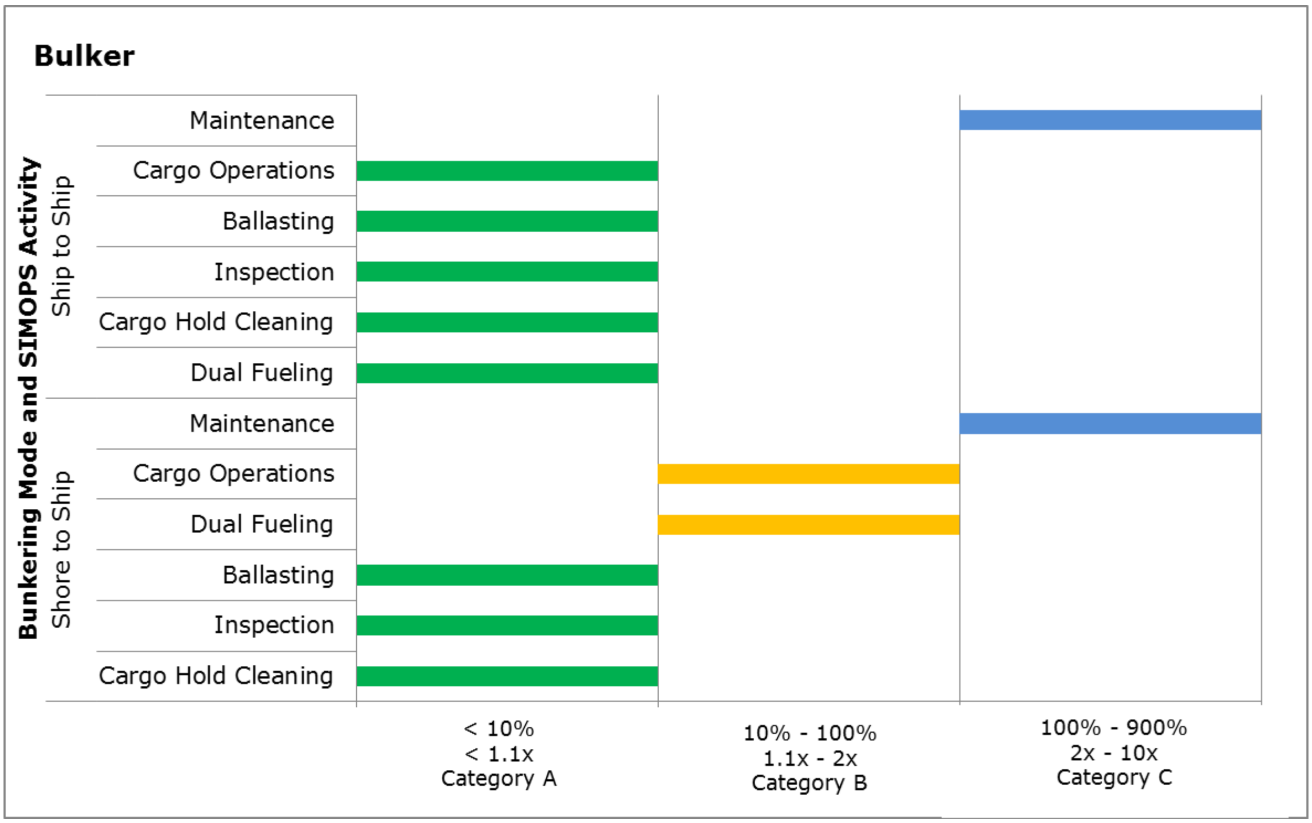
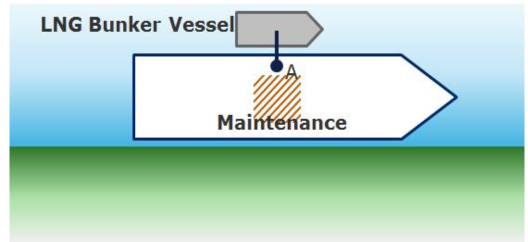


Figure 4-7 Bulker Change in Average Individual Risk by SIMOPS Activity

4.7.1 Ship-to-Ship Bunkering of Bulker

Generic analysis of Ship-to-Ship bunkering of Bulker includes six SIMOPS activities. Maintenance SIMOPS activities increase the risk to more than 2 times the Base Case risk. Cargo Operations, Ballasting, Inspection, Cargo Holder Cleaning and Dual Fueling cause an increase in the risk of less than 10% compared to the Base Case.

4.7.1.1 Maintenance



Maintenance while LNG bunkering in a Ship-to-Ship mode to a Bulker results in a risk increase to more than 2 times the Base Case risk in the generic analysis. Several parameters drive the risk increase including:

- Introduction of confined space
- Introduction of ignition source associated with confined space due to grinding
- Power outage combined with failure to disconnect the LNG bunkering line (either through a failure of the Quick Disconnect System or operator communication of power loss)

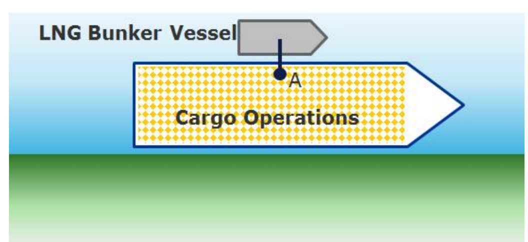
Swing Scenario

The generic analysis modeled the risk increase due to maintenance in a conservative way. More precise definitions of which maintenance activities are allowed in which areas of the ship are likely to limit the increases in risk. Some maintenance activities, like painting, do not introduce the same risk as activities that involve grinding or hot work. Operators of individual projects should define each allowed maintenance activity as specifically as possible in terms of both tasks and permissible locations. A SIMOPS QRA can be used to demonstrate that the more restricted maintenance activity does not significantly increase the risk.

Mitigations of risk from maintenance activities are as varied as the range of tasks included in the activity and should be selected to mitigate each task included in the restricted definition. Mitigations for the generic case include:

- Restricting the area where strong ignition sources such as grinding and hot work are introduced
- Restricting the area where hatches are opened
- Supplying back up power to the LNG loading system to allow for a safe disconnection between Bulker and LNG source, given a power failure due to maintenance

4.7.1.2 Cargo Operations



Cargo Operations while LNG bunkering in a Ship-to-Ship mode to a Bulker results in a risk increase of less than 10% in the generic analysis. Cargo operations include the potential for a dropped object due to loading cargo from either overhead lifting systems, conveyor systems or vehicle-based loading. Parameters leading to the risk increase are:

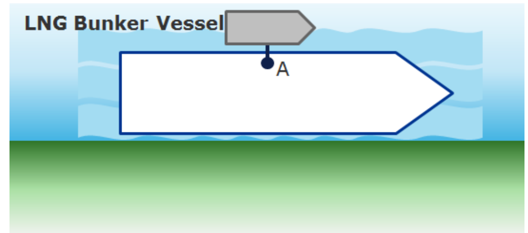
- Increased ignition probability from the introduction of both people and vehicles

  The generic analysis introduces running vehicles for the entire duration of bunkering resulting in an increase in ignition probability.

- Potential for a dropped object

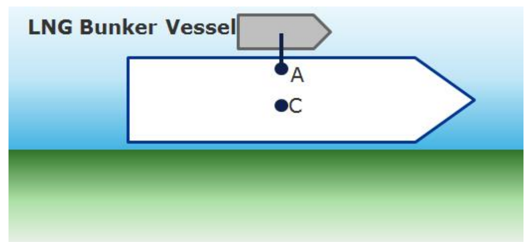
  Cargo Operations with various mechanical aids in the generic analysis are assumed to be conducted at most places on the ship (as shown in the Figure). Potentially dropping a load near the LNG bunkering location (point A) results in a small increase of the LNG release frequency.

4.7.1.3 Ballasting



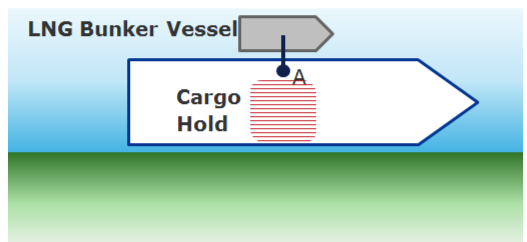
Ballasting while LNG bunkering in a Ship-to-Ship mode to a Bulker, results in a risk increase of less than 10% in the generic analysis. Ballasting is assumed to affect the stability of the entire vessel, increasing the LNG release frequency. Ballasting has the potential to increase the relative motion between the bunkering vessel and the Bulker and induce the LNG loading hose to shear or cause a misalignment in the quick release coupling. Historical loading failure rates include ranging failures as a potential failure mechanism. However, failures due to the excessive motion of the ship only account for a small fraction of the total LNG hose failure, limiting the increase in the risk due to ballasting operations.

4.7.1.4 Inspection



Inspection while LNG bunkering in a Ship-to-Ship mode to a Bulker results in a risk increase of less than 10% in the generic analysis. Inspection introduces several inspectors (Point C), each of which slightly increases the ignition probability. Since there are few inspectors, the increase in total ignition probability and the resulting increase in the risk, is limited.

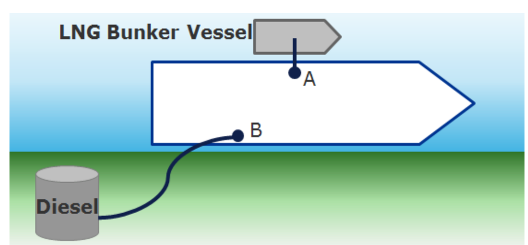
4.7.1.5 Cargo Hold Cleaning



Cargo Hold Cleaning while LNG bunkering in a Ship-to-Ship mode to a Bulker results in a risk increase of less than 10% in the generic analysis. Several parameters cause the small risk increase such as the introduction of confined space (cargo hold) and the introduction of additional ignition source due to the cleaning work done in the cargo hold.

Maintenance Activities also introduce both of those changes. The ignition probability for Cargo Hold Cleaning is assumed to be lower than the ignition introduced in the Maintenance Activities in the generic analysis. Hot work and grinding, included in Maintenance Activities, are much stronger sources of ignition than the ignition sources in Cargo Hold Cleaning. The cargo hold, introduced as a confined space, is assumed to be much larger than the confined space introduced in the Maintenance Activities analysis, leading to smaller overpressure build-up.

4.7.1.6 Dual Fueling



Dual Fueling while LNG bunkering in a Ship-to-Ship mode to a Bulker results in a risk increase of less than 10% in the generic analysis. In the analysis, Dual Fueling increases the number of persons aboard by ten. Each person is associated with a small increase in the ignition probability. Dual Fueling also has the potential to introduce escalation effects. The separation between the LNG bunkering location (point A) and the fuel oil bunkering location (point B) is sufficient to prevent escalation in the generic case.

Swing Scenario

A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release to come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil.

Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect independent SIMOPS have on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4.7.2 Shore-to-Ship Bunkering of Bulker

Generic analysis of Shore-to-Ship bunkering of Bulkers includes the same six SIMOPS activities as the Ship-to-Ship bunkering mode. As with the Ship-to-Ship bunkering mode, Maintenance increases the risk to more than 2 times the Base Case risk. Ballasting, Inspection and Cargo Hold Cleaning cause increases in the risk of less than 10% compared to the Base Case.

Unlike in a Ship-to-Ship bunkering mode, Cargo Operations and Dual Fueling increase the risk to less than 2 times the Base Case risk in the Shore-to-Ship bunkering mode. Each of these SIMOPS activities involves transferring cargo or fuel oil from the shore to the vessel. The bulk of these SIMOPS activities occur on the shore and the shore-side of the vessel. A Shore-to-Ship bunkering mode puts the LNG bunkering station closer to these activities and results in a larger increase to the risk.

4.7.2.1 Cargo Operations

Cargo Operations while LNG bunkering in a Shore-to-Ship mode to a Bulker results in a risk increase to less than 2 times the Base Case risk in the generic analysis. Cargo operations include the potential for a dropped object due to loading cargo from either overhead lifting systems, conveyor systems or vehicle-based loading. Parameters leading to the risk increase:

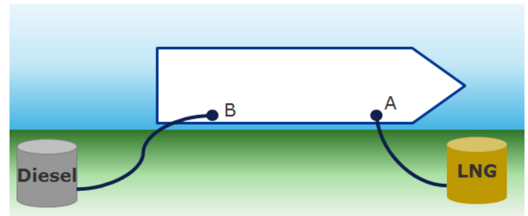
- Increased ignition probability from the introduction of both people and vehicles
- Potential for dropped objects

Several mitigations are available to manage the risk from cargo operations:

- Cargos are loaded into and out of vehicles. Making sure those vehicles are not running during LNG bunkering reduces the ignition probability.
- Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to limit the effects dropped object potential.

- Physical or structural barriers designed to prevent damage to the LNG bunkering equipment given a dropped object can serve as mitigation if sufficient distance cannot be achieved.

4.7.2.2 Dual Fueling



Dual Fueling while LNG bunkering in a Shore-to-Ship mode to a Bulker results in a risk increase to less than 2 times the Base Case risk in the generic analysis. In the analysis, Dual Fueling increases the number of persons at the fuel oil bunkering station by ten. Each person is associated with a small increase in the ignition probability. Dual Fueling also has the potential to introduce escalation effects.

Given that for the Shore-to-Ship Dual Fueling Activity, both the location of LNG bunkering and the location of diesel bunkering are on the same side of the Bulker, the risk increase will be more significant compared to Dual Fueling in a Ship-to-Ship bunkering mode.

Swing Scenario

A reduction in the separation distance between the LNG and fuel oil bunkering locations increases the likelihood that a release of either hydrocarbon escalates and induces a release from the other hydrocarbon. Both the LNG and the diesel fuel, if ignited, can result in a fire. If the two bunkering stations are too close together, radiation from such a fire weakens the equipment containing the other hydrocarbon and can result in a release. Additionally, if fuel oil bunkering equipment is close enough to the LNG release that it come in contact with the LNG, cryogenic embrittlement can cause a subsequent release of fuel oil. Proving sufficient distance, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, a leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.

Swing Scenario

Dual fueling is one of the most likely SIMOPS activities to be performed concurrently with other SIMOPS activities. In the generic analysis, each SIMOPS activity is treated independently to determine the effect on the Base Case. A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

5 CONCLUSIONS

This report and its references provide a framework for doing a SIMOPS QRA when taken as part of the overall risk assessment process as defined by ISO (2). As a result of this analysis many key issues are identified. Some relate to specific vessels and it is recommended to reference those sections of interest. Additionally, there are overarching issues which should be considered.

SIMOPS introduces risks

Introducing more activities has an unavoidable increase on risk. It is important for owners, operators, and regulators to first ensure that LNG bunkering without SIMOPS is acceptable before considering what activities will be allowed under SIMOPS with LNG bunkering. Analysis in this study shows the increases in risk are highly dependent on the specific case and SIMOPS activity considered.

A wide range of potential risk increases are estimated; the study provides evidence that a detailed SIMOPS QRA is a vital tool for decision-making

Overall, this report and study shows that the range of potential risk increases varies greatly and depends on a number of key parameters. Since this study is generic and assesses a proximate average case for LNG bunkering in all scenarios, the study provides further evidence that a project-specific SIMOPS QRA considering specific operational parameters, spacing considerations and mitigations is critical.

Typical risk mitigation measures reduce risks for SIMOPS

Although risk mitigation measures are not quantified in this report, it is apparent that some typical risk reduction strategies have good potential for reducing SIMOPS risks as well by comparing some of the results between vessels.

- Though exclusion and safety zones are not specifically addressed in this report and study, the results show that increasing the distance between the hazard sources (e.g., uncontrolled release of LNG) decreases the exposure of individuals.
- Control of ignition sources proves to be an important contributing factor to the risk exposure. In general, bunkering cases with additional ignition sources (e.g., maintenance, crane operations, etc.) have higher risks. Ignition sources can be controlled by operational limitations, automatic gas detection (especially in confined spaces) triggering ignition source shut-offs or a combination of the measures.
- The location of bunkering operations relative to SIMOPS can have an important effect on lowering risk. This may be achieved by
    - moving the bunkering location further away from potential ignition sources
    - modifying the arrangement so that the predominant wind direction is not blowing towards ignition sources

From this study, the results show that almost 2/3 of the SIMOPS activities studied resulted in risk increases less than 10% compared to the Base Case. The analysis also shows that the type of SIMOPS activity and the specific operating conditions play an important role. Changing any number of the parameters in this study may increase or decrease the estimated risk.

Owners, operators and risk assessment practitioners are encouraged to account for the key parameters in the risk assessment and ensure assumptions align with the operation when performing the risk assessment. The checklists developed as part of this report will provide a useful basis for further development of the project and risk management efforts.

Risk / operation trade-offs are key for decision-makers

This study shows that operating an LNG bunkering facility can be a trade-off between risk and operability. For example, this study shows the trade-off between loading duration (increasing hazardous exposure time) and loading flow rate (increasing the volume of hazardous material released) are factors that affect risk. While lower flow rates are attributed to decreasing risk because the hazard zones will be smaller, the increased time to bunker with LNG may expose individuals for a longer duration resulting in higher risks.

6 RECOMMENDATIONS

Align methodologies to assure consistent application of the SIMOPS QRA

This report along with the checklist in Appendix B provides a systematic approach for conducting a SIMOPS QRA. Assuring that methodologies align and meet regulatory requirements ensures that there is common understanding and path forward in the approval process. Regulators, proponents and the public will benefit from increased standardization as long as it does not sacrifice comprehensiveness for standardization. .

Project-specific QRA

Mentioned throughout this report, a project-specific SIMOPS QRA is important to assess the potential risk increase resulting from the actual operational conditions present. The SIMOPS QRA presented in this report are sensitive to the underlying assumptions. This suggest that the SIMOPS QRA, accounting for actual operating conditions, has the potential to be very different than this study if many of the actual operating conditions vary from the generic values.

A potential starting point for determining if a project-specific QRA will be required would be

- Review of the checklist in Appendix B
- Review of the swing scenarios and identify potential mitigations for swing scenarios prior to a detailed project-specific QRA. The identification of potential mitigations prior to the analysis can ensure that the study is designed to account for the specific effects of a mitigation option.
- Review of the SIMOPS activities which increase the risks by more than 10% to allow a project-specific QRA to focus on the details that drive those risks. Use of the best available data for the key parameters driving the risk increases the certainty around the decision to be made.

Individual and societal risk provide a more complete risk picture

Individual risk is useful to compare risk profiles spatially since it assumes exposure is uniform across the study area for every individual. In order to understand how specific populations are impacted by LNG bunkering and SIMOPS, a societal risk metric will be necessary.

Societal risk metrics account for the individuals level of exposure (e.g., indoors, outdoors, etc.), duration of exposure and number of individuals exposed. A societal risk metric can identify impacts to specific populations which can inform the development of risk mitigation strategies.

Therefore, when conducting an LNG Bunkering SIMOPS QRA, both Individual and Societal risk should be assessed to provide a full risk picture of the project specific situation. These complete risk results can also be used by regulators and other stake holders who want to benchmark the risk from their project of interest against the risk from other similar projects.

Other types of risks such as risk to assets, the environment and company reputation may be something for proponents to consider but this was outside of the scope of this study.

Approval of proposed LNG bunkering facilities in a given port presupposes that the existing risk at the port is acceptable and would not pose unacceptable risks onto the bunkering operations. Whereas, port-wide Individual risk acceptance criteria would ensure that risks from surrounding port operations do not pose undue risk to the bunkering facilities. Port-wide Societal risk acceptance criteria would limit the exposure to the untrained public. Such criteria would also inform acceptability of the risk as estimated by project-specific SIMOPS QRA.

7 REFERENCES

1. **Bailey, R. E., COMDT United States Coast Guard.** *CG-OES Policy Letter No. 01-15 Guidelines for Liquefied Natural Gas Fuel Transfer Operation and Training of Personnel on Vessels Using Natural Gas as Fuel.* 19 Feburary 2015.

2. **ISO.** Technical Specification 18683:2015(E) Guidelines for systems and installations for supply of LNG as fuel ships. [Online]

3. **DNV GL .** DNVGL-RP-0006: 2014-01 Development and Operation of Liquefied Natural Gas Bunkering Facilities. [Online]

4. **DNV GL.** Development and operation of liquefied natural gas bunkering facilities, Edition October 2015, DNVGL-RP-G105. [Online] [Cited: November 7, 2015.] http://rules.dnvgl.com/docs/pdf/DNVGL/RP/2015-10/DNVGL-RP-G105.pdf.

5. **Publicatiereeks Gevaarlijke Stoffen (PGS).** *Guidelines for Quantitative Risk Assessment (Purple Book).* s.l. : Ministry of VROM, 2005.

6. **Advisory Committee on Dangerous Substances (ACDS), Health & Safety Commission .** *Major Hazard Aspects of the Transport of Dangerous Substances,.* 1991.

APPENDIX A
Assumptions for Generic SIMOPS Scenarios

Generic Assumptions for LNG Bunkering SIMOPS Study

The final risk results are highly dependent on the assumptions. This document aims to provide generic assumptions, applicable to the SIMOPS studies for all ports.

<u>Meteorological Data</u>

- Average ambient temperature: 15 °C
- Average relative humidity: 82%
- Average barometric pressure: 1.01 bar
- Wind direction: uniformly distributed in all directions
- Wind speed
  - Day: D Stability, 5m/s
  - Night: F Stability, 2m/s
- Surface temperature: 15 °C
- Surface roughness parameter: 0.3 for land; 0.0002 for water

<u>Vessel Traffic</u>

- High nautical activity
- Annual passing vessel traffic: 40,000 large vessels (for midstreaming bunkering mode to tugs on rivers, 11,000 large vessels)
- Ship striking leading to tank rupture only plausible for Ship-to-Ship bunkering

<u>Bunkering Location on the Ship</u>

- On deck level for bulkers/tankers
- On side of hull for passenger ferry/cruise/container

<u>Process Condition</u>

- Generic bunkering hose pressure: 5 bar (g)
- Generic LNG storage and transfer temperature: -145°C

<u>Loss of Containment Scenario</u>

Scenario	Description	Representative Size (Diameter Equivalent) [mm]
Small	Manifold Small Release	5
Medium	Manifold Medium Release	25
Large	Manifold Large Release	Full Bore
Hose Leak	Small Hose Leak	10% of Hose Diameter
Hose Rupture	Hose Rupture	Full Bore
Cargo Tank Rupture*	Tank Rupture from Ship Striking	250
Ship Striking	Hose Rupture from Ship Striking	Full Bore

*Tank Rupture only applies to Ship-to-Ship option.

Detection and Isolation Time

For flexible loading hose:

Leak Size	Response Time (min)		Cumulative Time to Initiation (min)
	Detection	Isolation	Isolation
Leak	1	0.5	1.5
Rupture	0.5	0.25	0.75

For manifold piping:

Leak Size	Response Time (min)		Cumulative Time to Shutdown (min)
	Detection	Isolation	
Small	5	10	15
Medium	3	3	6
Large	1	1	2
Rupture	1	1	2

Immediate Ignition Probability (from TNO Purple Book)

Type and Size of Release		Immediate Ignition Probability
Continuous	Instantaneous	
<10 kg/s	< 1000 kg	0.02
10-100 kg/s	1,000-10,000 kg	0.04
>100 kg/s	>10,000 kg	0.09

Delayed Ignition Probability (from TNO Purple Book)

The Free field method is used. The free field method assumes that the cloud ignites when the maximum ground footprint area to the LFL fraction to finish is reached.

Summary of LNG Bunkering Scenarios

Ship Type		Passenger Ferry	River Push Boat	Bulker		Large Cruise		Large Container			Feeder Container			Platform Supply Vessel		
LNG Bunkering Mode		Truck to Ship	Midstreaming	Shore to Ship	Ship to Ship	Shore to Ship	Ship to Ship	Shore to Ship	Ship to Ship	Truck to Ship	Shore to Ship	Ship to Ship	Truck to Ship	Shore to Ship	Ship to Ship	Truck to Ship
Ship Dimension	Length (m)	100	35	225	225	362	362	290	290	290	170	170	170	80	80	80
	Width (m)	24	12	32	32	65	65	32	32	32	28	28	28	16	16	16
	Passenger Capacity	1000	-	-	-	6000	6000	-	-	-	-	-	-	-	-	-
	Car Capacity	120	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LNG Loading Specifications	Hose Diameter (inch)	3	3	8	8	6	6	8	8	8	6	6	4	4	4	4
	LNG Receiving Tank (m^3)	200	200	2500	2500	2500	2500	4800	4800	4800	1800	1800	1800	1200	1200	1200
	Bunkering Rate (m^3/h)	40	50	500	500	500	500	800	800	300	500	500	250	200	200	250
	Bunkering Duration (hours)	5	4	5	5	5	5	6	6	6	3.6	3.6	7.2	6	6	4.8
	Bunkering Frequency (per year)	365	365	52	52	52	52	52	52	52	52	52	52	182	182	182
Location of Activities*	LNG Bunkering	1	4	1	4	1	4	1	4	1	1	4	1	1	4	1
	Stores/concession/ cargo Loading	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Passenger Transfer	2	-	-	-	2	2	-	-	-	-	-	-	-	-	-
	Diesel Bunkering	3	-	3	3	3	3	3	3	3	3	3	3	3	3	3
Dual Fueling Bunkering	Diesel Bunkering Piping Size (inch)	3	-	8	8	6	6	8	8	8	6	6	6	4	4	4
	Diesel Bunkering Rate (m^3/h)	40	-	500	500	500	500	800	800	300	500	500	250	200	200	250
	Diesel Bunkering Duration (hours)	5	-	5	5	5	5	6	6	16	3.6	3.6	7.2	6	6	4.8
SIMOPs considered		dual fueling, maintenance work, car loading, passenger transfer, used consumables offloading, and stores/ concession loading	towing/pushing movement, crew member activities on the barges towed by river push boat, and transfer of people and supplies (e.g, crew member, lube oil, fresh water, grey water, groceries, and storage)	dual fueling, maintenance work, ballasting resulting in ranging failure, tank cleaning, inspections/ drills and bulk loading	dual fueling, maintenance work, ballasting resulting in ranging failure, tank cleaning, inspections/ drills and bulk loading	dual fueling, maintenance work, passenger transfer, crew member transfer, used consumables offloading, inspections and drills, stores concession loading/ offloading, and vehicle traffic and associated onshore storage	dual fueling, maintenance work, passenger transfer, crew member transfer, used consumables offloading, inspections and drills, and stores concession loading/ offloading	dual fueling, maintenance work, ballasting, gantry crane lifting, truck loading, stores loading/ offloading, and inspections/ drills	dual fueling, maintenance work, ballasting, gantry crane lifting, truck loading, stores loading/ offloading, and inspections/ drills	dual fueling, maintenance work, ballasting, gantry crane lifting, truck loading, stores loading/ offloading, inspections/ drills, and frequent connecting and disconnecting the trucks with manifolds.	dual fueling, maintenance work, ballasting, gantry crane lifting, truck loading, stores loading/ offloading, and inspections/ drills	dual fueling, maintenance work, ballasting, gantry crane lifting, truck loading, stores loading/ offloading, and inspections/ drills	dual fueling, maintenance work, ballasting, gantry crane lifting, truck loading, stores loading/ offloading, inspections/ drills, and frequent connecting and disconnecting the trucks with manifolds.	dual fueling, ballasting, crew/passenger transfer, transfer of supplies (tools, equipment, and groceries), vehicle traffic and associated onshore	dual fueling, ballasting, crew/passenger transfer, transfer of supplies (tools, equipment, and groceries), vehicle	dual fueling, ballasting, crew/passenger transfer, transfer of supplies (tools, equipment, and groceries), vehicle traffic and associated onshore storage, and frequent connecting and disconnecting the trucks with the manifolds

*Locations for Key Activities

- Location 1: FWD 1/3 of the vessel, deck level on inboard side
- Location 2: Mid-ship, deck level (and above) on inboard side
- Location 3: AFT 1/3 of the vessel, deck level on inboard side
- Location 4: Mid-ship, deck level on outboard side

Passenger Ferry – LNG Bunkering (Truck to Ship) Via Flexible Hose

LNG Loading Specifications

- Hose diameter: 3” (with 20 m long piping between two ends)
- Bunkering rate: 40 m^3/hr (filling 200 m^3 tank over 5 hours)
- Bunkering (truck) capacity: 40 m^3
- Bunkering duration: 7 hours operation, 5 hours of active loading
- Bunkering frequency: 1 per day (365/yr)

Passenger Ferry dimensions (Washington State Ferry Issaquah)

- Breadth: 24 m
- Overall length: 100 m
- Passenger capacity: 1000
- Car capacity: 120

Locations for key activities

- LNG Bunkering – fwd 1/3 of the vessel, deck level on inboard side
- Stores concession Loading - mid-ship, deck level (and above) on inboard side
- Passenger transfer – mid-ship, deck level on inboard side
- Diesel Bunkering - aft 1/3 of the vessel, deck level on inboard side

Dual fuel bunkering

- Released material: diesel (decane)
- Diesel bunkering pipe and size: 20m long, 3 inch diameter (same as LNG)

Bunkering rate: 40 m^3/hr (same as LNG)

Bunkering duration: 7 hours operation, 5 hours of active loading

Detection and isolation time: same as LNG

Maintenance

The explosion effect is simulated by introducing an obstructed zone.

Five possible classes of SIMOPS activities considered in this bunkering mode are dual fueling, maintenance work, car loading, passenger transfer, and supply transfer.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of diesel may initiate a fire. The thermal radiation from the fire together with quick-release coupling (QRC) system failure or communication failure can result in a rupture failure of LNG..	The increase of LNG rupture failure frequency is the product of • The frequency of 35 kw/m^2 radiation level from diesel pool fire reaching the LNG bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of 35 kw/m^2 radiation level will be obtained from PHAST risk modeling. QRC failure frequency is 0.001 on demand (from maritime hazards). Communication failure frequency is 0.01 on demand (from operations interviews of communications between vessels and assisting tugs).
1	Dual Fueling	The release of LNG may form a pool. The pool upon contacting with together with QRC failure or communication failure can result in a cryogenic crack/rupture of the diesel bunkering system.	The increase of LNG rupture failure frequency is the product of • The frequency of LNG pool reaching the diesel bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of LNG pool reaching diesel bunkering infrastructure will get from PHAST risk modeling. QRC failure frequency is 0.001 on demand (from Maritime hazards). Communication failure frequency is 0.01 on demand (from Operations interviews of communications between vessels and assisting tugs).

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The dual-fueling process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each person covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096
2	Maintenance	Maintenance work may result in power outage/loss, which may initiate the action of disconnecting the passenger ferry from LNG bunkering ship. This initiating event together with QRC failure or communication failure, which could lead to a LNG rupture release.	The increase of LNG rupture failure frequency is the product of • The probability of power loss due to maintenance work • The sum probability of QRC failure and communication failure	The frequency of power is about 0.05/year. QRC failure probability is 0.05 on demand (from Maritime hazards). Communication failure probability is 0.01 on demand (from Operations interviews of communications between vessels and assisting tugs).
2	Maintenance	The released LNG may enter a confined space which is partially open/open during maintenance work, resulting in a confined space explosion	Introduce an obstructed area into the model to simulate the possible explosion effect due to maintenance work • Blockage ratio 0.6 • BST speed 0.47	A typical confined space on passenger ferry is assumed 200m^3 (8m*8m*3m)
2	Maintenance	The maintenance work needs extra 10 people maybe close to the LNG bunkering process, together with the maintenance tools, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. for hot work with grinding, the ignition probability is 0.1	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096 The total delayed ignition probability is 0.1+0.096=0.196 The additional ignition is assumed to overlay with the obstructed area.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
3	Car loading	The loaded cars present additional ignition sources; they may also hit the LNG infrastructure causing a release	The failure frequency of loading hose due to vehicle impact is assumed to be doubled. Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute. Suppose the car loading also take 5 hours, the same as the LNG bunkering duration.	1.57% loading failures come from vehicle impact. Standard loading hose failure frequency is 4.04E-05 per hose per hour, 6.34E-07 per hose per hour due to vehicle impact. Doubling that portion results in 1.27E-06 per hose per hour and total failure frequency is 4.17E-5 per hose per hour; leak frequency will be 4.13E-05 per hose per hour; rupture will be 4.17E-07 per hose per hour. The ignition is assumed by modeling as a transferring line, with the traffic density of 24 cars per hour, and the speed for each person is 4 m/s.
4	Passenger transfer	The passenger SIMOPs will introduce additional ignition sources, resulting in increased ignition probability	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed to be around mid-ship Suppose 1000 passenger transfer takes 5 hours	The ignition is assumed by modeling as a transferring line, with the traffic density of 200 persons per hour, and the speed for each person is 1.5 m/s.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
5	Supply Transfer	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 10 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store concession during LNG bunkering is assumed as 50%, given that it only takes partial time of LNG bunkering
5	Supply Transfer	Loading is likely to include material handling equipment that could increase ignition probability	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud Assumed 3 motor vehicles are used

Large Cruise – LNG Bunkering Via Flexible Hose

LNG Loading Specifications

Hose diameter: 6" (with 20 m long piping between two ends)

Bunkering rate: 500 m^3/hr (filling 2500 m^3 tank over 5 hours)

Bunkering duration: 7 hours operation, 5 hours of active loading

Bunkering frequency: 1 per week (52/yr)

Large Cruise dimensions ("Allure of the Seas", Royal Caribbean International)

Beam: 65m

Overall length: 362 m

Passenger capacity: 6000

Locations for key activities

LNG Bunkering – mid-ship, deck level on outboard side

LNG Bunkering Mode	LNG Bunkering Location
Ship to Ship	mid-ship, deck level on outboard side
Shore to Ship	fwd 1/3 of the vessel, deck level on inboard side

Stores concession Loading – mid-ship, deck level (and above) on inboard side

Passenger/crew transfer – mid-ship, deck level on inboard side

Diesel Bunkering – aft 1/3 of the vessel, deck level on inboard side

Dual fuel bunkering

Released material: diesel (decane)

Diesel bunkering pipe and size: 20m long, 6 inch diameter (same as LNG)

Bunkering rate: 500 m^3/hr (same as LNG)

Bunkering duration: 6 hours operation, 5 hours of active loading

Detection and isolation time: same as LNG

Maintenance

The explosion effect is simulated by introducing an obstructed zone.

Seven possible classes of SIMOPS activities considered in this bunkering mode are dual fueling, maintenance, passenger transfer, crew member transfer, , drills, supply transfer, and terminal activity (only applies to Shore to Ship mode).

SIMOPS Activity Number	**SIMOPS Activity**	**The Impact of SIMOPS on the Risk Profile**	**Quantified Change**	**Detailed Value**
1	Dual Fueling	The release of diesel may initiate a fire. The thermal radiation from the fire together with quick-release coupling (QRC) system failure or communication failure can result in a rupture failure of LNG..	The increase of LNG rupture failure frequency is the product of • The frequency of 35 kw/m2 radiation level from diesel pool fire reaching the LNG bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of 35 kw/m2 radiation level reaching LNG line will be obtained from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from maritime hazards). Communication failure frequency is 0.01 on demand (from operations interviews of communications between vessels and assisting tugs).
1	Dual Fueling	The release of LNG may form a pool. The pool upon contacting with together with QRC failure or communication failure can result in a cryogenic crack/rupture of the diesel bunkering system.	The increase of LNG rupture failure frequency is the product of • The frequency of LNG pool reaching the diesel bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of LNG pool reaching diesel bunkering infrastructure will get from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from Maritime hazards). Communication failure frequency is 0.01 on demand (from Operations interviews of communications between vessels and assisting tugs).

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The dual-fueling process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each person covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096
2	Maintenance	Maintenance work may result in power outage/loss, which may initiate the action of disconnecting the passenger ferry from LNG bunkering ship. This initiating event together with QRC failure or communication failure, which could lead to a LNG rupture release.	The increase of LNG rupture failure frequency is the product of • The probability of power loss due to maintenance work • The sum probability of QRC failure and communication failure	The frequency of power outage is about 0.05/year. QRC failure probability is 0.05 on demand (from Maritime hazards). Communication failure probability is 0.01 on demand (from Operations interviews of communications between vessels and assisting tugs).
2	Maintenance	The released LNG may enter a confined space which is partially open/open during maintenance work, resulting in a confined space explosion	Introduce an obstructed area into the model to simulate the possible explosion effect due to maintenance work • Blockage ratio 0.6 • BST speed 0.47	A typical confined space on passenger ferry is about 320m3 (8m*8m*5m)
2	Maintenance	The maintenance work needs extra 10 people may be close to the LNG bunkering process, together with the maintenance tools, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. for hot work with grinding, the ignition probability is 0.1.	The 10 addition people will increase the delayed ignition probability by 1-0.99^10=0.096 The total delayed ignition probability is 0.1+0.096=0.196 The additional ignition is assumed to overlay with the obstructed area.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
3	Crew member transfer	The crew member transfer SIMOPs will introduce additional ignition sources, resulting in increased ignition probability	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed to be around mid-ship	350 crew member (2400/7=~350) is assumed to be transferred at a time during the LNG bunkering. It is treated as a transportation line type of ignition in the model, assuming 50 person/hr, with 1.5m/s speed.
4	Passenger transfer	The passenger transfer SIMOPs will introduce additional ignition sources, resulting in increased ignition probability	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed to be around mid-ship	A transportation line type of ignition is used, assuming 1200 person/hr, with 1.5m/s speed.
5	Supply Transfer	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 10 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store concession during LNG bunkering is assumed as 50%, given that it only takes partial time of LNG bunkering.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
5	Supply Transfer	Supply Transfer is likely to include material handling equipment that could increase ignition probability	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud Assume 6 vehicles are used
6	Drills	All 2400 crew members are assumed to participate in drills, who may be close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed to cover the whole ship.	The 2400 addition people will increase the delayed ignition probability by 1-0.99^2400=1
7	Terminal Activity (only applies to Shore to Ship Mode)	Jetty structure and mooring lines introduce potential confined/congested spaces; The passing vehicles in the nearby area onshore introduce ignition sources.	An obstructed area (equal to the area of the ship) was introduced adjacent to the ship. Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud. The obstructed area is 362m*65m*5m Assuming medium congestion level and blockage ratio of 0.3.

Platform Supply Vessel – LNG Bunkering Via Flexible Hose

LNG Loading Specifications

Hose diameter: 4” (with 20 m long piping between two ends); for truck to ship mode, 3” with 20m long piping between manifold and truck, 4”between manifold and ship

Bunkering rate:

LNG Bunkering Mode	LNG Bunkering Rate
Ship to Ship	200 m^3/hr (filling 1200 m^3 tank over 6 hours)
Shore to Ship	200 m^3/hr (filling 1200 m^3 tank over 6 hours)
Truck to Ship	250 m^3/hr (filling 1200 m^3 tank over 4.8 hours, 4 trucks with manifolds)

Bunkering duration:

LNG Bunkering Mode	LNG Bunkering Duration
Ship to Ship	8 hours operation, 6 hours of active loading
Shore to Ship	8 hours operation, 6 hours of active loading
Truck to Ship	6 hours operation, 4.8 hours of active loading

Bunkering frequency: 1 per two days (182/yr)

Platform Supply Vessel dimensions (Damen PSV 3300CD)

Beam: 16 m

Overall length: 80 m

Locations for key activities

LNG Bunkering

LNG Bunkering Mode	LNG Bunkering Location
Ship to Ship	mid-ship, deck level on outboard side
Shore to Ship	fwd 1/3 of the vessel, deck level on inboard side
Truck to Ship	fwd 1/3 of the vessel, deck level on inboard side

Transfer of personnel and supplies – mid-ship, deck level (and above) on inboard side

Truck loading – mid-ship, deck level on inboard side

Diesel Bunkering – aft 1/3 of the vessel, deck level on inboard side

Dual fuel bunkering

Released material: diesel (decane)

Diesel bunkering pipe and size: 20m long, 4 inch diameter (same as LNG)

Bunkering rate:

LNG Bunkering Mode	Diesel Bunkering Rate
Ship to Ship	200 m^3/hr (same as LNG)
Shore to Ship	200 m^3/hr (same as LNG)
Truck to Ship	250 m^3/hr (same as LNG)

Bunkering duration:

LNG Bunkering Mode	Diesel Bunkering Duration
Ship to Ship	8 hours operation, 6 hours of active loading
Shore to Ship	8 hours operation, 6 hours of active loading
Truck to Ship	6 hours operation, 4.8 hours of active loading

Detection and isolation time: same as LNG

Maintenance

The confined space explosion effect is simulated by introducing an obstructed zone.

Five possible classes of SIMOPS activities considered in this bunkering mode are dual fueling, ballasting, crew transfer, supply transfer (tools, equipment, and groceries), terminal activity (only applies to Shore to Ship and Truck to Ship Mode).

SIMOPS Activity Number	**SIMOPS Activity**	**The Impact of SIMOPS on the Risk Profile**	**Quantified Change**	**Detailed Value**
1	Dual Fueling	The release of diesel may initiate a fire. The thermal radiation from the fire together with quick-release coupling (QRC) system failure or communication failure can result in a rupture failure of LNG.	The increase of LNG rupture failure frequency is the product of • The frequency of 35 kw/m^2 radiation level from diesel pool fire reaching the LNG bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of 35 kw/m^2 radiation level reaching LNG line will be obtained from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from maritime hazards). Communication failure frequency is 0.01 on demand. (from operations interviews of communications between vessels and assisting tugs)

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of LNG may form a pool. The pool upon contacting with together with QRC failure or communication failure can result in a cryogenic crack/rupture of the diesel bunkering system.	The increase of LNG rupture failure frequency is the product of • The frequency of LNG pool reaching the diesel bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of LNG pool reaching diesel bunkering infrastructure will get from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from Maritime hazards). Communication failure frequency is 0.01 on demand. (from Operations interviews of communications between vessels and assisting tugs)
1	Dual Fueling	The dual-fueling process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each person covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
2	Ballasting	Those SIMOPs activities such as ballasting, affecting the stability of the ship, will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour
3	Crew transfer	This SIMOPs activity introduces additional ignition sources (trucks, operators), increasing the delayed ignition probability	For each people covered by flammable cloud, the delayed ignition probability is 0.01.	Assume this process involves 10 additional people. The 10 addition people will increase the delayed ignition probability by 1-0.99^10 =0.096

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
4	Supply Transfer	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 10 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store concession during LNG bunkering is assumed as 50%, given that it only takes partial time of LNG bunkering.
4	Supply Transfer	Transfer is likely to include material handling equipment that could increase ignition probability	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud 2 vehicles are assumed.
5	Terminal Activity (only for Shore to Ship and Truck to Ship bunkering mode)	Jetty structure and mooring lines introduce potential confined/congested spaces; The passing vehicles in the nearby area onshore introduce ignition sources.	An obstructed area (equal to the area of the ship) was introduced adjacent to the ship. Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud 4 cars are assumed. The obstructed area is 80*16m*5m

Feeder Container Ship (2000-4000 TEU) - LNG Bunkering Via Flexible Hose

LNG Loading Specifications

Hose diameter:

LNG Bunkering Mode	LNG Loading Hose Diameter
Ship to Ship	6” (with 20 m long piping between two ends)
Shore to Ship	6” (with 20 m long piping between two ends)
Truck to Ship	6” (with 20 m long piping between ship and manifolds); 3” (with 20m long piping between truck and manifolds)

Bunkering rate:

LNG Bunkering Mode	LNG Bunkering Rate
Ship to Ship	500 m^3/hr (filling 1800 m^3 tank over 3.6 hours)
Shore to Ship	500 m^3/hr (filling 1800 m^3 tank over 3.6 hours)
Truck to Ship	250 m^3/hr (filling 1800 m^3 tank over 7.2 hours, 4 trucks with manifolds)

Bunkering duration:

LNG Bunkering Mode	LNG Bunkering Duration
Ship to Ship	5 hours operation, 3.6 hours of active loading
Shore to Ship	5 hours operation, 3.6 hours of active loading
Truck to Ship	9 hours operation, 7.2 hours of active loading

Bunkering frequency: 1 per week (52/yr)

Container ship dimensions (Handysize class)

Beam: 28m

Overall length: 170 m

Draught/draft: 11 m

Locations for key activities

LNG Bunkering

LNG Bunkering Mode	**LNG Bunkering Location**
Ship to Ship	mid-ship, deck level on outboard side
Shore to Ship	fwd 1/3 of the vessel, deck level on inboard side
Truck to Ship	fwd 1/3 of the vessel, deck level on inboard side

Stores Loading – mid-ship, deck level (and above) on inboard side

Truck loading – mid-ship, deck level on inboard side

Diesel Bunkering – aft 1/3 of the vessel, deck level on inboard side

Dual fuel bunkering

Released material: diesel (decane)

Diesel bunkering pipe and size: 20m long, 6 inch diameter

Bunkering rate:

LNG Bunkering Mode	**Diesel Bunkering Rate**
Ship to Ship	500 m^3/hr (same as LNG)
Shore to Ship	500 m^3/hr (same as LNG)
Truck to Ship	250 m^3/hr (same as LNG)

Bunkering duration:

LNG Bunkering Mode	Diesel Bunkering Duration
Ship to Ship	5 hours operation, 3.6 hours of active loading
Shore to Ship	5 hours operation, 3.6 hours of active loading
Truck to Ship	9 hours operation, 7.2 hours of active loading

Detection and isolation time: same as LNG

Maintenance

The confined space explosion effect is simulated by introducing an obstructed zone.

Seven possible classes of SIMOPS activities considered in this bunkering mode are dual fueling, maintenance, ballasting, crane operations, truck loading, stores loading, and inspection.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of diesel may initiate a fire. The thermal radiation from the fire together with quick-release coupling (QRC) system failure or communication failure can result in a rupture failure of LNG.	The increase of LNG rupture failure frequency is the product of • The frequency of 35 kw/m^2 radiation level from diesel pool fire reaching the LNG bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of 35 kw/m^2 radiation level reaching LNG line will be obtained from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from maritime hazards). Communication failure frequency is 0.01 on demand. (from operations interviews of communications between vessels and assisting tugs)

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of LNG may form a pool. The pool upon contacting with together with QRC failure or communication failure can result in a cryogenic crack/rupture of the diesel bunkering system.	The increase of LNG rupture failure frequency is the product of • The frequency of LNG pool reaching the diesel bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of LNG pool reaching diesel bunkering infrastructure will get from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from Maritime hazards). Communication failure frequency is 0.01 on demand. (from Operations interviews of communications between vessels and assisting tugs)
1	Dual Fueling	The dual-fueling process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each person covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096
2	Maintenance	Maintenance work may result in power outage/loss, which may initiate the action of disconnecting the passenger ferry from LNG bunkering ship. This initiating event together with QRC failure or communication failure, which could lead to a LNG rupture release.	The increase of LNG rupture failure frequency is the product of • The probability of power loss due to maintenance work • The sum probability of QRC failure and communication failure	The frequency of power outage is about 0.05/year. QRC failure probability is 0.05 on demand (from Maritime hazards). Communication failure probability is 0.01 on demand (from Operations interviews of communications between vessels and assisting tugs).
2	Maintenance	The released LNG may enter a confined space which is partially open/open during maintenance work, resulting in a confined space explosion	Introduce an obstructed area into the model to simulate the possible explosion effect due to maintenance work • Blockage ratio 0.6 • BST speed 0.47	A typical confined space on passenger ferry is about 320m^3 (8m*8m*5m)

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
2	Maintenance	The maintenance work needs extra 10 people maybe close to the LNG bunkering process, together with the maintenance tools, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. For hot work with grinding, the ignition probability is 0.1	The 10 addition people will increase the delayed ignition probability by 1-0.99^10=0.096 The total delayed ignition probability is 0.1+0.096=0.196 The additional ignition is assumed to overlay with the obstructed area.
3	Ballasting	Those SIMOPs activities such as ballasting, affecting the stability of the ship, will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault. Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault. Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour.
4	Truck loading	This SIMOPs activity introduces additional ignition sources (trucks, operators), increasing the delayed ignition probability	For each people covered by flammable cloud, the delayed ignition probability is 0.01. For each vehicle covered by flammable cloud, the delayed ignition probability is 0.4. The ignition source is assumed to be around mid-ship	Assume this process involves 30 additional people and 5 trucks. The 30 addition people and 5 additional loading trucks will increase the delayed ignition probability by 1-(0.99^30)*(0.6^5)=0.943

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
4	Truck loading	The loading trucks may also hit the LNG infrastructure causing a release	The failure frequency of loading hose due to vehicle impact is assumed to be doubled.	1.57% loading failures come from vehicle impact Standard loading hose failure frequency is 4.04E-05 per hose per hour, 6.34E-07 per hose per hour due to vehicle impact Doubling that portion results in 1.27E-06 per hose per hour and total failure frequency is 4.17E-5 per hose per hour; leak frequency will be 4.13E-05 per hose per hour; rupture will be 4.17E-07 per hose per hour
5	Crane Operations	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 100 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store concession during LNG bunkering is assumed as 100%

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
5	Crane Operations	Those SIMOPs activities affecting the stability of the ship, will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour
5	Crane Operations	Increase delayed ignition probability (ignition sources from plug in containers, cranes and traffic)	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud. Two cranes are assumed. The ignition source is assumed to cover the whole ship

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
6	Stores Loading	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 10 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store during LNG bunkering is assumed as 50%, given that it only takes partial time of LNG bunkering
6	Stores Loading	Loading is likely to include material handling equipment that could increase ignition probability	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud 3 vehicles are assumed.
7	Inspection	10 crew members are assumed to participate in inspections/drills, who may be close to the LNG bunkering process, increasing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed as a point source.	The 10 addition people will increase the delayed ignition probability by 1-0.99^10=0.096

Large Container Ship (8000-10000 TEU) - LNG Bunkering Via Flexible Hose

LNG Loading Specifications

Hose diameter:

LNG Bunkering Mode	Hose Diameter
Ship to Ship	8” (with 20 m long piping between two ends)
Shore to Ship	8” (with 20 m long piping between two ends)
Truck to Ship	8” (with 20 m long piping between ship and manifold), 3” (with 20 m long piping between truck and manifold)

Bunkering rate:

LNG Bunkering Mode	LNG Bunkering Rate
Ship to Ship	800 m^3/hr (filling 4800 m^3 tank over 6 hours)
Shore to Ship	800 m^3/hr (filling 4800 m^3 tank over 6 hours)
Truck to Ship	300 m^3/hr (filling 4800 m^3 tank over 16 hours, 4 trucks with manifolds)

Bunkering duration:

LNG Bunkering Mode	LNG Bunkering Duration
Ship to Ship	8 hours operation, 6 hours of active loading
Shore to Ship	8 hours operation, 6 hours of active loading
Truck to Ship	18 hours operation, 16 hours of active loading

Bunkering frequency: 1 per week (52/yr)

Container ship dimensions (Panamax class)

Beam: 32m

Overall length: 290 m

Locations for key activities

LNG Bunkering

LNG Bunkering Mode	LNG Bunkering Location
Ship to Ship	mid-ship, deck level on outboard side
Shore to Ship	fwd 1/3 of the vessel, deck level on inboard side
Truck to Ship	fwd 1/3 of the vessel, deck level on inboard side

Stores Loading – mid-ship, deck level (and above) on inboard side

Truck loading – mid-ship, deck level on inboard side

Diesel Bunkering – aft 1/3 of the vessel, deck level on inboard side

Dual fuel bunkering

Released material: diesel (decane)

Diesel bunkering pipe and size: 20m long, 8 inch diameter (same as LNG)

Bunkering rate:

LNG Bunkering Mode	Diesel Bunkering Rate
Ship to Ship	800 m^3/hr (same as LNG)
Shore to Ship	800 m^3/hr (same as LNG)
Truck to Ship	300 m^3/hr (same as LNG)

Bunkering duration:

LNG Bunkering Mode	Diesel Bunkering Duration
Ship to Ship	8 hours operation, 6 hours of active loading
Shore to Ship	8 hours operation, 6 hours of active loading
Truck to Ship	18 hours operation, 16 hours of active loading

Detection and isolation time: same as LNG

Maintenance

The confined space explosion effect is simulated by introducing an obstructed zone.

Seven possible classes of SIMOPS activities considered in this bunkering mode are dual fueling, maintenance, ballasting, crane operations, truck loading, stores loading, and inspection.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of diesel may initiate a fire. The thermal radiation from the fire together with quick-release coupling (QRC) system failure or communication failure can result in a rupture failure of LNG..	The increase of LNG rupture failure frequency is the product of • The frequency of 35 kw/m^2 radiation level from diesel pool fire reaching the LNG bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of 35 kw/m^2 radiation level reaching LNG line will be obtained from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from maritime hazards). Communication failure frequency is 0.01 on demand. (from operations interviews of communications between vessels and assisting tugs)

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of LNG may form a pool. The pool upon contacting with together with QRC failure or communication failure can result in a cryogenic crack/rupture of the diesel bunkering system.	The increase of LNG rupture failure frequency is the product of • The frequency of LNG pool reaching the diesel bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of LNG pool reaching diesel bunkering infrastructure will get from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from Maritime hazards). Communication failure frequency is 0.01 on demand. (from Operations interviews of communications between vessels and assisting tugs)
1	Dual Fueling	The dual-fueling process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each person covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096
2	Maintenance	Maintenance work may result in power outage/loss, which may initiate the action of disconnecting the large container from LNG bunkering ship. This initiating event together with QRC failure or communication failure, which could lead to a LNG rupture release.	The increase of LNG rupture failure frequency is the product of • The probability of power loss due to maintenance work • The sum probability of QRC failure and communication failure	The frequency of power outage is about 0.05/year. QRC failure probability is 0.05 on demand (from Maritime hazards). Communication failure probability is 0.01 on demand. (from Operations interviews of communications between vessels and assisting tugs).
2	Maintenance	The released LNG may enter a confined space which is partially open/open during maintenance work, resulting in a confined space explosion	Introduce an obstructed area into the model to simulate the possible explosion effect due to maintenance work • Blockage ratio 0.6 • BST speed 0.47	A typical confined space on passenger ferry is about 320m3 (8m*8m*5m)

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
2	Maintenance	The maintenance work needs extra 10 people maybe close to the LNG bunkering process, together with the maintenance tools, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. for hot work with grinding, the ignition probability is 0.1	The 10 addition people will increase the delayed ignition probability by 1-0.99^10=0.096 The total delayed ignition probability is 0.1+0.096=0.196 The additional ignition is assumed to overlay with the obstructed area
3	Ballasting	Those SIMOPs activities such as ballasting, affecting the stability of the ship, will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour
4	Truck loading	This SIMOPs activity introduces additional ignition sources (trucks, operators), increasing the delayed ignition probability	For each people covered by flammable cloud, the delayed ignition probability is 0.01. For each vehicle covered by flammable cloud, the delayed ignition probability is 0.4. The ignition source is assumed to be around mid-ship	Assume this process involves 30 additional people and 5 trucks. The 30 addition people and 5 additional loading trucks will increase the delayed ignition probability by 1-(0.99^30)*(0.6^5)=0.943

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
4	Truck loading	The loading trucks may also hit the LNG infrastructure causing a release	The failure frequency of loading hose due to vehicle impact is assumed to be doubled.	1.57% loading failures come from vehicle impact Standard loading hose failure frequency is 4.04E-05 per hose per hour, 6.34E-07 per hose per hour due to vehicle impact Doubling that portion results in 1.27E-06 per hose per hour and total failure frequency is 4.17E-5 per hose per hour; leak frequency will be 4.13E-05 per hose per hour; rupture will be 4.17E-07 per hose per hour
5	Crane Operations	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 100 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store concession during LNG bunkering is assumed as 100%

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
5	Crane Operations	Those SIMOPs activities affecting the stability of the ship, will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour
5	Crane Operations	Increase delayed ignition probability (ignition sources from plug in containers, cranes and traffic)	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud. The ignition source is assumed to cover the whole ship. 2 Gantry Crane were assumed.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
6	Stores Loading	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5.0E-07/lift. 10 lift during LNG bunkering is assumed. It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure. The probability of having store during LNG bunkering is assumed as 50%, given that it only takes partial time of LNG bunkering.
6	Stores Loading	Loading is likely to include material handling equipment that could increase ignition probability	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	P=1-0.6^n, n is the number of motor vehicle covered by the flammable cloud 3 trucks were assumed
7	Inspection	10 crew members are assumed to participate in inspections/drills, who may be close to the LNG bunkering process, increasing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed to be in the center of the ship	The 10 addition people will increase the delayed ignition probability by 1-0.99^10=0.0956

Bulker – LNG Bunkering Via Flexible Hose

LNG Loading Specifications

Hose diameter: 8” (with 20 m long piping between two ends)

Bunkering rate: 500 m^3/hr (filling 2500 m^3 tank over 5 hours)

Bunkering duration: 7 hours operation, 5 hours of active loading

Bulker dimensions (Panamax class is assumed, due to the highest number in global service)

Breadth: 32m

Overall length: 225m

Locations for key activities

LNG Bunkering Mode	**LNG Bunkering Location**
Shore to Ship	fwd 1/3 of the vessel, deck level on inboard side (the connection is ON deck not at the side of hull, for bulkers)
Ship to Ship	mid-ship, deck level on outboard side (the connection is ON deck not at the side of hull, for bulkers)

Bulk Loading - mid-ship, deck level (and above) on inboard side (though moving a parts could extend to outboard edge of bulk hold)

Diesel Bunkering - aft 1/3 of the vessel, deck level on inboard side

Dual fuel bunkering

Released material: diesel (decane)

Diesel bunkering pipe and size: 20m long, 8 inch diameter (same as LNG)

Bunkering rate: 500 m^3/hr (same as LNG)

Bunkering duration: 7 hours operation, 5 hours of active loading

Detection and isolation time: same as LNG

Maintenance

The explosion effect is simulated by introducing an obstructed region

Six possible classes of SIMOPS activities considered in this bunkering model are dual fueling, maintenance, ballasting, cargo hold cleaning, inspection and cargo operations.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Dual Fueling	The release of diesel may initiate a fire. The thermal radiation from the fire together with quick-release coupling (QRC) system failure or communication failure can result in a rupture failure of LNG.	The increase of LNG rupture failure frequency is the product of • The frequency of 35 kw/m^2 radiation level from diesel pool fire reaching the LNG bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of 35 kw/m^2 radiation level will be obtained from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from maritime hazards). Communication failure frequency is 0.01 on demand. (from operations interviews of communications between vessels and assisting tugs).
1	Dual Fueling	The release of LNG may form a pool. The pool upon contacting with together with QRC failure or communication failure can result in a cryogenic crack/rupture of the diesel bunkering system.	The increase of LNG rupture failure frequency is the product of • The frequency of LNG pool reaching the diesel bunkering infrastructure • The sum probability of QRC failure and communication failure	The frequency of LNG pool reaching diesel bunkering infrastructure will get from PHAST risk modeling. QRC failure frequency is 0.05 on demand (from Maritime hazards). Communication failure frequency is 0.01 on demand. (from Operations interviews of communications between vessels and assisting tugs).
1	Dual Fueling	The dual-fueling process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each person covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
2	Maintenance	Maintenance work may result in power outage/loss, which may initiate the action of disconnecting the bulker from LNG bunkering ship. This initiating event together with QRC failure or communication failure, which could lead to a LNG rupture release.	The increase of LNG rupture failure frequency is the product of • The probability of power loss due to maintenance work • The sum probability of QRC failure and communication failure	The frequency of power outage is about 0.05/year. QRC failure probability is 0.05 on demand (from Maritime hazards). Communication failure probability is 0.01 on demand (from Operations interviews of communications between vessels and assisting tugs).
2	Maintenance	The released LNG may enter a confined space which is partially open/open during maintenance work, resulting in a confined space explosion	Introduce an obstructed area into the model to simulate the possible explosion effect due to maintenance work • Blockage ratio 0.6 • BST speed 0.47	A typical confined space (excluding the bulk storage tank) on bulker is about 320 m^3 (8m * 8m * 5m)
2	Maintenance	The maintenance work needs extra 10 people maybe close to the LNG bunkering process, together with the maintenance tools, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. for hot work with grinding, the ignition probability is 0.1	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096 The total delayed ignition probability is 0.1+0.096=0.196 The additional ignition is assumed to overlay with the obstructed area.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
3	Ballasting	Those SIMOPs activities such as ballasting, affecting the stability of the ship, will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault. Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault. Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour.
4	Inspection	The inspection/drills process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The ignition source is assumed to be in the center of the ship.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096
5	Cargo Hold cleaning	The tank cleaning process needs extra 10 people maybe close to the LNG bunkering process, introducing additional delayed ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01.	The ten addition people will increase the delayed ignition probability by 1-0.99^10=0.096

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
5	Cargo Hold Cleaning	The released LNG vapor may disperse into the bulk hold tank during the tank cleaning operation, and the confined explosion may be initiated	The probability of the confined space explosion is the product of • The frequency of LNG release reaching the confined space • The fraction of LNG loud dispersed into the storage tank, depending on the LNG dispersion and relative position of the confined space in LNG cloud	A typical confined space of the giant storage tank on bulker is assumed as about 8100 m^3 (30m*30m*9m)
6	Cargo Operations	Mechanical failure of the lifting equipment could result in dropping a load or piece of lifting equipment on the bunkering area	The LNG rupture frequency is increased by the product of • The probability of a mechanical failure of the crane resulting in dropping a piece of the loading equipment • The probability that the drop occurs while positioned at the outboard 1/3 of the nearest hold	Probability of a mechanical failure leading to a drop of a piece of loading equipment is 5E-07/lift. 10 lifts are assumed during LNG bunkering It is assumed that the lifts to the nearest hold are evenly distributed. Since typical loading operations do not include overhead lifting, the probability is added to the standard loading hose failure.
6	Cargo Operations	Cargo Operation is likely to include material handling equipment that could increase ignition probability	Delayed ignition probability increases by the equivalent of a motor vehicle per hold, 0.4 for motor vehicle in one minute.	$P=1-0.6^n$, n is the number of motor vehicle covered by the flammable cloud. Since each piece of material handling equipment could be anywhere on the vessel, the fraction of the coverage of LNG cloud on the deck will be estimated by the cloud footprint from PHAST Risk. 3 vehicles are assumed to be used.

River Push Boat – LNG Bunkering (Midstreaming) Via Flexible Hose

LNG Loading Specifications

Hose diameter: 3” (with 20 m long piping between two ends)

Bunkering rate: 50 m^3/hr (filling 200 m^3 tank over 4 hours)

Bunkering duration: 5 hours operation, 4 hours of active loading

Bunkering frequency: 1 per day (365/yr)

River Push Boat dimensions

Beam: 12 m

Overall length: 35 m

Locations for key activities

LNG Bunkering – mid-ship, deck level on outboard side

Transfer of storage, oil, water, crew – mid-ship, deck level on inboard side

Three possible classes of SIMOPS activities considered in this bunkering mode are pushing/towing movement, crew member activities on the barges towed by river push boat (barge crew activity), and transfer of people and supplies (e.g., crew member, lube oil, fresh water, grey water, groceries, and storage).

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
1	Pushing /Towing Activity	Those SIMOPs activities affecting the stability of the ship will increase the failure frequency of loading hose due to excessive motion.	The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	0.89% loading failures come from excessive motion due to mooring fault. Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault. Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour.
2	Barge Crew Activity	The addition people on the barges will increase the ignition probability (more ignition sources)	For each people covered by flammable cloud, the delayed ignition probability is 0.01.	The 5 addition people will increase the delayed ignition probability by 1-0.99^5=0.049 Assumed the people are 20m (half river boat length is 17.5m) away from the LNG bunkering location.

SIMOPS Activity Number	SIMOPS Activity	The Impact of SIMOPS on the Risk Profile	Quantified Change	Detailed Value
3	People and Supplies Transfer	This SIMOPs activity will introduce additional people (additional ignition source) and affect the stability of the ship, increasing the failure frequency of loading hose due to excessive motion	For each people covered by flammable cloud, the delayed ignition probability is 0.01. The failure frequency of loading hose due to excessive motion from mooring fault is assumed to be doubled.	The 2 addition people will increase the delayed ignition probability by 1-0.99^2=0.02 0.89% loading failures come from excessive motion due to mooring fault. Standard loading hose failure frequency is 4.04E-05 per hose per hour, 3.60E-07 per hose per hour due to excessive motion mooring fault. Doubling that portion results in 7.20E-07 per hose per hour and total failure frequency is 4.08E-5 per hose per hour; leak frequency will be 4.04E-05 per hose per hour; rupture will be 4.08E-07 per hose per hour.

APPENDIX B
Checklists

Summary Checklist for Comparative SIMOPS QRA

GUIDELINE AND USE OF SIMOPS RISK ASSESSMENT CHECKLIST

It is an assumption that LNG fuelled vessels will have their LNG Bunker facilities designed, certified and operated in accordance with the applicable USCG regulations, policy letters, and referenced standards and guideline as well as local codes and regulations. The specification used as a basis for this checklist is ISO/TS 18683 "Guideline for systems and installations for supply of LNG as fuel to Ship", which is referred to in the CG-OES Policy Letter No. 01-15. According to the ISO/TS 18683 a risk assessment shall be conducted as part of the planning and permitting of a LNG bunkering facility. The risk assessment should follow a schematic approach as described in the ISO/TS and DNVGL RP-G105 "*Development and operation of liquefied natural gas bunkering facilities*".

This checklist and guideline has been developed to assist the regulatory authority (e.g. USCG) when reviewing a Quantitative Risk Analysis (QRA) for an LNG bunkering facility where SIMOPS is occurring. It can also be used by other stakeholders to facilitate and guide the process of conducting a QRA for an LNG Bunkering facility.

1. RISK ASSESMENT STAGE				
Verification that LNG Bunkering facility follows the risk assessment approach				
1	Yes	No	N/A	Is the study basis defined for the LNG bunkering facility?
2	Yes	No	N/A	Has a qualitative risk assessment, e.g. HAZID been completed and reported?
3	Yes	No	N/A	Has a safety zone (exclusion zone) around the bunkering station/facility been established?
4	Yes	No	N/A	Has a security zone around the bunkering station/facility been established?
5	Yes	No	N/A	Will SIMOPS activities take place during the LNG bunkering?
Comments:				

IF yes has been answered to all of the five questions in 1, a dedicated QRA should be conducted to assess the effects of the SIMOPS. The SIMOPS QRA checklist attached to this document can then be used.

Checklist for SIMOPS QRA for LNG Bunkering

Simultaneous operations (SIMOPS) during LNG bunkering operations shall be addressed in a risk assessment. This assessment can be qualitative (HAZID) or quantitative (QRA) depending on the type of SIMOPS planned. The focus in the HAZID should be on the identification of mitigating measures to reduce the additional risks introduced with the SIMOPS. The effectiveness of the identified mitigating measures can be demonstrated with means of a QRA.

A QRA can be developed for two situations.

- The LNG bunkering operation *without* taking into account SIMOPS (**Base Case**)
- The LNG bunkering operation *with* SIMOPS and defined mitigating measures
- SIMOPS can be allowed in case it is demonstrated that the relative increase in risk is <10%.
- Furthermore, it should be demonstrated that the proposed mitigating measures are effective in reducing the risk by an ALARP (4) demonstration, taking into account the costs and benefits of any further risk reduction by implementing additional (or other) mitigating measures.

2. IDENTIFICATION OF SIMOPS ACTIVITIES				
A SIMOPS Activity is an activity typically performed while at berth performed in conjunction with LNG bunkering.				
1	Yes	No	N/A	Loading/unloading of cargo, provisions and other goods on the receiving vessel.
2	Yes	No	N/A	Activities in the vicinity of the bunker area (e.g. hoisting, maintenance activities or hot work).
3	Yes	No	N/A	Passenger embarking/disembarking during bunkering or bunkering with passengers on board.
4	Yes	No	N/A	The simultaneous transfer of other bunker fuels or flammable substances.
5	Yes	No	N/A	Other, please specify in the comments field.
Comments:				

NOTE:

Use the checklist on this page to identify the vessel type and the SIMOP activities. Based on the relevant scenario, select the applicable vessel type SIMOP sheet from pages 4 – 10.

Each vessel sheet lists the SIMOP activities that was defined and analyzed in the generic QRA. The swing scenarios for each case are described briefly. The main document should be used for a more detailed explanation on the swing scenarios and the key parameters.

The checklist pages 11-16 are common for all vessel types and SIMOPS.

3. IDENTIFICATION OF VESSEL SEGMENT RELEVANT SWING SCENARIOS				
The table below should be used to identify the vessel segment bunkering scenarios, type of SIMOP activities, and any swing scenarios based on the generic QRA white paper.				
1	Yes	No	N/A	Is the planned bunkering scenario for the facility one of the scenarios assessed in the ANGA white paper and in the table below?
2	Yes	No	N/A	Are the planned SIMOP activities in accordance with the table?
3	Yes	No	N/A	Are multiple SIMOP activities planned during LNG bunkering operation?
4	Yes	No	N/A	Are there swing scenarios identified, that could results in significant changes in the risk?
Comments:				

Vessel Type: River Push Boat

Applicable to:

Midstreaming Bunkering ☑

River Push Boat		
Midstreaming		
Yes		**SIMOPS**
		People and Supplies Transfer
	⚠	Barge Crew Activity
		Pushing/Towing Activity
		Dual fueling

Swing scenarios ⚠	
Barge Crew Activity	Activities that could result increase the ignition such as metal to metal contact while alongside the vessel.

Vessel Type: Passenger Ferry

Applicable to:

Truck to Ship Bunkering ☑

Passenger Ferry		
Truck to Ship		
Yes		**SIMOPS**
		Supply Transfer
	⚠	Maintenance
	⚠	Passenger Transfer
	⚠	Car Loading
	⚠	Dual Fueling

Swing scenarios ⚠	
Maintenance	Type and location of maintenance has a very significant influence on the risk.
Passenger Transfer	People indoors and people outdoors result in differences in ignition probability and exposure of the people. Indoor/outdoor distributions in terms of the number of people and fraction of bunkering time drive risk results.
Passenger Transfer	A project-specific SIMOPS QRA should consider both the individual risk and the additional societal risk metric, PLL and include careful consideration of ridership patterns when selecting the time of day for LNG bunkering.
Car loading	The presence of stationary, running vehicles outdoors either on the landing or on the ferry significantly increases the ignition probability. Requirements to turn off the ignition while waiting either on the landing or the ferry limits the increase in ignition probability.
Dual-fueling	Proving sufficient distance outside the overpressure, radiation and cryogenic zones, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, demonstration of the reliability of leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.
Dual fueling	A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

Vessel Type: Platform Service Vessel (PSV)

Applicable to:

Ship to ship bunkering ☑

Shore (tank) to ship bunkering ☑

Truck to Ship Bunkering ☑

Platform Supply Vessel (PSV)								
Ship to Ship			Shore to Ship			Truck to Ship		
Yes		**SIMOPS**	**Yes**		**SIMOPS**	**Yes**		**SIMOPS**
		Ballasting			Ballasting			Ballasting
		Supply transfer			Supply transfer			Supply transfer
		Crew transfer			Crew transfer		⚠	Crew transfer
	⚠	Dual fueling		⚠	Dual fueling		⚠	Dual fueling
					Terminal Vehicle Traffic			Terminal Vehicle Traffic

Swing scenarios ⚠	
Dual-fueling	Proving sufficient distance outside the overpressure, radiation and cryogenic zones, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, demonstration of the reliability of leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.
Dual fueling	A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.
Crew transfer	People indoors and people outdoors result in differences in ignition probability and exposure of the people. Indoor/outdoor distributions in terms of the number of people and fraction of bunkering time drive risk results.

Vessel Type: Large Cruise Ship

Applicable to:

Ship to ship bunkering ☑

Shore (tank) to ship bunkering ☑

Large Cruise Ship					
Ship to Ship			Shore to Ship		
Yes		**SIMOPS**	Yes		**SIMOPS**
	⚠	Maintenance		⚠	Maintenance
		Supply Transfer			Supply Transfer
	⚠	Dual Fueling		⚠	Dual Fueling
	⚠	Crew Member Transfer		⚠	Crew Member Transfer
	⚠	Passenger Transfer		⚠	Passenger Transfer
	⚠	Drills		⚠	Drills
					Terminal Activity

Swing scenarios ⚠	
Maintenance	Type and location of maintenance has a very significant influence on the risk.
Dual-fueling	Proving sufficient distance outside the overpressure, radiation and cryogenic zones, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, demonstration of the reliability of leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.
Dual fueling	A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.
Crew Member Transfer	People indoors and people outdoors result in differences in ignition probability and exposure of the people. Indoor/outdoor distributions in terms of the number of people and fraction of bunkering time drive risk results.
Passenger Transfer	People indoors and people outdoors result in differences in ignition probability and exposure of the people. Indoor/outdoor distributions in terms of the number of people and fraction of bunkering time drive risk results.
Passenger Transfer	A project-specific SIMOPS QRA should consider both the individual risk and the additional societal risk metric, PLL.
Drills	A project-specific SIMOPS QRA should consider both the individual risk and the additional societal risk metric, PLL.
Crane operations:	Truck Loading and Crane Operations are likely activities to be performed concurrently. A SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the base case.
Truck loading:	Truck Loading and Crane Operations are likely activities to be performed concurrently. A SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the base case.

Vessel Type: Large Container Vessel

Applicable to:

Ship to ship bunkering ☑
Shore (tank) to ship bunkering ☑
Truck to Ship Bunkering ☑

Large Container Vessel								
Ship to Ship			Shore to Ship			Truck to Ship		
Yes		**SIMOPS**	**Yes**		**SIMOPS**	**Yes**		**SIMOPS**
	⚠	Maintenance		⚠	Maintenance		⚠	Maintenance
	⚠	Crane operations		⚠	Crane operations		⚠	Crane operations
		Ballasting			Ballasting			Ballasting
		Stores loading			Stores loading			Stores loading
	⚠	Dual fueling		⚠	Dual fueling		⚠	Dual fueling
	⚠	Truck loading		⚠	Truck loading		⚠	Truck loading
		Inspection			Inspection			Inspection

Swing scenarios ⚠	
Maintenance	Type and location of maintenance has a very significant influence on the risk.
Dual-fueling	Proving sufficient distance outside the overpressure, radiation and cryogenic zones, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, demonstration of the reliability of leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.
Dual fueling	A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.
Crane operations:	Truck Loading and Crane Operations are likely activities to be performed concurrently. A SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the base case.
Truck loading:	Truck Loading and Crane Operations are likely activities to be performed concurrently. A SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the base case.

Vessel Type: Feeder Container Vessel

Applicable to:

Ship to ship bunkering ☑

Shore (tank) to ship bunkering ☑

Truck to Ship Bunkering ☑

Feeder Container Vessel								
Ship to Ship			Shore to Ship			Truck to Ship		
Yes		**SIMOPS**	**Yes**		**SIMOPS**	**Yes**		**SIMOPS**
	⚠	Maintenance		⚠	Maintenance		⚠	Maintenance
	⚠	Crane operations		⚠	Crane operations		⚠	Crane operations
		Ballasting			Ballasting			Ballasting
		Stores loading			Stores loading			Stores loading
	⚠	Dual fueling		⚠	Dual fueling		⚠	Dual fueling
	⚠	Truck loading		⚠	Truck loading		⚠	Truck loading
		Inspection			Inspection			Inspection

Swing scenarios	⚠
Maintenance	Type and location of maintenance has a very significant influence on the risk.
Dual-fueling	Proving sufficient distance outside the overpressure, radiation and cryogenic zones, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, demonstration of the reliability of leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.
Dual fueling	A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.
Crane operations:	Truck Loading and Crane Operations are likely activities to be performed concurrently. A SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the base case.
Truck loading:	Truck Loading and Crane Operations are likely activities to be performed concurrently. A SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the base case.

Vessel Type: Bulker (Bulk carrier)

Applicable to:

Ship to ship bunkering ☑

Shore (tank) to ship bunkering ☑

Bulker					
Ship to Ship			Shore to Ship		
Yes		**SIMOPS**	Yes		**SIMOPS**
	⚠	Maintenance		⚠	Maintenance
		Cargo operations			Cargo operations
		Ballasting			Ballasting
		Inspection			Inspection
		Cargo Hold Cleaning			Cargo Hold Cleaning
	⚠	Dual fueling		⚠	Dual fueling

Swing scenarios	⚠
Maintenance	Type and location of maintenance has a very significant influence on the risk
Dual-fueling	Proving sufficient distance outside the overpressure, radiation and cryogenic zones, as determined by a project-specific SIMOPS QRA, is the most robust mitigation to prevent escalation. If the vessel size prevents sufficient spacing, demonstration of the reliability of leak detection and shutdown system with an interlock between the two bunkering stations could mitigate escalation risk.
Dual fueling	A project-specific SIMOPS QRA should combine all SIMOPS activities that are permitted to occur concurrently into a single SIMOPS Case for comparison with the Base Case. The combination allows the interactions between multiple SIMOPS activities to be fully quantified.

4. IDENTIFICATION OF RELEVANT ACCIDENT SCENARIOS AND EFFECT OF SIMOPS				
Typical accident scenarios and loss of containment scenarios for LNG bunkering facilities that shall be assessed for relevance. Section D4.3 (Table D-1) in DNVGL RP-G105 "*Development and operation of liquefied natural gas bunkering facilities*" contains a list of relevant scenarios.				
1	Yes	No	N/A	Does the documentation list the relevant scenarios based on the SIMOPS performed, bunkering method, and vessel type?
2	Yes	No	N/A	Are the locations and of potential LNG and gas releases identified?
3	Yes	No	N/A	Is the risk increase from the Base Case documented?
Comments:				

5. DEFINITION OF THE KEY PARAMETERS FOR BASE CASE AND SIMOPS ACTIVITIES				
The key parameters and assumptions should be specified and if any of those parameters change in the SIMOPS Case.				
1	Yes	No	N/A	Does the documentation list the sources of historical data/method for LNG/NG release frequencies for the relevant accident scenarios, such as; • Failures of loading arm/hose • Failure of quick release connection • Failure of vessel bunkering piping • Operator error • Mooring faults • Collisions with passing ships • Dropped object or impacts
2	Yes	No	N/A	Are the activity frequencies and durations documented; • Bunkering frequency and duration • SIMOPS Activity frequency and duration
3	Yes	No	N/A	Is the defined hole size distribution documented? (This basis rarely if ever differs between the Base Case and SIMOPS Activities)
4	Yes	No	N/A	Are the quantities of LNG available to release documented; • Flow rate • Detection and isolation time • Inventories vulnerable to collisions
5	Yes	No	N/A	Is the pressure and temperature of released material documented?
6	Yes	No	N/A	Is the weather data documented? • Probability of wind direction and speed • Range of air temperatures seasonally and day/night differences • Operational restrictions due to weather
7	Yes	No	N/A	Are the ignition sources/probabilities documented? • Location of ignition sources (including location of people) • Type and strength of ignition sources • Time required to shut down ignition sources given a release event
8	Yes	No	N/A	Are there areas available to confine LNG vapor – e.g. open hatches, spaces under docks?
9	Yes	No	N/A	Are there significantly congested areas - areas where localized turbulence is likely to create overpressures, typically tight clusters of solid objects?
10	Yes	No	N/A	Are the location and number of personnel in the area defined? • Likelihood of being indoors or outdoors with or without PPE • Fraction of the time that an individual is present during bunkering
Comments:				

6. IDENTIFY POTENTIAL ESCALATING EFFECTS				
Escalating effects are caused by other hazardous or flammable substances that could escalate an accident scenario.				
1	Yes	No	N/A	Do the SIMOPS activities include the following: • The addition of any hydrocarbon transfers or storage • Transfers or storage of materials with LNG reactivity
2	Yes	No	N/A	Are the locations of the transfers and/or storages identified?
3	Yes	No	N/A	Is the fraction of the bunkering time that the material will be transferred or stored documented?
4	Yes	No	N/A	Are the independent (not initiated as the result of an LNG release) causes of a release identified?
5	Yes	No	N/A	Is the release frequency for each independent release mechanism estimated?
6	Yes	No	N/A	Is the inventory available to release estimated? • Static stored inventory • Normal flow rates • Detection and isolation time
7	Yes	No	N/A	Are the physical thresholds required to initiate an escalation release of the LNG being bunkered and other hazardous inventories identified and documented?
Comments:				

7. IDENTICATION OF CONCURRENT SIMOPS ACTIVITIES				
If there are more than one SIMOPS occurring at the same time, they should be combined into a combined case scenario.				
1	Yes	No	N/A	Are there more than one SIMOPS that could occur at the same time?
2	Yes	No	N/A	Is the increase in risk from the base case determined for each SIMOPS activity separately?
3	Yes	No	N/A	Is the increase in risk from the base case determined for the combined SIMOPS activities?
4	Yes	No	N/A	Are any changes in the key parameters and assumptions discussed and documented?
Comments:				

8. **MODELING AND RISK CALCULATION**				
The frequency and consequence modeling together with the risk calculation and evaluation should follow the structured QRA methodology.				
1	Yes	No	N/A	Is the frequency modeling and assessment for each case and release scenario conducted and documented?
2	Yes	No	N/A	Is the consequence assessment, including discharge, dispersion, fire and explosion modelling, conducted and documented for each independent release scenario?
3	Yes	No	N/A	Does the consequence modelling also include potential escalating effects?
4	Yes	No	N/A	Is the frequency of each release scenario exceeding an identified physical threshold identified?
5	Yes	No	N/A	Is the frequencies of the intermediate SIMOPS case and release of other hazardous inventories adjusted to account for escalating effects in order to complete the SIMOPS case?
Comments:				

9. **COMPARE RISK INCREASE AND NEED FOR MITIGATION**				
The increase in risk between the base case and SIMOPS case should be compared and the need for additional mitigation should be identified				
1	Yes	No	N/A	Is the risk between the base case and SIMOPS cases compared and documented?
2	Yes	No	N/A	Is there a comparison based on changes in individual risk?
3	Yes	No	N/A	Is there a comparison based on changes to the frequency contours of physical thresholds, such as the LFL cloud?
4	Yes	No	N/A	Is there a comparison based on changes in PLL? This could be warranted IF large populations are introduced.
5	Yes	No	N/A	Is the need for additional safeguards or mitigation identified?
6	Yes	No	N/A	If yes on 5, are these safeguard identified and are the effect on the risk assessed?
Comments:				

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.