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Original Paper

Hazard identification (HAZID) of LNG dual-fueled ships operating between the Korean port of Busan and the Iranian port of Bandar Abbas

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Abstract: This study investigates the scope of hazard identification (HAZID), focusing in particular on analysis of the causes and consequences of hazardous scenarios for overall LNG fuel systems. The main categories of hazard scenarios are: fire and explosion initiating from LNG systems, fire and explosion not LNG-initiated, dropped objects, collisions, grounding, foundering, and occupational accidents. The main goals of this study are: identifying potential hazards to be addressed in further concept risk analysis assessment; providing input on possible solutions to be assessed in the vessel concept development work; and providing input to external communication from the vessel/project, clearly describing how potential risk should be identified and addressed through the vessel/project. The purpose of the HAZID in our study is to identify safety hazards that may represent risks to crew and third parties, e.g., maintenance personnel, yard workers, and other ships during operation.

We identified 34 hazards and made 18 recommendations with a comprehensive summary in terms of design and operation, which covered a wide-range of design and operation topics with the division in high prioritization. The main result from the HAZID shows that the estimated HAZID increase is mainly due to the presence of the LNG tank and its effect on the risk from fire/explosions due to ship collision. The HAZID results confirm that there are no major HSE showstoppers to perform construction and conversion on vessels using dual-fuel. The main selection criterion is the potential design, worst-case scenario for location of LNG tank below accommodation, and technical and operational capabilities in conducting such a HAZID study and investigations. Several significant gaps in mandatory regulations, standards, guidelines, or of relevant organizations beyond mandatory regulations were identified and addressed.

Keywords: Liquefied natural gas, Hazard Identification (HAZID), The IMO interim guideline MSC.285(86), IGF code, LNG-dual - fueled ship, Fire and explosion, Hazard and effects

1. Introduction

Utilization of liquefied natural gas (LNG) is rapidly increasing and it is seen as a viable alternative to heavy fuel oils/marine diesel oil owing to several factors, such as its properties, economic and environment circumstances, and its business reaching a mature phase **[1]-[6]**.

To cope with the demand of the LNG Market with flexibility, this study has novelly assessed and developed the Hazard Identification (HAZID) system that addresses all areas that need special consideration. For the usage of the natural gas fuel- low flashpoint fuel to become a global fuel choice, it is essential that gaps and barriers on national and international regulations and standards are assessed and evaluated to promote safety and minimize the risk to the ship, its crew, and the environment, and conform to the regulations in the new energy sector, ensuring that any risks, gaps and barriers arising from the use of Natural Gas-fueled engines affecting the integrity of the vessel's main safety functions are addressed **[11]-[18] [43]**.

The first version of the international Code of safety for ships using Gases or other low-flashpoints (IGF Code) was adopted by resolution MSC.391(95), which was implemented on 1 January 2017. This first version of the IGF Code addresses only LNG (methane). Other low flashpoint fuels are being considered and amendments are made to the IGF Code as necessary.

The IMO has been tasked to develop the second version of the code, addressing methyl/ethyl alcohol and other low-flashpoint fuels such as low-flashpoint diesel.

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The IMO Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships MSC 285(86) (Interim Guideline) and IGF code (International Code of Safety for Ships using Gases or other Low Flashpoint Fuels) requires that a ship using an alternative fuel demonstrates by risk analysis that the safety level is equivalent to that of a conventional oil-fueled ship **[8]-[10]**. Therefore, the aim of this study is to perform a HAZID to meet the requirements of the IMO Interim Guideline and IGF Code. The goal of these Interim Guidelines is to provide criteria for the arrangement and installation of machinery for propulsion and auxiliary purposes, using natural gas as fuel, which will have an equivalent level of integrity in terms of safety, reliability, and dependability as that which can be achieved with new and comparable conventional oil-fueled main and auxiliary machinery. It is assumed that the vessel is powered by on gas while performing on-loading and off-loading operations of containers.

This analysis represents the HAZID concept and is based on innovative thinking, maritime industrial experience, and the design concept of the vessel; the vessel is a typical container ship operating between the Korean port of Busan and the Iranian Port of Bandar Abbas **[19]-[41][46]**.

2. Vessel Design Concept

The vessel design data, which complies with IMO Interim Guidelines on Safety for Natural Gas Fuelled Engine Installations in Ships MSC 285(86), is shown in **Table 1**. The deadweight is approximately 81,000 ton on a draft of 13.20 m. The design speed (suitable service speed) is approximately 21 knots. The endurance for using gas fuel is set to 11, 200 NM (Nautical mile) for one round trip between Iran/Bandar Abbas and Korea/Busan. In addition, the endurance for emergencies (using diesel oil) is estimated to be 5,600 NM.

The accommodation is arranged in the forepart of the vessel to facilitate and increased number of containers on deck whilst remaining in accordance with IMO visibility requirements. The safety barriers around the bunkering station (i.e., ventilation and shielding, drip trays, protection against overfilling, emergency shutdown (ESD) system and other safeguards) are aimed at reducing the likelihood of an accidental spill. Further, they minimize the consequence in the event of spilled LNG, where safety barriers for the “Room for LNG Tanks” (i.e., ventilation, gas detection and fire]/ extinguishing, independent bilge system, LNG tank support, and anti-rolling and anti-pitching chocks) are designed and comply with IMO Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships MSC 285(86) **[7]-[9]**.

Table 1: Design data of LNG-fueled 8,000 TEU container ship - ship design data compared to the 8,000 TEU reference ship

	Conventional fuel oil design	dual fuel design
Length x Breadth x Depth	280.00 x 46.40 x 24.00m	280.00 x 46.40 x 24.00m
Maine engine	low speed diesel engine fuel engine	low speed dual fuel
Alternator/ Generator	4x diesel generators	4 x dual fuel generators
HFO	6,500 m^3	-
DO	600 m^3	5,000 m^3
LNG	-	6,000 m^3

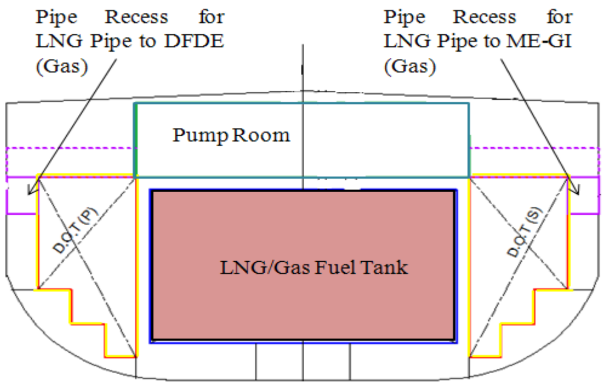

Figure 1: LNG fuel tank arrangement

The vessel has one room for the LNG tank around the mid ship, under the accommodation area, as shown in **Figure 1**. The general arrangement is shown in **Figure 2**.

The bunker station is located under the accommodation space on each side of the ship in a semi-enclosed space allowing the vessel to berth and bunker at any side. The bunker station has manifolds for liquid gas, vapor gas, nitrogen, and marine diesel oil.

The LNG is stored in a prismatic low-pressure insulated tank (A-type). Forced and natural boil off gas (BOG) is supplied to the main and auxiliary engines. The LNG tank is safeguarded by the B/5 location to the sides according to the IMO Interim Guidelines, with additional protection by the double hull, diesel oil tanks, including the structure of LNG tank itself hindering a potential penetration **[8]-[10]**. However, when sufficient impact energy overcomes the structural resistance of the outer hull, internal stringers, and bulkheads, the LNG tank may become punctured. Such high energy collisions are rare events and to date no collision resulting in the loss of cargo on LNG carriers has occurred **[42]**.

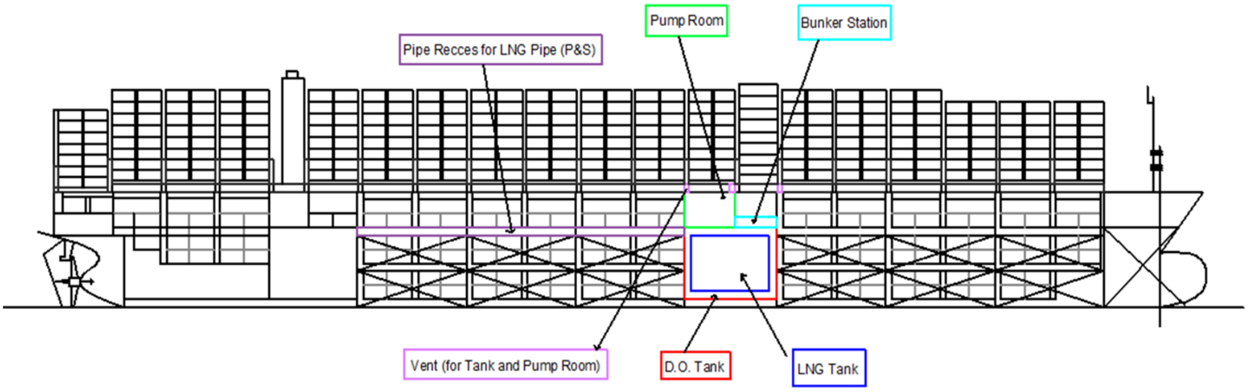

Figure 2: General General arrangement showing locations of bunker station, pump room, LNG tank, and pipe recess

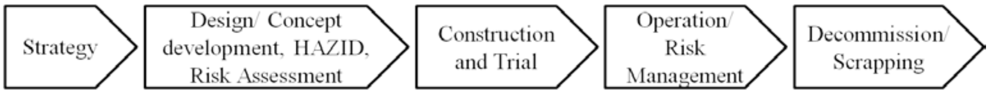

Figure 3: Vessel life cycle

The pump room is located between the upper deck and the "room for LNG tank". This space is utilized for pumps, heaters, vaporizers, gas heaters, and compressors for the gas supply system to the main engine and auxiliary engines. The airlock space provides access from the underdeck passage.

Two pipe recesses for the gas supply system are provided below the underdeck passage on each side of the vessel, between the engine room and pump room. A single-wall pipe is arranged in each pipe recess. One pipe recess is arranged for the pipe for main engine, and the other for the pipe for the generator engines. The pipe duct for diesel oil pipes, water ballast pipes etc. is provided in the double bottom at the center of the ship.

The high-pressure gas supply piping is led to the engine room from the starboard side pipe recess, and the low-pressure gas supply piping is led to engine room from the port side pipe recess. The gas flow to the generator engines is regulated and measured in the gas valve unit (GVU) room located in the engine room. The gas to the main engine is regulated using the high-pressure (HP) pump.

The engine room arrangement is based on that of conventional container ships. However, the main engine type changed from a conventional two-stroke diesel engine to a dual-fuel engine. The generator engine type is changed from a conventional four-stroke diesel engine to a dual-fuel engine. In addition, a high-pressure gas supply system for the main engine, and a low-pressure gas supply system for the generator engines are provided.

The boil-off gas from the LNG tank is burnt in the ship's main propulsion engine and generators engines. Under normal operating conditions when the ship is at sea, one FG compressor, gas heater, LP pump, and HP pump operate to supply gas fuel to the ship's main propulsion engine and generator engines. The FG compressor then discharges the gas to the engines via the gas heater. The HP vaporizer is used to discharge high-pressure gas to the main propulsion engine. If the fuel consumption of the main propulsion engine and generator engines cannot be met by the gas supplied by natural boil-off from the tank, additional gas is obtained by utilizing the HP vaporizer via the LP and HP pumps, where the vaporizer is fed by the liquid supply of these pumps. The outlet gas from the vaporizer is controlled by the gas heater.

3. Analysis Basis and Methodology

HAZID is a structured approach and involves exercises where documentation/drawings and a set of guidewords form the basis for identifying hazards involved with an operation or the use of equipment and/or systems. HAZIDs are commonly used throughout the maritime industry for all types of safety and risk assessments **[12]-[17][45][47]-[52]**.

Figure 3 shows the vessel lifecycle. The focus of the HAZID assessment is the LNG fuel system and gas engines encompassing the following sequence of operations during the vessel's lifecycle:

1. Construction/installation, including testing and sea trials.
2. Operations (loading/offloading of cargo, voyage, bunkering, docking, maintenance, lay-up/idle).
3. Decommissioning/scrapping

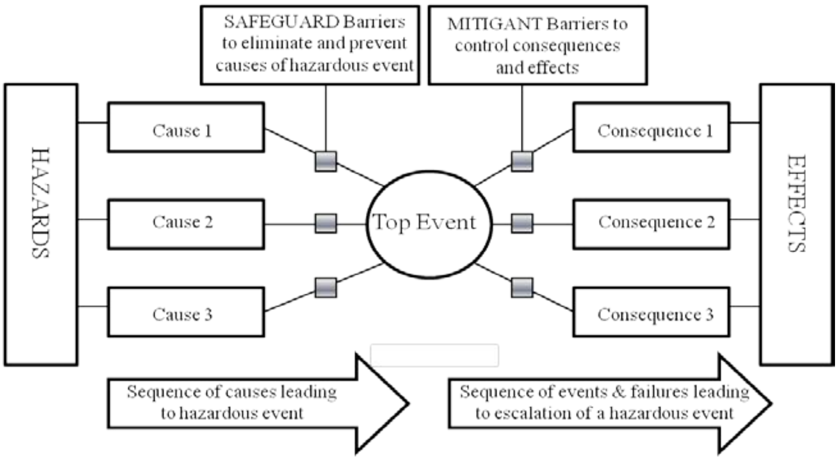

Figure 4: Bowtie hazard and effect model **[53]**

The safety of ship propulsion during a voyage and in maneuvering to avoid blackout has been taken into account.

The following hazard guidewords are used as a basis for the HAZID study **[12]-[17][44][46]**: fire or explosion hazard; fire/explosion – LNG initiated; fire/explosion – not LNG initiated, other hazards generated by materials and substances, leakage of liquid LNG causing loss of structural integrity, mechanical hazards, electrical hazards, thermal hazards, hazards generated by malfunctions, collisions, dropped object, grounding, foundering, environmental hazards, pollution, occupational accidents, hazards generated by neglecting ergonomic principles, and hazards generated by erroneous human intervention.

For each hazard cause/treatment/initiating event, consequences and controls (preventive and mitigating) are identified and presented in Section 4 (i.e., HAZID findings and results), following the Bow Tie hazard and effect model shown in **Figure 4**.

The diagram/model in **Figure 4** is shaped like bowties, creating a clear differentiation between proactive and reactive hazards and effects. The hazard and top event always appear together in the center of the bow-tie diagram.

A hazard is a situation or object with the potential to cause harm. If the hazard is kept under control, then it is “safe” and unwanted consequences do not arise. A cause is an object or phenomenon that initiates a sequence of events that, if unchecked, leads to the top event. If a cause is present, and there are no barriers in place to intercept it, then the top event occurs. For example, over-pressurization could be a cause of loss of containment/tank of a hydrocarbon-carrying LNG/gas fuel. Causes appear on the left-hand side of the bow-tie diagram. Causes should be independent of each other and should lead to the top event directly. Causes should not be failures of equipment, as this is a barrier failure.

A consequence is an unwanted, undesirable, and potentially dangerous outcome of the top event occurring. A consequence results in loss or damage. It is common to think of consequences as affecting people, the environment, assets, business, and reputation. More safeguards/barriers are put in place to attempt to stop the top event from developing into consequences. Consequences appear on the right-hand side of the bow-tie diagram. Barriers control the top event, by either preventing its occurrence or preventing the consequences should it occur. Preventive barriers (safeguards) appear on the left of the diagram and are designed to prevent the top event from occurring. They should be seen to prevent each cause from resulting in the occurrence of the top event. Mitigation barriers appear on the right of the diagram. Given that control of the hazard is lost, they are designed to prevent the consequences. Barriers should only appear on one side of the bow-tie diagram, and not on both sides. Barriers can, however, appear on a number of cause lines simultaneously.

4. Findings and Results

The identified hazards are summarized in **Table 2**. **Figure 5** classifies and ranks the main hazards and consequences. A total of 34 hazards were identified; this is ranked with respect to: fire/explosion – LNG initiated (19), loss of propulsion power (3), dropped objects (3), collision (2), fire/explosion - not LNG initiated (1), other hazards generated by materials and substances (1), leakage of liquid LNG causing loss of structural integrity (1), grounding (1), foundering (1), hazards during installation (1), and hazards during scrapping (1).

Table 2: Hazard Identification (HAZID)

ID	Hazard	Cause	Consequence	Safeguards
1	Leak in bunkering manifold (flange connection) during ship-to- ship (STS) bunkering.	1. Human error 2. Design. 3. Wear and tear. 4. Smaller leaks may be difficult to detect. 5. Bigger scale (1000m^3 per hour) and high pressure 6. Long filling time (7hour), i.e. longer hazard exposure 7. Dropped objects 8. Mooring failure (ship drifting and breaking connection between shore and Vessel, or between bunker ship and the receiving Vessel)	1. Outflow of LNG. 2. Flash fire/pool fire if ignition source present, (e.g. use of non-explosion equipment). 3. Injuries/fatalities to crew. 4. Large amount of liquid may be released due to rupture of hose or connection break. 5. Frost burns. 6. Potential escalation to dislodge neighboring equipment.	1. Design according to standard and regulations **[8][9]**. 2. Drip tray at bunker station (draining out to sea, avoiding brittle fracture for small leaks). 3. Bunkering procedures (tighten the flange is important). 4. This area is classified as a gas zone 1 and then will require explosion proof equipment. 5. Gas detection sensors. 6. Pressure measurement upstream and downstream of the manifold. 7. Personnel performance equipment(PPE) during bunkering. 8. The certified flexible hose by recognize organization/certified body. 9. Emergency shutdown (ESD) system. 10. Procedures for mooring and ship-to-ship (STS) bunkering. 11. Weather restrictions. 12. Watchmen onboard the bunker ship and receiving vessel. 13. Installation and commissioning procedures including leak test. 14. Limited flange connection-all welded pipework/or Stud fitted flange. 15. Training of personnel. 16. Regular inspection and maintenance. 17. All piping located underneath dropped object protection. 18. Pipe stress analysis to be conducted considering cool down and heat up. 19. Emergency plan and procedure. 20. Dry chemical powder and water spray remotely controlled from fire control station in accommodation. 21. One fusible plug by vapor return valve automatically trigger ESD in event of fire.
2	Shutdown of gas supply from fuel tank to engines resulting in blackout.	Gas detection (two gas detectors)	Lack of power (blackout), may increase the severity in case of accident (e.g. fire), i.e. running of emergency fire pumps etc.	1. Duel fuel, the Vessel may also run on diesel oil 2. For system configurations with inherently safe machinery spaces, there are two situations where automatic shutdown of gas supply to engine room is required, according to the requirements for gas supply system safety function **[8][9]**. 3. also, automatic shutdown (ESD) should only be given if there is gas detection in two detectors. Gas detection in one detector should give alarm.
3	Leak in bunkering pipes to LNG tank	leak in pipes, cracks etc.	Liquid leak	1. Double piping or pipe and ducting 2. Leak is vented to mast 3. The duct is monitored by the gas detectors.

4	Overpressure in tank (during bunkering)	1. BOG suction function on the bunker ship or land facility is failed. (Capacity of BOG compressor of the vessel is not considered to return the BOG at the bunkering operation) 2. Higher temperature of the LNG fuel tank or higher flow rate of bunkering.	1. Pressure will increase in the tank 2. May result in tank rupture and flash fire/pool fire/explosion	1. Vapour return system to shore or feeder ship during bunkering 2. Pressure monitoring of LNG fuel tank 3. Reduce flow rate or stop bunkering operation (ESD). 4. Safety valves (pressure relief), no damage is expected (gas will be vented through mast).
5	LNG leak in the tank containment system	1. Cracks due to fatigue 2. Corrosion, erosion 3. operation exceeding maximum design condition (pressure, tempreture) 4. ship collision and grounding 5. human error 6. lack of testing following construction 7. failure of tank bulkhead (e.g. welding defect, material defect, and sloshing)	1. Release of LNG in “Room for LNG tanks” 2. Both fire/explosion risk and frost burns to crew. 3. Gas released from vent system being ignited (Flash fire burning back to the vent mast where the gas will continue to burn as long as it is released. Consequences will depend on the vented gas rate and venting duration). 4. Cryogenic vapor inside inerted hold space 5. Overpressure of hold space 6. Damage to hold space bulkhead	1. Design according to standard and regulations 2. Drip trays for LNG tank designed to meet requirements 3. Two barriers for tank plus the “Room for LNG tank” as secondary/partial barrier 4. Tank Insulation 5. Ventilation to mast (evaporated LNG) 6. The annular space between the LNG fuel tank and the insulation will have continuous nitrogen supply and no venting to open deck 7. Design for fatigue life in the tank structure
6	LNG tank located below accommodation	Fire/Explosion in the LNG tank (below accommodation)	1. Fire/Explosion in accommodation area 2. Consequence high for crew	Design according to standard and regulations
7	LNG leak in Pump Room (HP/LP Vaporizer, Gas heater, Connections, Compressor)	1. Malfunction/failure of equipment 2. failure in the vaporizer 3. High pressure piping (for main engine) 4. more crew present for maintenance in pump room, in general there is expected some activity in this space.	1. Liquid/gas leak inside the pump room while crew is present with a following ignition due to use of non-explosion equipment or other types of ignition sources. 2. Flash Fire / Jet fire / explosion risk 3. Gas released from vent system being ignited (Flash fire burning back to the vent mast where the gas will continue to burn as long as it is released. Consequences will depend on the vented gas rate and venting duration).	1. This area is classified as a gas zone 1. 2. The pump room is also classified as machinery space category A according to IMO Interim Guideline and should thus have appurtenant fire protection/insulation. 3. Ventilation (30 air changes per hour) 4. Gas detection and shut down (ESD). 5. materials of piping in pump room of stainless steel 6. Connections covered in order to prevent spray/splash if leak. 7. Dome top covered by stainless steel

8	Leak in piping leading to the GVU room (inside the pipe recess)	High pressure (250-300 bar) gas passing inside the pipe recess without double piping (only one pipe and ducting)	1. Rupture of the pipe and high pressure gas leak is possible (jet fire), not only leak from connections 2. Vented to mast (large gas cloud), dispersion and gas cloud may be ignited (flash fire).	1. Pipe and duct (pipe recess) for low pressure gas to aux. engines and high pressure gas to main engine. 2. suitable materials Seamless carbon manganese steel with cast steel valve bodies. 3. Protection of flanges from cold jets (gas leak) 4. ESD 5. Ventilation 6. Gas detection
9	Gas leak in GVU room from piping, connections, valves	any malfunction causing leak inside the GVU room	1. Gas cloud release, vented to GVU exhaust line. 2. Crew is normally not expected to be present in the GVU room, besides maintenance.	1. Gas detection 2. Ventilation 3. ESD 4. Zone one protection equipment
10	Gas leak in the engine room	1. Leaks in valves, pipe connections 2. Corrosion and erosion 3. Vibration 4. Dropped objects 5. Gas ingress to engine room from GVU room	1. Ignitable mixture of gas 2. Ignition of such a cloud (flash fire) due to possible sparks from non-explosion proof electrical equipment or faulty ex-equipment. 3. Multiple fatalty	1. Engine room is classified as inherently gas safe machinery space. 2. Ventilation system 3. Gas detection in double walled piping inside engine room 4. ESD 5. Installation and commissioning procedure 6. Positive air pressure maintained in the engine room 7. Negative air pressure maintained in the GVU room minimizing gas release to engine room from GVU room 8. Engine room ventilation
11	Ignition failure (start-up of engines)	Malfunction of engine	1. Gas leak to exhaust system 2. Flash fire/explosion	Interim Guidelines states in “Requirements dual fuel engines that start and normal stop should be on oil fuel only. Gas injection should not be possible without a corresponding pilot oil injection **[9]**.
12	Gas in the exhaust system	1. a leak from the exhaust system during start-up of the gas engines. 2. Fail in ignition system	Flash fire/explosion	1. It is required that exhaust receiver is equipped with explosion relief ventilation to prevent excessive explosion pressures or the exhaust system has sufficient strength to contain the worst case explosion. 2. Ventilation system in exhaust systems for gas fuelled engines.
13	Fire/explosion or uncontrolled release of gas from the bunker ship affecting the vessel.	any fault or malfunctions on the feeder ship	1. Fire (if ignition source exists) resulting in personnel injuries and/or brittle fractures of materials 2. Gas may be vented to mast a may reach possible ignition sources on the Vessel (gas cloud escaping the safety zone)	1. Vent mast on bunker ship 2. Safety systems onboard the Vessel and bunker ship

14	Hazards to 3rd party (yard) due to venting gas during docking.	any hazardous situations leading to venting of gas during docking (opening of pressure-relief valves)	Gas may ignite when reaching the yard/dock	1. Tank freeing system to empty the LNG tank before docking (liquid discharge followed by heating), 2. no LNG in the tank (gas free ship) during docking, etc. thus no venting, 3. possible to inert the supply system while doing liquid discharge.
15	Hazards to crew due to vessel in lay-up condition	Continuous boil-off gas (need to handle BOG)	Pressure increase in the tank	1. Ship should not be cold- ship during lay-up, continually running of generators. 2. Possibility to gas-free the ship before layup
16	Entering hazardous areas for maintenance (e.g. pump room or GVU room)	Inspections, maintenance	1. Ignition sources may be present during maintenance (welding etc.) 2. Flash fire/explosion risk	1. Isolate local systems and rooms by valves for maintenance 2. Drain and inert (gas-free) before entering the space 3. Gas detectors 4. Ventilation
17	Transfer of gas to vent head	1. Leakage 2. Mechanical damage, fatigue	Release of minor amounts of gas into non-hazardous spaces	1. Vent piping of stainless steel 2. Routing and shielding of piping, protecting for mechanical damage
18	Blockage of vent mast	Materials or ice formation	Failure or reduce pressure relief, with subsequent pressure increase in tank.	This is normal standard for gas vessels.
19	Fire/explosion(Switchboard rooms(both sides of ECR), Aux.Boiler,Luboil system, Engine workshop, Cargo/containe)	1. explosion in the switchboard (short circuit, breaker fails etc.) 2. Human error 3. malfunction and failure	1. Fire/explosion 2. The fire may escalate to the LNG fuel system	1. The switchboard will be located in a separate room 2. A60 fire protection 3. Fire detection and gas supply shut-down (ESD)
20	Fire on container deck impacting bunker areas	1. Fire in one of the containers 2. human error	escalation to bunker area during bunker operation	1. stowing arrangement to prevent hazard material being stored in this area 2. emergency plans and procedures 3. Dry chemical powder and water spray remotely controlled from fire control station in accommodation 4. water curtain 5. LNG and vapor lines inerted when not in use 6. ship-to shore and ship-to-vessel communication link to allow remote shutdown of LNG supply pump and valve.
21	1. Hazards from contact with or inhalation of harmful fluids, gases, mists, fumes and dusts 2. Asphyxiation	Entering gas dangerous spaces of zone one, e.g. bunker station, pump room or GVU room	Injury or fatality	See separate safeguards for bunker station (HAZID ID No.1), GVU room (HAZID ID No 9.) and pump room (HAZID ID No.7).

22	Brittle fracture of structures	LNG spill	Loss of structural integrity	1. Stainless steel drip trays below potential LNG leak sources (bunker station and LNG tank) 2. Equipment of stainless steel
23	Damage to pipes/pipe recess (starboard or port side)	1. Low energy collision 2. Hit by other vessel 3. Navigation error of other ship	1. Gas leak up to accommodation 2. Some gas, but very limited amount	1. adequate shutdown (ESD) to be provided to minimize gas volume to be released. 2. Pipe, duct and ventilation 3. Gas detection sensors
24	Damage to LNG tank	High energy collision or other type of impact	1. Outflow of LNG 2. Large pool fire on sea.	1. Design according to standard and regulations 2. B/5 from ships side 3. Diesel oil tanks (on both sides) will also functions as protection 4. Independent tanks
25	Failure of the HP pump for main engine	Malfunction/system failure	1. No gas supply to main engine 2. Loss of power for propulsion	Duel fuel system, may run on diesel oil
26	Black-out (major system failure)	any system failure causing blackout, e.g. short circuit in switchboard.	1. Loss of power for vaporizers, gas heaters etc. 2. Trapped LNG/freezing equipment may cause these equipment to break/fail due to the lack of circulation	1. Stand-by generators will be started before using emergency generator. If no standby generator is started, emergency generator will be used. (It is the second or third back up). 2. LNG will evaporate 3. Safety valves (if high pressure)
27	Failure of glycol system (lack of re-circulation)	any causes leading to brine/glycol system failure	1. gas heater will not function and we cannot send gas to engine, will thus need to vent the gas. 2. lack of circulation 3. not very safety critical, more an environmental issue	One of the Brine pump supplies electric power from emergency generator.
28	Dropped object on bunkering hose	Container(s) falling on the bunkering hose(s)	1. Large leak 2. Ignition sources resulting in flash fire/pool fire	1. Containers will come from quay side (not on feeder ship side) 2. Loading procedures and Securing containers according to industry guidelines
29	Dropped objects on Pump room (below cargo deck)	1. any impact loads that could penetrate the deck and further damage LNG equipment in Pump room. 2. falling containers 3. dropped objects from provision crane	1. Flash fire/Explosion 2. Crew injuries/fatalities	1. Deck structure (strength) 2. Sensors for pressure drop, will lead to shut-down
30	Dropped objects inside the pump room	Lifting activity inside the pump room	1. Cutting gas pipes 2. Damaging equipment 3. Fire/Explosion	

31	Grounding	any failures causing vessel to ground	1. water ingress/filling of LNG tank space 2. damage to tank, but we should have no dangerous leak of LNG from the tank	1. Support in upper deck (protect from tank impact) 2. Independent tanks 3. anti-floatation supports 4. Tank can be damaged or be buckle, but not collapse (primary members in the tank should take these loads)
32	Foundering	any causes leading to foundering	1. If the vessel sinks or list, LNG will probably start to "leak" from the tank. 2. Natural BOG and maybe leak due to tank/piping damage.	Evacuation of crew in lifeboats and life rafts before the Vessel sink.
33	Hazards during installation (at dock/yard).	First time in use	Leakage in LNG fuel system equipment	1. Supervision by LNG fuel system supplier 2. FAT testing for valves etc. standard test, including pressure testing for leaks etc. 3. First test with diesel fuel, then do the "gas trial" 4. Part of the gas trial to check for leakages 5. using yard with experience in building LNG carriers (known concept – LNG fuel system)
34	Hazards during scrapping of the Vessel.	Vessel to be phased out, no more in service due to age and market situation	Scrapping	Gas free (same as for entering dry-dock)

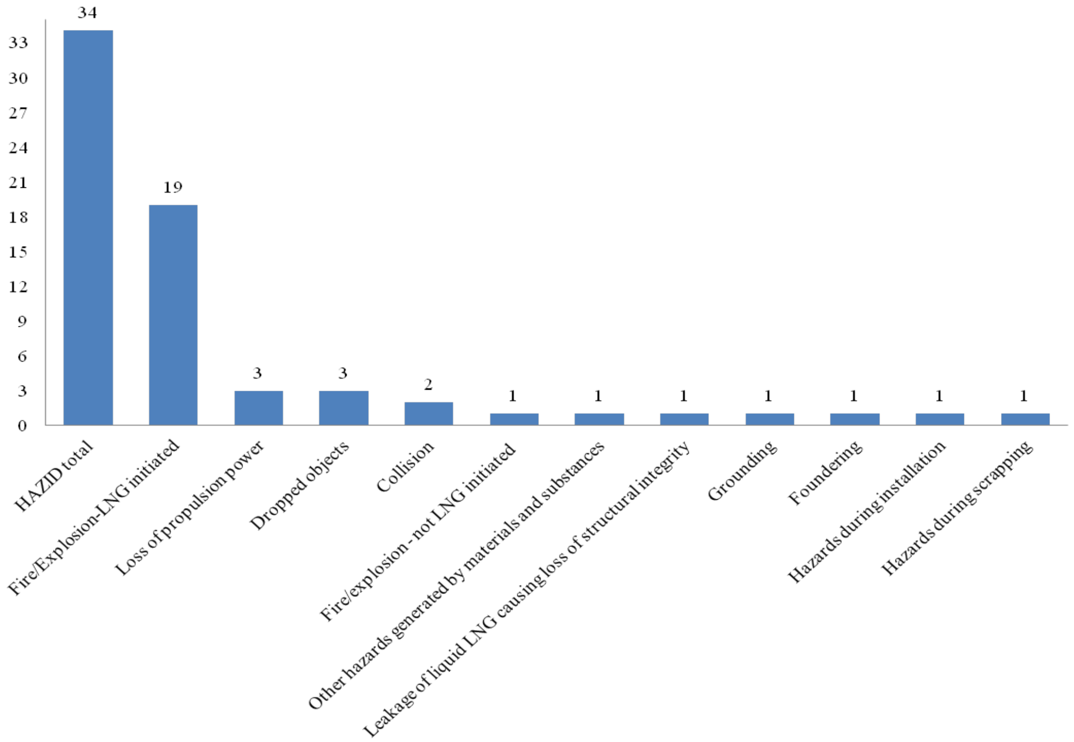

Figure 5: Classification and ranking of main hazards

5. Recomendations

Eighteen recommendations with a comprehensive summary in terms of design and operation are made, covering a wide-range of design and operation topics with the division in high prioritization for follow-up. Several important gaps beyond mandatory regulations, standards, and guidelines or of relevant organizations were identified requiring the following actions.

A. The following design recommendations should be considered for the safe operation of gas-fueled container ships based on Section 4 (i.e., HAZID findings and results):

(1) Thermal shielding of the ship structure using a water curtain.

A water curtain system covering the bunker area and side shell to mitigate damages in the case of LNG leakage should be considered. While the drip tray in the bunker station is intended for small leaks, the waterfall curtain will provide thermal shielding to protect and maintain the integrity of the ship's structure, including tanks and neighboring equipment in case of larger liquid leaks during bunkering.

(2) Mechanical ventilation in bunker station.

Mechanical ventilation should be provided in the semi-enclosed bunker station to prevent any accumulation of gas. The bunker station is too enclosed to ensure efficient natural ventilation; thus, mechanical ventilation should be added.

(3) Avoiding blackout when automatic shutdown (ESD) is activated.

A gas leakage with required shutdown (ESD) functions should not damage the entire propulsion and power generation system, thus causing blackout. For system configurations with inherently safe machinery spaces, there are two situations where automatic shutdown of the gas supply to the engine room is required according to the international requirements for gas supply system safety functions. In addition, ESD should only be followed if there is gas detection in two detectors. Gas detection in one detector should sound an alarm.

(4) Full double-pipe arrangement for high-pressure piping.

Due to high pressure (300 bar) gas passing inside the pipe recess without double piping (only single pipe and ducting), full double pipe arrangement inside the pipe recess should be considered, considering crew safety and structural integrity.

However, protection of flanges may not be sufficient. Rupture of the pipe, rather than only leaking from connections, due to high pressure is possible. Alternatively, the pipe recess (ducting) should have sufficient constructive strength to maintain its structural integrity in the case of pipe rupture, e.g. pressure testing, and installed and protected so as to minimize the risk of injury to personnel in case of rupture.

(5) Airlocks for access to the GVU room.

Direct access through doors, gastight or otherwise, is generally not permitted from a gas-safe space to a gas-dangerous space, according to the IMO Interim Guidelines.

Non-hazardous spaces (engine room) with openings to hazardous areas (GVU room) should be arranged with an airlock and be maintained at an overpressure relative to the external hazardous area. This is to prevent any gas from the GVU room reaching the engine room, which contains non-EX rated equipment; this is because otherwise, it may ignite the gas.

(6) Redundant gas heating system for supply to generator engines.

Arrange for an additional heat exchanger for use as back-up for the one (1) gas heater currently proposed for the supply of gas to the generator engines. If the gas heater does not function, the vessel needs to vent the gas. This is not a safety critical issue, but an environmental concern.

(7) Locations of double-pipe ventilation air inlet and exhaust to be in safe positions. In addition, the locations of a vent mast is to be especially considered to prevent ignition from funnel and ingress into any air inlet. In addition, this ensures that vent piping is routed in a way that external leakages do not result in hazardous situations (e.g., release of gas to container spaces, accommodation).

(8) High-pressure components in the gas injection and system must be designed in accordance with international standards.

B. The following operational recommendations are considered for the safe operation of gas-fueled container ships based on Section 4 (i.e., HAZID findings and results):

(1) Attention to dropped objects, i.e., restrict/prohibit loading of containers near bunker station while bunkering.

Loading near the bunkering station is restricted/prohibited while bunkering LNG to avoid containers tipping over the side (on the water side/bunker shipside) or unintentionally being dropped on the bunkering hose or above the pump room. There is constant monitoring of the entire bunkering operation, and the use of guards. Company procedures are also established for special concerns regarding internal lifting activity in the pump room and protection of LNG equipment.

(2) Using checklist during bunkering.

Procedures/checklists are established between the ship owner and gas supplier for safe bunkering operation. The bunker station should have restricted access during bunkering operation, i.e., safety zone to be established. It must be ensured that the responsibilities during the LNG bunkering process are clearly defined for all foreseen LNG bunkering configurations and locations. The bunkering procedures are the preferred instrument with which to document the responsibilities during LNG bunkering.

(3) Entering hazardous areas, e.g., pump room and GVU room. Personal protective equipment is mandatory for entering the pump room owing to cold piping and high-pressure systems. In addition, training of personnel to operate the system is given.

(4) Harmonize the requirements for emergency repairs (including competence requirements of personnel performing these activities) of LNG-fueled vessels in shipyards, and develop initiatives to build competence and knowledge with regard to salvation of LNG -fueled vessels.

(5) The main potential for risk reduction is the potential for personnel to escape. Key aspects of this include ensuring that the detection of releases is communicated to personnel onboard effectively. In terms of minimizing risks to personnel, and from delayed ignition events in particular, the most effective mitigation is to escape to a place of safety, which is either to accommodation or suitable shelter or to an area outside the flammable cloud envelope. The former is the most reliable, although the latter is likely to be practicable in most cases (noting, however, that larger releases, e.g., due to collision or large leak during bunkering, cover a significant proportion of the vessel). Training is fundamental in escape, although measures such as temporary shelters or ensuring that accommodation can be used as required are recommended.

(6) Fatalities during evacuation by lifeboat or life raft, e.g., due to malfunctioning of the evacuation means, or as a consequence of the attempted escape by sea, may occur.

(7) Continuously promote the developments on the effect of methane number over dual-fuel engine operations. Operational guidelines need to be developed to reduce potential negative environmental impacts related to the possible release of methane. Establish a comprehensive approach for methane slip management, i.e., boil-off gas, vapor management, and emergency venting.

(8) It is further recommended to work actively to promote a strong and sound safety culture. Involvement by all parties in the organization in the process of defining, prioritizing, and controlling risk and hazards, along with a sense of shared purpose in safety, is important to the health and safety level onboard the vessel.

(9) The specific locations of Busan and Bandar Abbas ports for LNG Bunkering by ship-to-ship (STS) or other means must be separately assessed to identify HAZID (if any) and mitigate and eliminate potential hazards. The actual risk depends on the location of operation. Analysis of the following parameters, amongst others, is also taken into account:

- Operating environment (service conditions between various ships may differ, and these might result in different leak frequencies for otherwise similar equipment. Comparisons of data sets from different ships are difficult because of inconsistent reporting, varying standards of safety management, different types of fluid, and differences in environmental factors).
- Safety management (the quality of operation, inspection, maintenance etc. is a critical influence on leak frequencies; the leak frequencies for ships with lower standards may be higher).
- Materials (as different materials have different properties for corrosion, erosion, fatigue, etc., the materials used for the gas fuel system design are expected to affect the leak frequencies).
- Operating conditions of temperature/pressure (equipment operating close to its design pressure may be more vulnerable to accidental overpressure; also in addition, equipment operating above or below the normal temperature for its construction material may be more vulnerable to material failure).
- Equipment age (in theory, new equipment is vulnerable to teething problems and old equipment to wear-out, producing a

bath-tub curve of failure rate versus time. Equipment that is subject to corrosion or fatigue is normally designed with a finite life, and the probability of failure increases as it nears the end of this period).

Process continuity (numerous failures occur during shut-down or start-up; failures are more likely in systems that experience many shutdowns).

- Manning levels (a high manning level is expected to increase the risk of process leaks as a large fraction of the registered leaks is related to human impact/intervention; thus, an increased activity level in the vicinity of the gas fuel system may increase the potential for damaging equipment).

(10) Arrangements for simultaneous bunkering and use of accommodation ladder near the bunker station are to be considered.

In summary, the proposed recommendations are taken into account and considered as follows:

(1) Work actively to promote a strong and sound safety culture. Involvement by all parties in the organization in the process of defining, prioritizing, and controlling risk and hazards, along with a sense of shared purpose in safety, is important to the health and safety level onboard the vessel.

(2) The bunkering procedures are the preferred instrument to document the responsibilities during LNG bunkering.

(3) The bunker station should have restricted access during bunkering operation, i.e., safety zone to be established.

(4) Personal protective equipment shall be mandatory for entering the pump room owing to cold piping and high-pressure systems.

(5) Training and competency of personnel to operate and maintain the system should be conducted and checked, respectively.

(6) Escape and evacuation routes and means are to be available continuously; at least two widely separated escape routes and two evacuation means must be present.

(7) Operational guidelines need to be developed to reduce potential negative environmental impacts related to the possible release of methane. Establish a comprehensive approach for methane slip management to mitigate and eliminate both environment and safety operation of engines.

(8) Parameters such as operating environment, safety management, materials specification/properties, operating conditions, process continuity, and manning levels for specific locations of LNG bunkering by STS or other means to be assessed to identify HAZID and mitigate and eliminate potential hazards (if any).

(9) A separate HAZID study and investigation shall be conducted on-site to select appropriate and feasible potential LNG bunkering methods and locations at Bandar Abbas port and Busan port considering the relevant hazards and risks at these locations. The focus of the selection bunkering methods (i.e., STS, truck-to-ship transfer via flexible hose, intermediate tank-to-ship transfer, and portable tank-to-ship bunkering methods) should also comply with relevant national regulatory requirements on usage of LNG as a marine fuel. The provision of bunkering services is to be considered part of the location selection and risk identification exercise.

Existing structures are to be evaluated in terms of capability of accommodating such activities without upgrading and rebuilding the jetty (technical feasibility and significant costs). The main selection criteria are the potential technical and operational capabilities of handling LNG bunkering in these areas, without requiring prohibitive infrastructure development. In addition, all the locations meet the requirement of being suitably distant from on-site operations and populations. The HAZID studies are aimed at answering the key question of whether LNG activities are possible at the proposed locations, from the perspective of major risks, public safety, and other activities in the direct vicinity. Where specific major risks or public safety issues are identified, the study advises on a set of possible mitigation measures.

The HAZID study for LNG bunkering at Bandar Abbas port and Busan port includes the following steps: assumption of terminal layout and fuel consumption of vessels; assessment of surrounding area of the location, including the potential presence of population, industrial areas, waterway traffic, and nautical layout; identification of major hazards and high-level assessments of credible events associated with the LNG bunkering operations; hazard identification study; identification of significant consequences that could imply strong arguments to effect the continuation of the present efforts on the proposed project and the necessary mitigation measures to enable the continuation of the project; risk ranking based on the consequence and likelihood.

The study should conclude that it is technically feasible to locate an LNG bunkering facility at the proposed locations/ jetties while meeting the requirements of local and international regulations and standards.

6. Conclusions

The overall and key results from the HAZID, covering the entire range of potential safety issues, various hazards that reached a level of safety and unsafe operation, and technical showstoppers, are identified. The HAZID results confirm that there are no major HSE showstoppers in terms of performing construction and conversion on dual-fueled vessels. The main selection criterion is the potential design, worst-case scenario for location of LNG tank below accommodation, and technical and operational capabilities in conducting the HAZID study and investigations.

The estimated HAZID increase is mainly due to the presence of the LNG tank and its effect on the risk from fire/explosions due to ship collision. A dropped container potentially penetrates the main deck and damages gas piping and equipment in the pump room if dropped from a great height. However, a dropped container only penetrates the main deck structure if no other containers are stored on the main deck. A dropped container also potentially damages/ruptures the bunker line/hose if dropped and tipped over the shipside and onto the bunker ship/barge, causing fire/explosion.

Several important gaps in mandatory regulations, standards, and guidelines or of relevant organizations are identified as requiring further action following the recommendations. However, this study concludes that it is technically feasible for the arrangement and installation of machinery for propulsion and auxiliary purposes, using natural gas as fuel, to have an equivalent level of integrity in terms of safety, reliability, and dependability as that of new and comparable conventional oil-fueled main and auxiliary machinery, while meeting the requirements of local and international regulations and standards.

The study and investigation concludes that there are no health, safety, and environment showstoppers for construction / conversion of conventional oil-fueled to dual-fueled LNG vessels for which HAZID can be mitigated and eliminated with sufficient design, engineering, and operational controls that meet the required standards.

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