Hazard Indentification Study (HAZID)

LNG Bunkering from Bunker Vessel in the Port of Hamburg

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LNG Bunkering from Bunker Vessel in the Port of Hamburg

Abstract:

Within the LNG Showcase in the Clean North Sea Shipping (CNSS) project, a hazard identification (HAZID) has been carried out. The scope of this HAZID is to identify the main risks which can occur during the bunkering from a LNG bunker vessel to a receiving vessel.

The safety analysis of the above mentioned content was performed at the premises of the Hamburg Port Authority in Hamburg, Germany. The aim was the identification of the main risks of LNG bunkering and their possible handling. The analysis focussed on the identification of hazards caused by LNG or NG leakages.

The analysis shows that five single point failures can lead to a critical situation.

A number of recommendations for technical and procedural measures have been identified to prevent failures or reduce the effects of possible failures. These recommendations are listed in the documentation of this FMEA.

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Contents

1 Summary

Within the LNG Showcase in the Clean North Sea Shipping (CNSS) project, a hazard identification (HAZID) has been carried out. The scope of this HAZID is to identify the main risks which can occur during the bunkering from a LNG bunker vessel to a receiving vessel.

The safety analysis of the above mentioned content was performed at the premises of the Hamburg Port Authority in Hamburg, Germany. The aim was the identification of the main risks of LNG bunkering and their possible handling. The analysis is orientated on the Failure Mode and Effects Analysis (FMEA) method and the requirements given in IEC 60812. The analysis focussed on the identification of hazards caused by the LNG bunkering procedure.

It should be mentioned that without a LNG of NG leakage no additional risk for fire and explosion can occur. Therefore the aim is to prevent any leakages or to prepare the respective critical areas to be able to manage any leakage.

During the analysis 41 failures have been investigated. The analysis shows that five single point failures can lead to a critical situation. These failures are mainly related to big LNG leakages caused by e.g. collision or other reasons.

A number of recommendations for technical and procedural measures have been identified to prevent failures or reduce the effects of possible failures. These recommendations are listed in the documentation of the FMEA which is enclosed to this report.

For the limitations of the study compare section “Limitations” of this report.

2 Definition of project

Within the Clean North Sea Shipping (CNSS) project, founded by the EU in the Interreg IVB North Sea Region programme, in work package 4 – 'Clean Shipping Technology' there is an activity which is working on an LNG Showcase (Activity 2). The aim of this showcase is to provide recommendations, exchange experiences and discuss how to stimulate stakeholders like ports, terminal operators or shipping companies to use LNG and to start to create a market. In the action plan for this show case it was decided to work in Action C on a physical show case. As part of that it was decided to investigate the possible risks which may occur during LNG bunkering form a bunker vessel on a realistic example. Therefore a hazard identification (HAZID) has been carried out in this document to identify the main risks which can occur during the bunkering from a bunker vessel.

For the example of the LNG Show case it was decided to investigate the bunkering from the bunker vessel to the receiving vessel in the Port of Hamburg (Figure 1).

Figure 1 – Port of Hamburg (aerial view)

At least today there is no LNG infrastructure in the Port of Hamburg. Therefore it is required that LNG will be delivered to Hamburg. The most likely supply chain for the Port of Hamburg is shown in Figure 2. Firstly LNG will be transported to Hamburg form a large LNG Import terminal in Europe (e.g. Zeebrügge) or a small scale LNG production plant in Northern Europe by a LNG Feeder vessel. Because the distance to a LNG source is longer that practical it was assumed, that an intermediate LNG terminal will be constructed in Hamburg to store and redistribute LNG in the harbour. This intermediate terminal will be the basis for the LNG bunker vessel, which distributes the LNG to the respective receiving vessels. As today for traditional oil bunkering, it could be assumed, that a bunker vessel will normally only transport the ordered amount of fuel for one customer (delivery on demand).

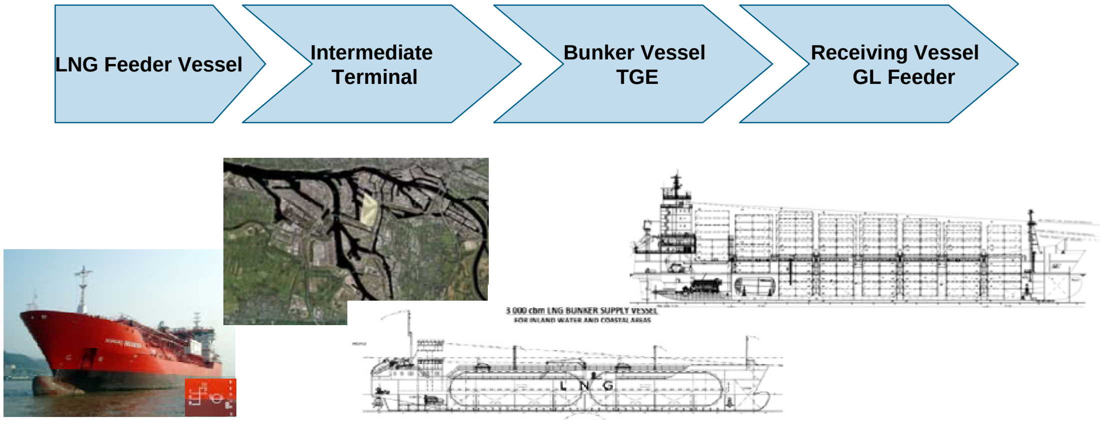

Figure 2 - LNG supply chain for the example Port of Hamburg

For this hazard identification the bunkering from a LNG bunker vessel to a receiving container feeder vessel was investigated to identify all main risks which can occur during the bunkering of LNG in the harbour. As basis for the investigation a LNG bunker vessel design from TGE and a GL LNG container feeder vessel was chosen. Details of both vessels are described in Chapter 5.

The HAZID was carried out with the Failure Mode and Effects Analysis (FMEA) method. The method is described in Chapter 3.

3 Principle of the applied FMEA Method

The FMEA – Failure Mode and Effect Analysis is a systematic, semi quantitative risk analysis method for the identification of potential failures of technical systems and/or components, for the detection of failure consequences and for the classification of failures.

The overall aim of an FMEA is the detection of hidden failures and their prevention. The results of an FMEA can be used for quantitative analysis like fault tree analysis as input parameters.

The basic FMEA procedure involves the following steps:

- Define boundary conditions/assumptions for FMEA
- Decompose system into functional blocks
- Describe function and interfaces of each block (consider different operational modes)
- Functional narrative of component/block
- Definition of possible failures
- Identification of failure effects on the component and the system (local and end effect)
- Identification of failure cause
- Criticality Analysis:
    - Consequence severity
    - Occurrence probability of failure
    - Probability of failure detection
- Provide recommendations for control measures and necessary actions

The procedure also integrates the assessment of the consequences from the identified failures. Therefore the procedure is strictly spoken a FMECA (Failure Mode Effect and Criticality Analysis).

The FMEA method is described by different technical standards. The most relevant standards are:

1. IEC Standard 60812 “Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis”, second edition 2006
2. DIN 25448 “Ausfalleffektanalyse”,
3. US Military Standard MIL-STD-1629A “Procedures for Performing a Failure Mode and Effect Analysis”, (first description of FMEA method)
4. British Standard BS 5760
5. MoD Defence Standard 00-41 (focus on military equipment)

The FMEA which was accomplished in this document was orientated on the IEC Standard 60812. As defined in this standard, the single failure criterion is used. This means, that while considering one failure in a component, it is assumed that all other components work properly. Generally hidden failures are not considered. Hidden failures which may be caused by non identifiable malfunctions of a component are kept in consideration as far as possible. The used definitions are shown in Table 1.

Term	Definition
Item	Delimited part of the investigated system.
Failure	Definition of the deviations of the component behaviour from its normality, including the description of the nature of the deviation.
Causes	Definition of the triggering cause of the failure. For this the single failure presumption is used. However hidden failures are considered if they are not detectable and therefore can occur together with a single failure at any time.
Effect	Definition of the consequence of a failure on the component, the system and the function of the system.
Control	Definition of the detection options for a failure.
Action	Descriptions of the essential measures for the prevention of a failure, including changes of the component and the system.
Occurrence	Qualitative assessment of the occurrence, severity and detection probability. The assessment carried out under the rating scales showed in Annex 7.
Severity	
Detection	
Comment	Annotation to proposed changes of the system, to operation and to boundary conditions.

Table 1 – FMEA definitions

The function of the component was described at the beginning of the discussion and is listed in Annex 1. In Annex 7 the definitions for occurrence, severity and detection are displayed.

For this investigation a Functional FMEA was carried out. This is an approach where sub-assemblies are treated as “black boxes” providing required functions in the system. In this approach the analyst considers the effect of loss of inputs and internal failures of each “black box” on the required function of the system.

The assessment of occurrence, severity and detection was carried out, first without considering any safety measures and in a second revised step all existing safety measures were taken into account additionally.

4 Procedure for the Assessment of the FMEA results

Fundamental for the assessment of the different failure modes in the FMEA are the expected consequences as well as the probability of their occurrence.

For the assessment of the FMEA results a ranking of the detected failures is determined. For this several different evaluating procedures are available. Here, the assessment by means of a criticality matrix, as mentioned in the IEC 60812 is used. An example of a criticality matrix is shown in Figure 3. In this matrix the detected failures are shown in dependency to the severity and the probability of occurrence. In the matrix acceptable and unacceptable regions can be defined. It should be noted that there is no universal definition of criticality. The criticality needs to be defined by the analyst. The definitions differ widely between different branches.

		Probability of Occurence				
		1	2	3	4	5
Severity	**1**	**Low Risk**				
	2				Failure mode 2	
	3					
	4		Failure mode 1			
	5					**High Risk**

Figure 3 – Criticality matrix

In Figure 3 it is implied that the severity increases with the ascending order of numbers, where number 5 has the highest severity (fatalities and/or loss of system/other systems). It is also implied that likelihood of occurrence, on the Y-axis is also represented in ascending order.

The high risk region (red) is the intolerable region. Failures in this region can not be justified on any reasons. Failures in the "As Low As Reasonable Practical" (ALARP) region (yellow) the risk is only tolerable if risk reduction measures are impractical or if the costs are grossly disproportionate to the benefits gained. It has to be demonstrated, that all reasonable practical measures have been taken. Failures in the low risk area (green) have a negligible risk. It is no need for detailed work to demonstrate ALARP.

For a cross check the failures were listed according their risk priority number (RPN). The risk priority number is also a method for quantitative determination of criticality. Risk is here evaluated by a subjective measure of the severity of the effect and an estimate of the expected probability of its occurrence for a predetermined time period assumed for analysis. Additionally the level of failure detection at system level will be evaluated.

The so defined risk priority number (RPN) in a FMEA is expressed as follows:

$$RPN = S \times P \times D$$

where

S is a non-dimensional number that stands for severity, i.e. an estimate of how strongly the effects of the failure will affect the system or the user.

P is also a non-dimensional number that denotes probability of occurrence

D is a non-dimensional number that estimates the chance to identify the failure

5 Work principle of the bunkering between the bunker vessel and the receiving vessel

For this hazard identification the bunkering from a LNG bunker vessel to a receiving container feeder vessel was investigated to identify all main risks which can occur during the bunkering of LNG in the harbour.

As basis for the investigation a LNG bunker vessel design from TGE was chosen (Figure 4). The vessel is designed for the handling and transportation of LNG and marine gas oil (MGO). The purpose of the vessel is the use as a bunker supply vessel for LNG and MGO fuelled ships. The vessel is able to bunker the receiving vessel simultaneously with LNG and MGO.

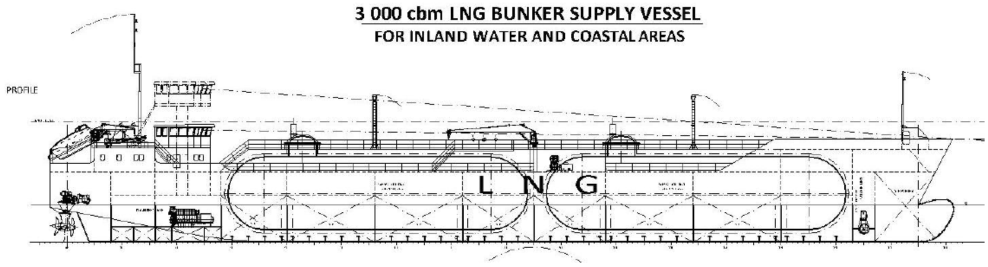

Figure 4 – TGE bunker supply vessel (side view)

The principle dimensions of the vessel are given in the following:

Length overall	98.60 m
Length b.p.	93.00 m
Breath moulded	14.20 m
Depth moulded	7.60 m
Draugt (design)	4.20 m
Deadweight	2050 t
Cargo tank volume LNG (100%)	3000 m^3
Cargo tank volume MGO (100%)	400 m^3

The bunker vessel is equipped with a special transfer arm, comparable to a hard arm solution, carrying the piping and all relevant systems for the transfer of LNG and MGO. The transfer arm has an operating distance of 20 m and is supported within the ship structure between the LNG storage tanks. Movements of both ships during fuel transfer can be balanced by an automatic adjustment control system which equalizes all relative movements.

The bunker supply vessel will bunker a LNG fuelled container feeder. For the investigation of this study the design of the GL LNG container feeder was used (see Figure 5).

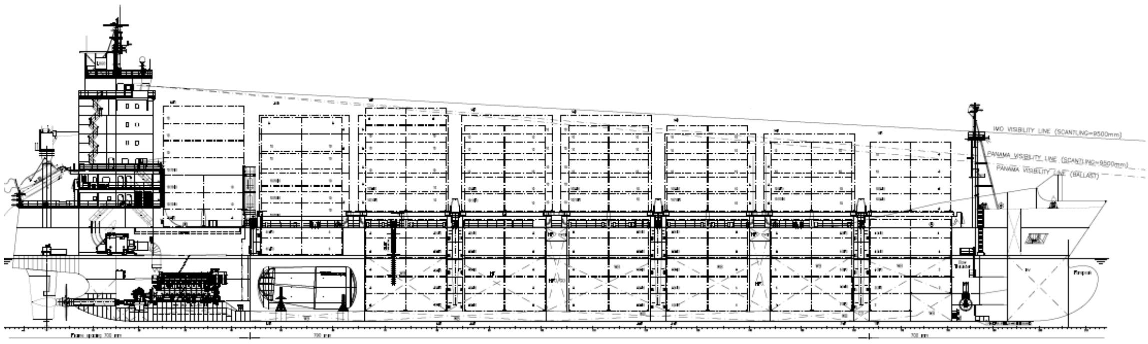

Figure 5 – Gas-fuelled feeder container vessel (side view)

The principle dimensions of the container feeder are given in the following:

Length overall	166.15 m
Length b.p.	155.08 m
Breath moulded	25.00 m
Depth moulded	14.20 m
Draugt (design)	9.50 m
Deadweight	18300 t
Capacity	1240 TEU
Bunker tank volume LNG (100%)	670 m^3

The bunker station on board of the receiving vessel was located beside the superstructure on the poop deck to ensure that the bunker station is not located in the cargo area and to have a short distance to the storage tank.

The bunkering was carried out at the container terminal Burchardkai in Hamburg, because it was intended for this investigation to use a berth with a lot of passing traffic. Furthermore the vessels which will enter the Parkhafen have to pass with higher speed to be still manoeuvrable. Therefore the berth Athabaskakai 8 was chosen (see Figure 6).

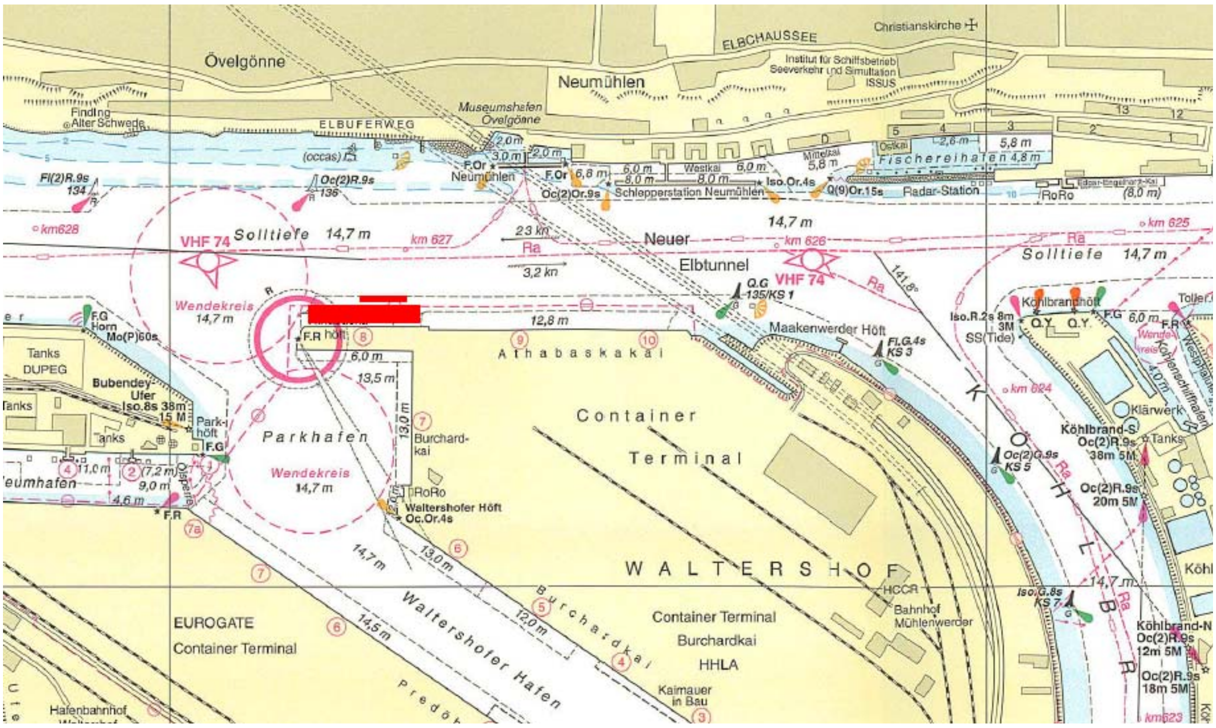

Figure 6 – Location of bunkering in the port of Hamburg (nautical chart)

The bunkering was carried out during normal loading and unloading of the vessel.

According to the aim of the analysis it was checked, where the main hazards can occur during LNG bunkering.

6 Participants

The following persons participated during the HAZID session from the 23rd to 24th of November 2011 at Hamburg Port Authority premises in Hamburg, Germany:

No.	Company	Name	Role	23.11.2011	24.11.2011
1	Hamburg Port Authority	Wolfgang Becker	Enviromental and spatial planning	temporary	N
2	Hamburg Port Authority	Hendrik Hollstein	Enviromental and spatial planning	temporary	temporary
3	Hamburg Port Authority	Katja Leuteritz	Trainee	Y	N
4	Hartmann Reederei	Meindert Bildhoff	Gas carrier specialist	Y	Y
5	HHLA	Birgit Schwarz	Terminal technoloy specialist	Y	N
6	HHLA	Peter Voltmann	Specialist for operational sequences	Y	N
7	Germanischer Lloyd	Lars Langfeldt	Project engineer	Y	Y
8	Germanischer Lloyd	Finn Vogler	Senior project engineer	Y	Y
9	Meyer Werft	Gerhard Untiedt	Gas and machinery specialist	Y	N
10	Meyer Werft	Johannes Beuse	Gas engineering specialist	Y	Y
11	TGE Matrine Gas Engineering	Dr. Hans-Christian Haarmann-Kühn	Gas engineering specialist	Y	Y
12	Unifeeder	Egmont Piepiorka	Operations Manager	temporary	N
13	Harbour police Hamburg	Lutz Dreyer	Dangerous goods specialist	Y	Y

Table 2 – Participants (Y = present, N = not attending)

All persons participated the whole time if not additionally mentioned.

7 Limitations

The analysis is based on following assumptions:

1. the study is limited to the bunkering of LNG from the bunker supply vessel to the container feeder at the berth Alabaskakai 8
2. the analysis focussed on the identification of the main hazards during LNG bunkering
3. the LNGPac is operating within its design limitations
4. attention was given to single point failure
5. regular inspection and maintenance is stipulated
6. the machine is operated by an experienced crew
7. the analysis was conducted based on technical information supplied by TGE and GL

8 Evaluated Operating Conditions

In general for a safety analysis different operation conditions were examined, to identify possible system weaknesses. For this analysis it was assumed during the FMEA that all critical failures will occur during normal operation (bunkering). The FMEA team concluded that during the start-up, shut-down procedure or ESD the risk is equal or lower to the risk during normal operation (bunkering).

Therefore only the following operational condition has been considered during the FMEA:

1. Normal operation (bunkering)

9 Evaluated Subsystems

For the HAZID the main areas which are affected by the bunkering at the berth have been identified. Grouped by these areas the HAZID was carried out. For the failures subject to this areas ranking of severity, occurrence and detection were done. Five categories have been defined for occurrences, for severity and for detection. The used definitions are given in the annex of this report.

The following areas were included in this procedure:

1. Terminal
2. Receiving vessel (Container Feeder)
3. Bunker equipment
4. Bunker operation
5. Bunker supply vessel
6. Waterway river Elbe

10 Assessment of the FMEA results

During the FMEA 41 failures have been investigated. The assessment of occurrence, severity and detection was carried out, in two steps: first without considering any safety measures (initial rating) and in a second revised step all existing safety measures, like monitoring, safety valves, alarm and shut-down systems, etc. were taken into account additionally (revised rating). Therefore Figure 7 shows distribution of the overall result in the criticality matrix for the initial rating and Figure 8 shows the criticality matrix including all safety measures.

		Probability of Occurence				
		1	2	3	4	5
Severity	1				1	
	2			2	1	6
	3			4	4	1
	4		1	7	3	2
	5		6	2		1

Figure 7 - Distribution of Failures (initial rating)

		Probability of Occurence				
		1	2	3	4	5
Severity	1			1	1	1
	2		1	5	1	8
	3		4	4	2	1
	4		1	5	2	
	5		2	2		

Figure 8 - Distribution of Failures (revised rating)

In Figure 9 the distribution of the failures is shown according to their Risk Priority Number (RPN). On the x-axis the 30 failures with the highest RPN are shown and on the y-axis the RPN is given. The initial RPN is shown for each failure in blue coloured bar (without considering any safety measure). The revised rating (considering all safety measures) is shown in green coloured bar beneath the bar for the initial rating to show the effect of the safety measures on the RPN. The difference of the blue and the green bar show clearly this effect. In failure cases with lower RPN numbers it can be shown, that safety measures not necessarily lead to a risk reduction. Nevertheless it is recommended to provide safety measures also for these cases.

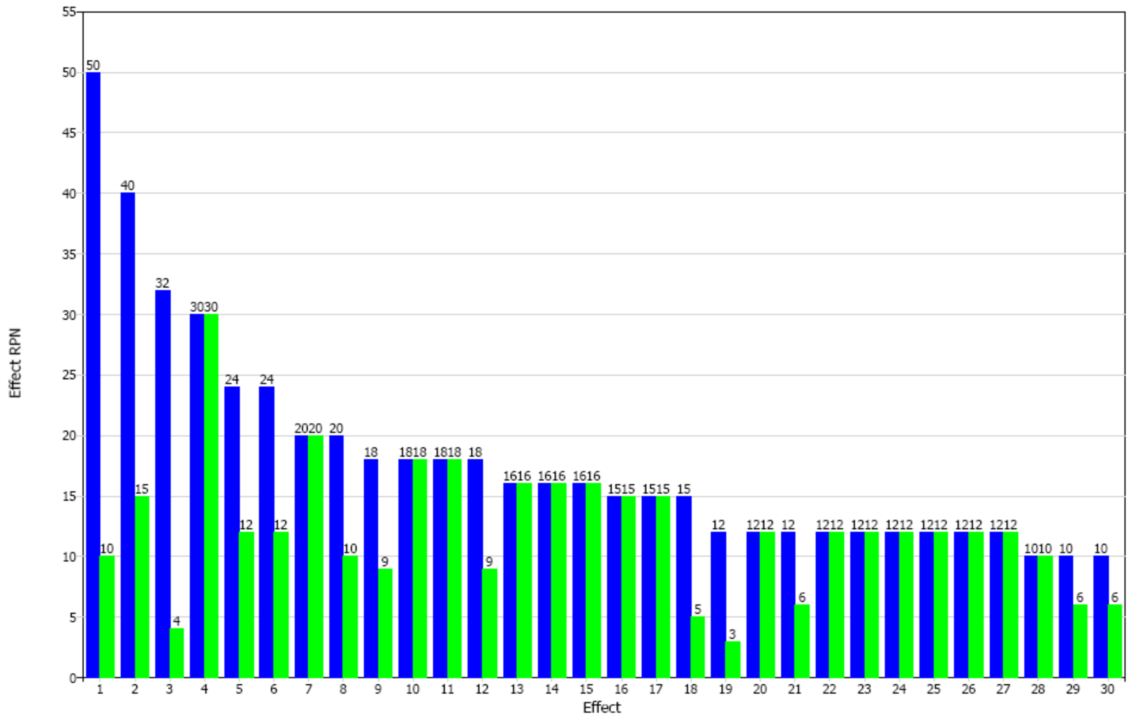

Figure 9 – Effects ranked by RPN (initial: blue; revised: green)

List of effects corresponding to Figure 9:

1. RPNi = 50, RPNr = 10 - in case of overfilling, LNG may be pressed through the safety valves and vent lines to atmosphere, big gas cloud (Item: 4.2 - Overfilling)
2. RPNi = 40, RPNr = 15 - may lead to overfilling if bunker crew is not informed probably about status in tank (Item: 3.4.2 - Communication problems between vessels)
3. RPNi = 32, RPNr = 4 - if critical pressure is reached safety valves will open and gas will be vented to atmosphere (Item: 4.2 - Overpressure)
4. RPNi = 30, RPNr = 30 - Equipotential bonding not possible, sparks may be possible (but only in case of double failure, presence of gas, ignition possible) (Item: 3.26 - Equipotential bonding)

5. RPNi = 24, RPNr = 12 - loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection (Item: 5.2.21 - Loss of mooring)
6. RPNi = 24, RPNr = 12 - strong relative movements, loss of one mooring line, loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection it could be assumed, that the feeder vessel will lose the mooring to the berth prior to the loss of mooring between feeder and bunker barge. (Item: 6.1.14 - Surge from passing vessels)
7. RPNi = 20, RPNr = 20 - no effect, no reaction time for crew on bunker vessel and passing vessels, local traffic control may inform passing vessels prior to entering safety zone (Item: 6.1.2 - Vessel entering Safety Zone)
8. RPNi = 20, RPNr = 10 - lightning may ignite present gas clouds (Item: 4.1.1 - Lightning)
9. RPNi = 18, RPNr = 9 - LNG will evaporate direct after leakage, drip tray will protect ship structure (Item: 3.2.18 - Leakage of connection)
10. RPNi = 18, RPNr = 18 - LNG will evaporate direct after leakage (Item: 3.1.18 - Leakage of filling line)
11. RPNi = 18, RPNr = 18 - LNG will evaporate direct after leakage (Item: 3.1.18 - Leakage of filling line)
12. RPNi = 18, RPNr = 9 - parallel ESD of bunkering not possible (Item: 3.4.1 - Loss of ESD Connection)
13. RPNi = 16, RPNr = 16 - Big fallen objects may destroy piping on deck or the coverage of the tank system, LNG leakage and big gas cloud, fire must be assumed on deck area and in the adjacent open spaces, a damage of storage tank of bunker vessel will not be expected. (Item: 5.1.9 - Big falling objects on the bunker vessel from terminal)
14. RPNi = 16, RPNr = 16 - person will fall in the water of lower vessel, one heavily injured or dead person (Item: 4.20 - Crew member falling over board)
15. RPNi = 16, RPNr = 16 - loss of proper mooring to berth, bigger relative movements to berth, master decision to stop bunkering (Item: 2.2.23 - Loss of mooring)
16. RPNi = 15, RPNr = 15 - Damage of outer shell and LNG storage tank of bunker vessel, LNG leakage and gas cloud, ignition assumed, big fire, low flame velocity, structural damage of ship structure according to leaking LNG, rapid phase transition could be expected. (Item: 6.1.1 - Collision)
17. RPNi = 15, RPNr = 15 - LNG spill, large gas cloud (Item: 3.2.12 - Loss of connection)
18. RPNi = 15, RPNr = 5 - icing around the hose, load of hoses will increase, if critical loads are reached, emergency release of piping (Item: 4.15 - Loads due to snow and icing of the piping)
19. RPNi = 12, RPNr = 3 - only tension, buckling of hose, damage of hose can not be excluded, leakage possible (Item: 3.1.10 - Excessive forces, stress on valves, hoses and pipes)
20. RPNi = 12, RPNr = 12 - hard arm stays in last position, if critical forces are reached connections emergency release couplings will open, mechanical damages can not be excluded. According to black

out bunkering has stopped and all valves go to fail safe position, no LNG leakage possible (Item: 5.28 - Black-Out)

21. RPNi = 12, RPNr = 6 - hard arm, bunker manifold will be mechanically damaged, double walled piping connection will break first, leakage (Item: 3.1.10 – Excessive forces, stress on valves, hoses and pipes)
22. RPNi = 12, RPNr = 12 - fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel (Item: 2.1.2 - Fire - Explosion in machine spaces - LNG system of vessel)
23. RPNi = 12, RPNr = 12 - Vessel will approach with low speed, mechanical damage of the outer hull possible, damage of storage tank and gas system not expected (Item: 6.1.1 - Collision)
24. RPNi = 12, RPNr = 12 - fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, (Item: 5.1.2 - Fire - Explosion in machine spaces - LNG system of vessel)
25. RPNi = 12, RPNr = 12 - fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release (Item: 5.1.1 - Fire on Board)
26. RPNi = 12, RPNr = 12 - fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel. (Item: 2.1.1 - Fire on Board)
27. RPNi = 12, RPNr = 12 - bunker vessel will be heavily mechanically damaged, a damage of storage tank will not be assumed (no difference to normal operated vessel), possible break of mooring lines, bunker envelope will be left, Emergency shut down and disconnection of bunker line. (Item: 6.1.1 - Collision)
28. RPNi = 10, RPNr = 10 - passing traffic may be restricted according to the bunkering procedure (Item: 6.25 - restriction of shipping channel)
29. RPNi = 10, RPNr = 6 - flexible hose at the arm is of double walled design, rest of fixed piping is single walled, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded, (Item: 3.1.1 - Rupture of Filling Line)
30. RPNi = 10, RPNr = 6 - hose of composite design, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded, (Item: 3.1.1 - Rupture of Filling Line)

Furthermore Figure 10 and Figure 11 show the distribution of the failures according their severity ranking in the pie-charts. Figure 10 shows the initial rating (without any safety measures) and Figure 11 the revised version (consideration of all safety measures). The comparison of both charts clearly shows the positive effect of the safety measures. The effects of the failures could be significantly reduced by implementing the safety measures.

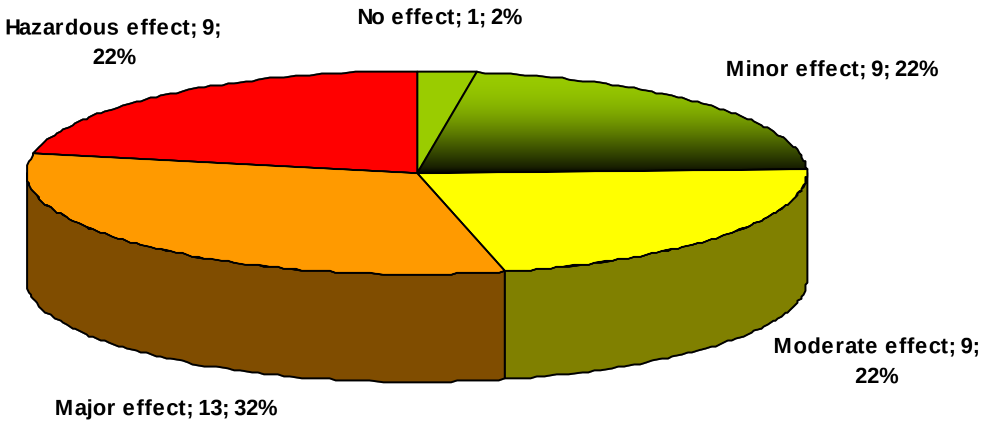

Figure 10 - Distribution of Effects (initial rating)

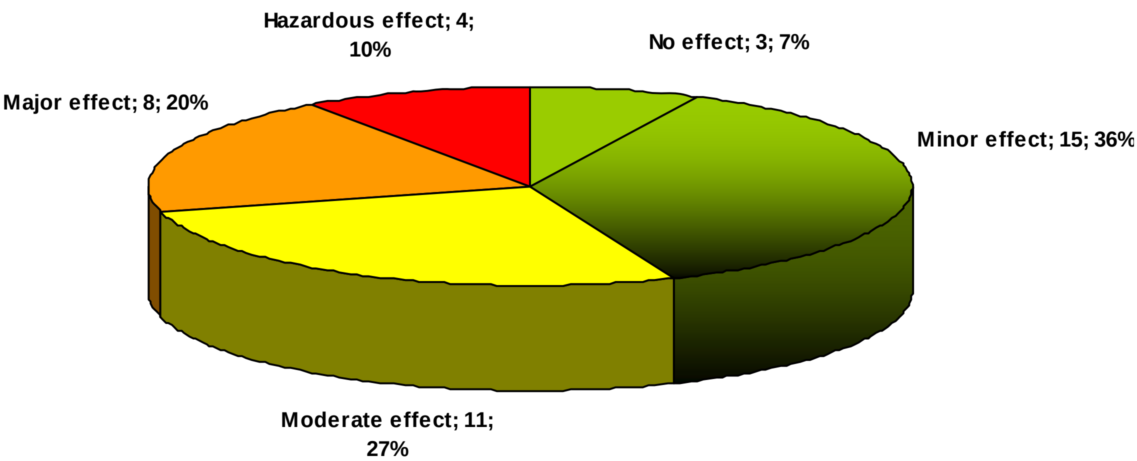

Figure 11 - Distribution of Effects (revised rating)

After entering all failures into the revised criticality matrix (consideration of all safety measures), it was judged were a failure or leakage will cause the most severe effect during the LNG bunkering. For verification these failures in the criticality matrix, they were cross checked against the failure list, where all failures were listed according their individual risk priority number from high to low numbers (high to low risk potential).

The analysis shows that the most critical situations could be expected in case of big LNG leakages. Furthermore it pointed out, that failures which lead to injury to persons are most critical. But the cases for injury of persons will not be different to conventional oil bunkering.

It pointed out, that 5 failure is in the high risk region of the criticality matrix, which displays an intolerable risk. These are related to the following failures:

1. Loss of bunker connection during bunkering (Item 3.2.12) resulting in a large LNG spill
   Mitigation measures: To avoid the probability of failures during connection a QC/DC should be considered. Furthermore the Emergency Shut-Down times should be minimised as far as possible to minimise the amount of leaking LNG.

2. Communication problems during the bunkering (Item: 3.4.2) may lead to critical situations
   (the severity of this failure is moderate, but the occurrence is very frequent; this failure is not different to the conventional bunkering)
   Mitigation measures: Bunker procedures and check lists should ensure sufficient communication.

3. Crew member is falling over board (Item: 4.20)
   (this failure is not different to the conventional bunkering)
   Mitigation measures: The bunker vessel must have a safe possibility for transfer of bunker crew to the receiving vessel.

4. Big falling objects from the terminal will hit the bunker vessel, damage of storage tank not expected but damage of bunker line possible (Item 5.1.9)
   Mitigation measures: To avoid the probability of failures during connection a QC/DC should be considered. Furthermore the Emergency Shut-Down times should be minimised as far as possible to minimise the amount of leaking LNG.

5. Side collision of passing vessel in bunker vessel (90° angle), damage of storage tank expected (Item: 6.1.1)
   Mitigation measures: The probability for a collision can be lowered by using defined areas for bunkering or traffic restrictions.

11 Recommendations

The analysis pointed out, that the most critical situations could be expected in case of large LNG leakages. The most critical case is a damage of the shell of the storage tank of the bunker vessel which can occur in case of collision.

During the FMEA several actions have been discussed to reduce the risk potential of the respective failures. In total 16 recommendations have been agreed on during the study. These recommendations are listed in the list of “Actions” enclosed to this report (Annex 5).

The ranking of occurrence, severity and detection in the FMEA assumes the “as is situation”. Observation of recommended actions and implementation of given additional control options will give the opportunity to re-evaluate these rankings by a follow up FMEA.

The main actions resulting from the analysis are given in chapter 12.1 and 12.2. Further actions are given in Annex 5.

11.1 Safety Related Actions

The following main safety related actions were discussed during the analysis:

1. Item 6.1.1, Side collision (90°)
   The probability for a collision can be lowered by using defined areas for bunkering or traffic restrictions. It should be considered, that this risk is no specific risk of the bunkering and bunker vessel, but similar to all gas fuelled vessel.

2. Item 6.1.14, Surge from passing traffic; Item 5.2.21, Loss of mooring
   Bunker Vessel: The manoeuvrability of the bunker vessel should ensure always a safe approach and departure to the receiving vessel under all foreseeable conditions.

3. Item 6.1.14, Surge from passing traffic; Item 5.2.21, Loss of mooring
   Bunker procedure: the bunker vessel should be moored with a sufficient number of mooring lines (compare e.g. Exxon mooring requirements). Mooring lines should be supplied by bunker vessel (regularly checked).

4. Item 3.2.12: Loss of bunker connection during bunkering
   To avoid the probability of failures during connection a QC/DC should be considered.

5. Item 4.20: Crew member falling overboard
   Bunker Procedure: the bunker vessel must have a safe possibility for transfer of people to the receiving vessel.

6. Item 1.17: Quay side safety zone during bunkering
   Bunker station design: the unused bunker station must be separated from the rest of the gas system (gas safe zone), otherwise the ex-zones will influence the terminal operation (according ex-zone no harbour operation in this area possible).

11.2 Non Safety Related Actions

During the analysis it pointed out, that no non safety related actions have to be carried out.

12 Used Documentation

The following documentation was used for the study:

1. Presentations

   a. TGE, Dr. Hans-Christian Haarmann-Kühn: Technisches Konzept Bunkerschiff, Transfersystem, Bunkervorgang; 2011-11-23/24

2. Manuals / Reports

   a. -

3. Diagrams / Lists

   a. TGE: General Data Sheet 3000 m^3 LNG Bunker supply vessel, RD0038, 2011-09-26

4. Drawings

   a. TGE: General Arrangement Preliminary Layout 3000 m^3 LNG Bunker supply vessel, RD0038 TH65 ADW 6501 0100, Rev. 2, 2011-09-26

   b. Neptun Stahlkonstruktion:General Arrangement Plan CV Neptun 1200, 3104-0110-004-01-C, Rev. C

5. Literature

   a. IEC Standard 60812 "Analysis techniques for system reliability – Procedure for failure mode and effect analysis (FMEA)" (CEI / IEC 60812: 2006-01)

13 FMEA Documentation

The following documentation of the FMEA is enclosed to this report:

1. List of “Function” evaluated
2. Summary of evaluated “Failures”
3. List of “Effects”
4. List of “Causes”
5. List of “Actions”
6. List of “Controls”
7. Definitions for Severity, Occurrence and Detection
8. FMEA Sheets

Annex

Annex 1

List of evaluated “Functions“

Source: Germanischer Lloyd

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Functions

Functions

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)

GL Report Number: RD-ER 2011.31
Prepared by: Finn Vogler
FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

Item #	Item Name	Function #	Function
1.1.1	Fire on Terminal	1	Fire on Terminal
1.17	Difficult to arrange large safety zones on quay areas	1	A safety zone on the terminal will not be necessary if no crossover to the unused bunker station is existing and the bunker station can be defined as safe area.
2.1.1	Fire on Board	1	Fire on Board
2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1	Fire/Explosion on Board
2.1.8	Big falling objects on the receiving vessel from terminal	1	Falling Objects
2.16.24	Pressure release during loading and unloading	1	Pressure release during loading and unloading
2.2.23	Loss of mooring	1	Loss of mooring
3.1.1	Rupture of Filling Line	1	For bunker hose
3.1.1	Rupture of Filling Line	2	For hard arm
3.1.10	Excessive forces, stress on valves, hoses and pipes	1	For bunker hose
3.1.10	Excessive forces, stress on valves, hoses and pipes	2	For hard arm
3.1.18	Leakage of filling line	1	For bunker hose
3.1.18	Leakage of filling line	2	For hard arm
3.2.11	Excessive forces, stress on valves, connections	1	Failure similar to Filling Line
3.2.12	Loss of connection	1	Loss of connection
3.2.18	Leakage of connection	1	Leakage of connection
3.26	Equipotential bonding	1	Equipotential bonding
3.3.1	Rupture of Vapour Return Line	1	For bunker hose
3.3.1	Rupture of Vapour Return Line	2	For hard arm
3.3.10	Excessive forces, stress on valves, hoses and pipes	1	Failure similar to Filling Line
3.3.18	Leakage of vapour return line	1	Failure similar to Filling Line
3.4.1	Loss of ESD Connection	1	Loss of ESD Connection
3.4.2	Communication problems between vessels	1	Communication problems between vessels
4.1.1	Lightning	1	Lightning
4.1.2	Storm	1	Storm
4.1.27	Fog	1	Fog
4.1.7	High Waves - Relative Movements between the Vessels	1	high waves

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Functions

Item #	Item Name	Function #	Function
4.13	Long shut-down times for ESD	1	Long shut-down times for ESD
4.15	Loads due to snow and icing of the piping	1	Loads due to snow and icing of the piping
4.19	Deviations from Bunker Procedures	1	see action
4.2	Overpressure	1	Overpressure
4.2	Overfilling	1	Overfilling
4.20	Crew member falling over board	1	Crew member falling over board
4.3	Emergency Release System activated	1	ESD activated
4.4	Lack of Training	1	see action
4.5	Unclear Responsibilities	1	Unclear Responsibilities
4.6	Regulation Gaps	1	Regulation Gaps
5.1.1	Fire on Board	1	Fire on Board
5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1	Fire/Explosion on Board
5.1.9	Big falling objects on the bunker vessel from terminal	1	Falling Objects
5.2.21	Loss of mooring	1	Loss of mooring
5.2.22	Release of mooring in wrong way	1	See failure 3 Collision
5.24	Pressure release during loading and unloading	1	Pressure release during loading and unloading
5.28	Black-Out	1	Hard arm
6.1.1	Collision	1	Collision
6.1.14	Surge from passing vessels	1	Surge of passing vessel
6.1.2	Vessel entering Safety Zone	1	Vessel entering Safety Zone
6.25	restriction of shipping channel	1	Restriction of shipping channel

Annex 2

Summary of evaluated “Failures“

Source: Germanischer Lloyd

Failures (Summary)

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)
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FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

Failure #	Failure	Item #	Item Name	Function
1.1	Fire on Terminal	1.1.1	Fire on Terminal	Fire on Terminal
1.1	see action	1.17	Difficult to arrange large safety zones on quay areas	A safety zone on the terminal will not be necessary if no crossover to the unused bunker station is existing and the bunker station can be defined as safe area
1.1	Fire on the vessel	2.1.1	Fire on Board	Fire on Board
1.1	Fire/Explosion in the machinery space of LNG system	2.1.2	Fire - Explosion in machine	Fire/Explosion on Board
1.1	Big falling objects on bunker vessel from terminal	2.1.8	Big falling objects on the receiving vessel from terminal	Falling Objects
1.1	unintended pressure release	2.16.24	Pressure release during loading and unloading	Pressure release during loading and unloading
1.1	Loss of one mooring line	2.2.23	Loss of mooring	Loss of mooring
1.1	rupture of pipe	3.1.1	Rupture of Filling Line	For bunker hose
2.1	rupture of pipe	3.1.1	Rupture of Filling Line	For hard arm
1.1	Excessive forces	3.1.10	Excessive forces, stress on valves, hoses and pipes	For bunker hose
2.1	Excessive forces	3.1.10	Excessive forces, stress on valves, hoses and pipes	For hard arm
1.1	small leakage	3.1.18	Leakage of filling line	For bunker hose
2.1	small leakage	3.1.18	Leakage of filling line	For hard arm
1.1	unintended disconnection	3.2.12	Loss of connection	Loss of connection
1.1	small leakage	3.2.18	Leakage of connection	Leakage of connection
1.1	Loss of connection	3.26	Equipotential bonding	Equipotential bonding
1.1	rupture of pipe	3.3.1	Rupture of Vapour Return Line	For bunker hose
2.1	rupture of pipe	3.3.1	Rupture of Vapour Return Line	For hard arm
1.1	Loss of ESD Connection	3.4.1	Loss of ESD Connection	Loss of ESD Connection
1.1	Communication problems between vessels	3.4.2	Communication problems between vessels	Communication problems between vessels
1.1	Lightning's	4.1.1	Lightning	Lightning
1.1	high wind velocities	4.1.2	Storm	Storm
1.1	bad visibility	4.1.27	Fog	Fog
1.1	high relative movements between vessels	4.1.7	High Waves - Relative Movements between the Vessels	high waves
1.1	Long shut down times (in case of leakage)	4.13	Long shut-down times for ESD	Long shut-down times for ESD
1.1	Loads due to snow and icing of the piping	4.15	Loads due to snow and icing of the piping	Loads due to snow and icing of the piping
1.1	see action	4.19	Deviations from Bunker Procedures	see action
1.1	Over pressurization of storage tanks	4.2	Overpressure	Overpressure
1.1	Overfilling of storage tanks	4.2	Overfilling	Overfilling
1.1	Crew member falling over board	4.20	Crew member falling over board	Crew member falling over board
1.1	Emergency Release System activated	4.3	Emergency Release System activated	ESD activated
1.1	see action	4.4	Lack of Training	see action
1.1	see action	4.5	Unclear Responsibilities	Unclear Responsibilities
1.1	see action	4.6	Regulation Gaps	Regulation Gaps
1.1	Fire on the vessel	5.1.1	Fire on Board	Fire on Board
1.1	Fire/Explosion in the machinery space of LNG system	5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board
1.1	Big falling objects on bunker vessel from terminal	5.1.9	Big falling objects on the bunker vessel from terminal	Falling Objects
1.1	Loss of one mooring line	5.2.21	Loss of mooring	Loss of mooring
1.1	unintended pressure release	5.24	Pressure release during loading and unloading	Pressure release during loading and unloading
1.1	Black out of bunker vessel	5.28	Black-Out	Hard arm
1.1	Passing vessel collides with ships during bunkering (fore/aft collision, side collision)	6.1.1	Collision	Collision

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Failures (Summary)

Failure #	Failure	Item #	Item Name	Function
1.2	Passing vessel collides with bunker vessel from side (90°), (only smaller vessel assumed (< 160 m), bigger vessel will not turn so quickly, most of the vessel will already supplied by a tug).	6.1.1	Collision	Collision
1.3	Collision of bunker vessel during approach or leave	6.1.1	Collision	Collision
1.1	Surge of passing vessel	6.1.14	Surge from passing vessels	Surge of passing vessel
1.1	Vessel entering safety zone	6.1.2	Vessel entering Safety Zone	Vessel entering Safety Zone
1.1	Restriction of shipping channel	6.25	restriction of shipping channel	Restriction of shipping channel

Annex 3

List of “Effects“

Source: Germanischer Lloyd

Effects

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)
GL Report Number: RD-ER 2011.31
Prepared by: Finn Vogler
FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

Effect #	Effects			Sev (Init)	Sev (Rev)	Item #	Item Name	Function	Failure
	Effect	Next Level Effect	Revised Effect						
1.1.1	LNG spill, large gas cloud		gas detection will detect leakage, ESD of bunkering	5	5	3.2.12	Loss of connection	Loss of connection	unintended disconnection
1.1.1	larger LNG leakage and big gas cloud, ignition possible			5	5	4.13	Long shut-down times for ESD	Long shut-down times for ESD	Long shut down times (in case of leakage)
1.1.1	location of vent exits in cargo area, big gas cloud assumed, gas cloud may be ignited			5	5	5.24	Pressure release during loading and unloading	Pressure release during loading and unloading	unintended pressure release
1.1.1	Damage of outer shell and LNG storage tank of bunker vessel, LNG leakage and gas cloud, ignition assumed, big fire, low flame velocity, structural damage of ship structure according to leaking LNG, rapid phase transition could be			5	5	6.1.1	Collision	Collision	Passing vessel collides with bunker vessel from side (90°), (only smaller vessel assumed (< 160 m), bigger vessel will not turn so quickly, most of the vessel will already supplied by a tug).
1.1.1	hose of composite design, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded,		hose will get small pinhole leakages before rupture, emergency shut down of bunker procedure.	5	3	3.1.1	Rupture of Filling Line	For bunker hose	rupture of pipe
1.1.1	hose of composite design, big gas cloud, gas alarm, ESD initiated, bunkering stopped, ignition of gas cloud can not be excluded		hose will get small pinhole leakages before rupture, emergency shut down of bunker procedure.	5	3	3.3.1	Rupture of Vapour Return Line	For bunker hose	rupture of pipe
2.2.1	flexible hose at the arm is of double walled design, rest of fixed piping is single walled, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded,		According to the regular tests and qualification procedures of system a total rupture is not assumed	5	3	3.1.1	Rupture of Filling Line	For hard arm	rupture of pipe
2.2.1	flexible hose at the arm is of double walled design, rest of fixed piping is single walled, big gas cloud, gas alarm, ESD initiated, bunkering stopped, ignition of gas cloud can not be excluded,		According to the regular tests and qualification procedures of system a total rupture is not assumed	5	3	3.3.1	Rupture of Vapour Return Line	For hard arm	rupture of pipe

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Effects

Effect #	Effects			Sev (Init)	Sev (Rev)	Item #	Item Name	Function	Failure
	Effect	Next Level Effect	Revised Effect						
1.1.1	in case of overfilling, LNG may be pressed through the safety valves and vent lines to atmosphere, big gas cloud		Tank condition is permanently monitored by bunker crew on receiving vessel. Pre alarm for overfilling at 95 %. Bunkering will be stopped automatically by two independent systems at 98,5 % and 99 % filling level (SIGTTO guideline).	5	2	4.2	Overfilling	Overfilling	Overfilling of storage tanks
1.1.1	location of vent exits above superstructure, gas cloud above vent exit, gas cloud could reach container bridge and may be ignited (double-failure, other safety systems act before safety valve, no difference to the vessel at normal operation)			4	4	2.16.24	Pressure release during loading and unloading	Pressure release during loading and unloading	unintended pressure release
1.1.1	hard arm stays in last position, if critical forces are reached connections emergency release couplings will open, mechanical damages can not be excluded. According to black out bunkering has stopped and all valves go to fail safe position, no LNG leakage possible			4	4	5.28	Black-Out	Hard arm	Black out of bunker vessel
1.1.1	person will fall in the water of lower vessel, one heavily injured or dead person			4	4	4.20	Crew member falling over board	Crew member falling over board	Crew member falling over board
1.1.1	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release		sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage	4	4	5.1.1	Fire on Board	Fire on Board	Fire on the vessel
1.1.1	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release,		sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage	4	4	5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board	Fire/Explosion in the machinery space of LNG system
1.1.1	Big fallen objects may destroy piping on deck or the coverage of the tank system, LNG leakage and big gas cloud, fire must be assumed on deck area and in the adjacent open spaces, a damage of storage tank of bunker vessel will not		Bunker ship will separated by fender system from the vessel (approximately 2 m) emergency shut down of bunkering, sprinkler system for storage tanks activated. Storage tank is protected by safety valves for the fire	4	4	5.1.9	Big falling objects on the bunker vessel from terminal	Falling Objects	Big falling objects on bunker vessel from terminal

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Effects

Effect #	Effects			Sev (Init)	Sev (Rev)	Item #	Item Name	Function	Failure
	Effect	Next Level Effect	Revised Effect						
1.1.1	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel.		sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage on bunker vessel	4	4	2.1.1	Fire on Board	Fire on Board	Fire on the vessel
1.1.1	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel		sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage on bunker vessel	4	4	2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board	Fire/Explosion in the machinery space of LNG system
1.1.1	may lead to overfilling if bunker crew is not informed probably about status in tank		Overfilling protection will close valves automatically.	4	3	3.4.2	Communication problems between vessels	Communication problems between vessels	Communication problems between vessels
1.1.1	lightning may ignite present gas clouds		During thunderstorm and lightning the bunkering is not allowed (e.g. port of Hamburg)	4	2	4.1.1	Lightning	Lightning	Lightning's
1.1.1	if critical pressure is reached safety valves will open and gas will be vented to atmosphere		pressure monitoring system will give alarm to operator, tank shut-down if critical limit is reached (prior to opening of safety valves)	4	2	4.2	Overpressure	Overpressure	Over pressurization of storage tanks
2.2.1	hard arm, bunker manifold will be mechanically damaged, double walled piping connection will break first, leakage		hard arm will actively follow the movements of the bunker connection, forces at the connection monitored, disconnection in case of to high forces. Emergency release coupling will disconnect if forces exceed critical limits.	4	2	3.1.10	Excessive forces, stress on valves, hoses and pipes	For hard arm	Excessive forces
1.1.1	only tension, buckling of hose, damage of hose can not be excluded, leakage possible		hose support excludes high tension forces and buckling of hoes Emergency release coupling will disconnect if forces exceed critical limits.	4	1	3.1.10	Excessive forces, stress on valves, hoses and pipes	For bunker hose	Excessive forces
1.1.1	LNG will evaporate direct after leakage		failure can be detected by visual inspection	3	3	3.1.18	Leakage of filling line	For bunker hose	small leakage
1.1.1	LNG will evaporate direct after leakage, drip tray will protect ship structure		failure will be detected by gas detection at bunker station	3	3	3.2.18	Leakage of connection	Leakage of connection	small leakage
1.1.1	parallel ESD of bunkering not possible		Bunkering procedure will be automatically stopped	3	3	3.4.1	Loss of ESD Connection	Loss of ESD Connection	Loss of ESD Connection
1.1.1	Vessel will approach with low speed, mechanical damage of the outer hull possible, damage of storage tank and gas system not expected		vessel is designed for high manoeuvrability. Safety distances of storage tanks to outside are designed for small collisions	3	3	6.1.1	Collision	Collision	Collision of bunker vessel during approach or leave

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Effects

Effect #	Effects			Sev (Init)	Sev (Rev)	Item #	Item Name	Function	Failure
	Effect	Next Level Effect	Revised Effect						
1.1.1	bunker vessel will be heavily mechanically damaged, a damage of storage tank will not be assumed (no difference to normal operated vessel), possible break of mooring lines, bunker envelope will be left, Emergency shut down and disconnection of bunker line.			3	3	6.1.1	Collision	Collision	Passing vessel collides with ships during bunkering (fore/aft collision, side collision)
2.2.1	LNG will evaporate direct after leakage		failure can be detected by visual inspection	3	3	3.1.18	Leakage of filling line	For hard arm	small leakage
1.1.1	loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection		According sufficient number of mooring lines the probability for overload is lower. A single loss of line should not influence the mooring.	3	2	5.2.21	Loss of mooring	Loss of mooring	Loss of one mooring line
1.1.1	strong relative movements, loss of one mooring line, loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection it could be assumed, that the feeder vessel will lose the mooring to the berth prior to the loss of mooring between feeder and bunker barge.		According sufficient number of mooring lines the probability for overload is lower. A single loss of line should not influence the mooring.	3	2	6.1.14	Surge from passing vessels	Surge of passing vessel	Surge of passing vessel
1.1.1	icing around the hose, load of hoses will increase, if critical loads are reached, emergency release of piping		Piping system is designed to handle ice loads on the piping.	3	1	4.15	Loads due to snow and icing of the piping	Loads due to snow and icing of the piping	Loads due to snow and icing of the piping
1.1.1	local fires expected, no direct influence on bunker procedure, affects on berthed ships is not expected			2	2	1.1.1	Fire on Terminal	Fire on Terminal	Fire on Terminal
1.1.1	passing traffic may be restricted according to the bunkering procedure		Traffic will be organized by local traffic control	2	2	6.25	restriction of shipping channel	Restriction of shipping channel	Restriction of shipping channel
1.1.1	mooring lines make break, strong movements of vessel, operation cycle of bunkering may be left, emergency disconnection		During strong weather conditions the bunkering is not allowed (e.g. port of Hamburg)	2	2	4.1.2	Storm	Storm	high wind velocities
1.1.1	mooring lines make break, operation cycle of bunkering may be left, emergency disconnection		During strong weather conditions the bunkering is not allowed (e.g. port of Hamburg)	2	2	4.1.7	High Waves - Relative Movements between the Vessels	high waves	high relative movements between vessels
1.1.1	according to the higher risk of collision, bunkering during bad visibility condition is more critical		According the visibility conditions the local traffic control will restrict the voyage of bunker vessel (e.g. port of Hamburg)	2	2	4.1.27	Fog	Fog	bad visibility

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Effects

Effect #	Effects			Sev (Init)	Sev (Rev)	Item #	Item Name	Function	Failure
	Effect	Next Level Effect	Revised Effect						
1.1.1	during Emergency Release Disconnection approximately 1,5 l LNG will leak into the drip tray. hard arm or hose crane will go to safe position.			2	2	4.3	Emergency Release System activated	ESD activated	Emergency Release System activated
1.1.1	no effect, no reaction time for crew on bunker vessel and passing vessels, local traffic control may inform passing vessels prior to entering safety zone			2	2	6.1.2	Vessel entering Safety Zone	Vessel entering Safety Zone	Vessel entering safety zone
1.1.1	Equipotential bonding not possible, sparks may be possible (but only in case of double failure, presence of gas, ignition possible)			2	2	3.26	Equipotential bonding	Equipotential bonding	Loss of connection
1.1.1	loss of proper mooring to berth, bigger relative movements to berth, master decision to stop bunkering			2	2	2.2.23	Loss of mooring	Loss of mooring	Loss of one mooring line
1.1.1	Big fallen objects may destroy components in the cargo area, gas system will not be affected			1	1	2.1.8	Big falling objects on the receiving vessel from terminal	Falling Objects	Big falling objects on bunker vessel from terminal
1.1.1	see action					1.17	Difficult to arrange large safety zones on quay areas	A safety zone on the terminal will not be necessary if no crossover to the unused bunker station is existing and the bunker station can be defined as safe area.	see action
1.1.1	see action					4.5	Unclear Responsibilities	Unclear Responsibilities	see action
1.1.1	see action					4.6	Regulation Gaps	Regulation Gaps	see action
1.1.1	see action					4.4	Lack of Training	see action	see action
1.1.1	see action					4.19	Deviations from Bunker Procedures	see action	see action

Annex 4

List of “Causes“

Source: Germanischer Lloyd

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Causes

Causes

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL
GL Report Number: RD-ER 2011.31
Prepared by: Finn Vogler
FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

Cause #	Cause	Occ (Init)	Occ (Rev)	Det (Init)	Det (Rev)	Cause RPN (Initial)	Cause RPN (Revised)	% Reduction in Cause RPN	Item #	Item Name	Function	Failure	Effect
1.1.1.1	see action								1,17	Difficult to arrange large safety zones on quay areas	A safety zone on the terminal will not be necessary if no crossover to the unused bunker station is existing and the bunker station can be defined as safe area.	see action	see action
1.1.1.1	e.g. broken wire	5	5	3	3	30	30	0	3,26	Equipotential bonding	Equipotential bonding	Loss of connection	Equipotential bonding not possible, sparks may be possible (but only in case of double failure, presence of gas, ignition possible)
1.1.1.1	LNG leakage	2	2	1	1	10	10	0	4,13	Long shut-down times for ESD	Long shut-down times for ESD	Long shut down times (in case of leakage)	larger LNG leakage and big gas cloud, ignition possible
1.1.1.1	e.g. high humidity, spray from water curtain	5	5	1	1	15	5	66,67	4,15	Loads due to snow and icing of the piping	Loads due to snow and icing of the piping	Loads due to snow and icing of the piping	icing around the hose, load of hoses will increase if critical loads are reached, emergency release of piping
1.1.1.1	see action								4,19	Deviations from Bunker Procedures	see action	see action	see action
1.1.1.1	e.g. loss of overpressure protection	4	2	2	1	32	4	87,5	4,2	Overpressure	Overpressure	Over pressurization of storage tanks	if critical pressure is reached safety valves will open and gas will be vented to atmosphere
1.1.1.1	e.g. loss of overfilling protection	5	5	2	1	50	10	80	4,2	Overfilling	Overfilling	Overfilling of storage tanks	in case of overfilling, LNG may be pressed through the safety valves and vent lines to atmosphere, big gas cloud
1.1.1.1	e.g. falling crew member	4	4	1	1	16	16	0	4,2	Crew member falling over board	Crew member falling over board	Crew member falling over board	person will fall in the water of lower vessel, one heavily injured or dead person

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Causes

Cause #	Cause	Occ (Init)	Occ (Rev)	Det (Init)	Det (Rev)	Cause RPN (Initial)	Cause RPN (Revised)	% Reduction in Cause RPN	Item #	Item Name	Function	Failure	Effect
1.1.1.1	e.g. strong relative movements between vessel	3	3	1	1	6	6	0	4,3	Emergency Release System activated	ESD activated	Emergency Release System activated	during Emergency Release Disconnection approximately 1,5 l LNG will leak into the drip tray. hard arm or hose crane will go to safe position.
1.1.1.1	see action								4,4	Lack of Training	see action	see action	see action
1.1.1.1	see action								4,5	Unclear Responsibilities	Unclear Responsibilities	see action	see action
1.1.1.1	see action								4,6	Regulation Gaps	Regulation Gaps	see action	see action
1.1.1.1	- mechanical damage of valve	2	2	1	1	10	10	0	5,24	Pressure release during loading and unloading	Pressure release during loading and unloading	unintended pressure release	location of vent exits in cargo area, big gas cloud assumed, gas cloud may be ignited
1.1.1.1	e.g. short cut	3	3	1	1	12	12	0	5,28	Black-Out	Hard arm	Black out of bunker vessel	hard arm stays in last position, if critical forces are reached connections emergency release couplings will open, mechanical damages can not be excluded. According to black out bunkering has stopped and all valves go to fail safe position, no LNG leakage possible
1.1.1.1	e.g. wide of vessel, additional safety distance	5	5	1	1	10	10	0	6,25	restriction of shipping channel	Restriction of shipping channel	Restriction of shipping channel	passing traffic may be restricted according to the bunkering procedure
1.1.1.1	e.g. burning van carrier	3	3	1	1	6	6	0	1.1.1	Fire on Terminal	Fire on Terminal	Fire on Terminal	local fires expected, no direct influence on bunker procedure, affects on berthed ships is not expected
1.1.1.1	e.g. fire in accommodation	3	3	1	1	12	12	0	2.1.1	Fire on Board	Fire on Board	Fire on the vessel	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel.
1.1.1.1	e.g. fire in accommodation	3	3	1	1	12	12	0	2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board	Fire/Explosion in the machinery space of LNG system	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel
1.1.1.1	e.g. bottom of container will break, container will fall down	4	4	1	1	4	4	0	2.1.8	Big falling objects on the receiving vessel from terminal	Falling Objects	Big falling objects on bunker vessel from terminal	Big fallen objects may destroy components in the cargo area, gas system will not be affected

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Causes

Cause #	Cause	Occ (Init)	Occ (Rev)	Det (Init)	Det (Rev)	Cause RPN (Initial)	Cause RPN (Revised)	% Reduction in Cause RPN	Item #	Item Name	Function	Failure	Effect
1.1.1.1	- safety valves will open e. g. in case of fire or overfilling, active safety systems will avoid opening of safety valves, safety valves are the last level of protection - mechanical damage of valve	2	2	1	1	8	8	0	2.16.24	Pressure release during loading and unloading	Pressure release during loading and unloading	unintended pressure release	location of vent exits above superstructure, gas cloud above vent exit, gas cloud could reach container bridge and may be ignited (double-failure, other safety systems act before safety valve, no difference to the vessel at normal operation)
1.1.1.1	e.g. pre damaged mooring line	4	4	2	2	16	16	0	2.2.23	Loss of mooring	Loss of mooring	Loss of one mooring line	loss of proper mooring to berth, bigger relative movements to berth, master decision to stop bunkering
1.1.1.1	e.g. material failure	2	2	1	1	10	6	40	3.1.1	Rupture of Filling Line	For bunker hose	rupture of pipe	hose of composite design, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded,
1.1.1.1	e.g. material failure	2	2	1	1	10	6	40	3.1.1	Rupture of Filling Line	For hard arm	rupture of pipe	flexible hose at the arm is of double walled design, rest of fixed piping is single walled, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded
1.1.1.1	e.g. relative movements between vessel	3	3	1	1	12	3	75	3.1.10	Excessive forces, stress on valves, hoses and pipes	For bunker hose	Excessive forces	only tension, buckling of hose, damage of hose can not be excluded, leakage possible
1.1.1.1	e.g. relative movements between vessel	3	3	1	1	12	6	50	3.1.10	Excessive forces, stress on valves, hoses and pipes	For hard arm	Excessive forces	hard arm, bunker manifold will be mechanically damaged, double walled piping connection will break first, leakage
1.1.1.1	e.g. untight gasket	3	3	2	2	18	18	0	3.1.18	Leakage of filling line	For bunker hose	small leakage	LNG will evaporate direct after leakage
1.1.1.1	e.g. untight gasket	3	3	2	2	18	18	0	3.1.18	Leakage of filling line	For hard arm	small leakage	LNG will evaporate direct after leakage
1.1.1.1	e.g. ERC will not be activated	3	3	1	1	15	15	0	3.2.12	Loss of connection	Loss of connection	unintended disconnection	LNG spill, large gas cloud
1.1.1.1	e.g. untight gasket	3	3	2	1	18	9	50	3.2.18	Leakage of connection	Leakage of connection	small leakage	LNG will evaporate direct after leakage, drip tray will protect ship structure
1.1.1.1	e.g. material failure	2	2	1	1	10	6	40	3.3.1	Rupture of Vapour Return Line	For bunker hose	rupture of pipe	hose of composite design, big gas cloud, gas alarm, ESD initiated, bunkering stopped, ignition of gas cloud can not be excluded
1.1.1.1	e.g. material failure	2	2	1	1	10	6	40	3.3.1	Rupture of Vapour Return Line	For hard arm	rupture of pipe	flexible hose at the arm is of double walled design, rest of fixed piping is single walled, big gas cloud, gas alarm, ESD initiated, bunkering stopped, ignition of gas cloud can not be excluded

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Causes

Cause #	Cause	Occ (Init)	Occ (Rev)	Det (Init)	Det (Rev)	Cause RPN (Initial)	Cause RPN (Revised)	% Reduction in Cause RPN	Item #	Item Name	Function	Failure	Effect
1.1.1.1	e.g. broken wire	3	3	2	1	18	9	50	3.4.1	Loss of ESD Connection	Loss of ESD Connection	Loss of ESD Connection	parallel ESD of bunkering not possible
1.1.1.1	e.g. loss of VHF	5	5	2	1	40	15	62,5	3.4.2	Communication problems between vessels	Communication problems between vessels	Communication problems between vessels	may lead to overfilling if bunker crew is not informed probably about status in tank
1.1.1.1	weather conditions	5	5	1	1	20	10	50	4.1.1	Lightning	Lightning	Lightning's	lightning may ignite present gas clouds
1.1.1.1	weather conditions	5	5	1	1	10	10	0	4.1.2	Storm	Storm	high wind velocities	mooring lines make break, strong movements of vessel, operation cycle of bunkering may be left, emergency disconnection
1.1.1.1	weather conditions	5	5	1	1	10	10	0	4.1.27	Fog	Fog	bad visibility	according to the higher risk of collision, bunkering during bad visibility condition is more critical
1.1.1.1	weather conditions	5	5	1	1	10	10	0	4.1.7	High Waves - Relative Movements between the Vessels	high waves	high relative movements between vessels	mooring lines make break, operation cycle of bunkering may be left, emergency disconnection
1.1.1.1	e.g. fire in accommodation	3	3	1	1	12	12	0	5.1.1	Fire on Board	Fire on Board	Fire on the vessel	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release
1.1.1.1	e.g. fire in accommodation	3	3	1	1	12	12	0	5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board	Fire/Explosion in the machinery space of LNG system	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release,
1.1.1.1	e.g. bottom of container will break, container will fall down	4	4	1	1	16	16	0	5.1.9	Big falling objects on the bunker vessel from terminal	Falling Objects	Big falling objects on bunker vessel from terminal	Big fallen objects may destroy piping on deck or the coverage of the tank system, LNG leakage and big gas cloud, fire must be assumed on deck area and in the adjacent open spaces, a damage of storage tank of bunker vessel will not be expected
1.2.1.1	e.g. pre damaged mooring line	4	3	2	2	24	12	50	5.2.21	Loss of mooring	Loss of mooring	Loss of one mooring line	loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection
1.3.1.1	failure of passing vessel	4	4	1	1	12	12	0	6.1.1	Collision	Collision	Passing vessel collides with ships during bunkering (fore/aft collision, side collision)	bunker vessel will be heavily mechanically damaged, a damage of storage tank will not be assumed (no difference to normal operated vessel), possible break of mooring lines, bunker envelope will be left, Emergency shut down and disconnection of bunker line.

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Causes

Cause #	Cause	Occ (Init)	Occ (Rev)	Det (Init)	Det (Rev)	Cause RPN (Initial)	Cause RPN (Revised)	% Reduction in Cause RPN	Item #	Item Name	Function	Failure	Effect
2.1.1.1	e.g. black out of passing vessel, loss of steering machinery	3	3	1	1	15	15	0	6.1.1	Collision	Collision	Passing vessel collides with bunker vessel from side (90°), (only smaller vessel assumed (< 160 m), bigger vessel will not turn so quickly, most of the vessel will already supplied by a tug).	Damage of outer shell and LNG storage tank of bunker vessel, LNG leakage and gas cloud, ignition assumed, big fire, low flame velocity, structural damage of ship structure according to leaking LNG, rapid phase transition could be expected.
2.1.1.1	operator failure	4	4	1	1	12	12	0	6.1.1	Collision	Collision	Collision of bunker vessel during approach or leave	Vessel will approach with low speed, mechanical damage of the outer hull possible, damage of storage tank and gas system not expected
2.1.1.1	e.g. pre damaged mooring line	4	3	2	2	24	12	50	6.1.14	Surge from passing vessels	Surge of passing vessel	Surge of passing vessel	strong relative movements, loss of one mooring line, loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection it could be assumed, that the feeder vessel will lose the mooring to the berth prior to the loss of mooring between feeder and bunker barge.
2.1.1.1	e.g. wrong master decision	5	5	2	2	20	20	0	6.1.2	Vessel entering Safety Zone	Vessel entering Safety Zone	Vessel entering safety zone	no effect, no reaction time for crew on bunker vessel and passing vessels, local traffic control may inform passing vessels prior to entering safety zone

Annex 5

List of “Actions“

Source: Germanischer Lloyd

Actions (Summary)

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)
GL Report Number: RD-ER 2011.31
Prepared by: Finn Vogler
FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

Action #	Action	Item #	Item Name	Cause #	Cause	Cause RPN (Initial)	Cause RPN (Revised)
1	For the size off possible gas clouds the SIGTTO study should be checked	2.16.24	Pressure release during loading and unloading	1.1.1.1	- safety valves will open e. g. in case of fire or overfilling, active safety systems will avoid opening of safety valves, safety valves are the last level of protection□ - mechanical damage of valve□	8	8
1	For the size off possible gas clouds the SIGTTO study should be checked	5.24	Pressure release during loading and unloading	1.1.1.1	- mechanical damage of valve□	10	10
2	Terminal: a gas detection system on the container bridge should be discussed/recommended (alarm, ESD).	2.16.24	Pressure release during loading and unloading	1.1.1.1	- safety valves will open e. g. in case of fire or overfilling, active safety systems will avoid opening of safety valves, safety valves are the last level of protection□ - mechanical damage of valve□	8	8
2	Terminal: a gas detection system on the container bridge should be discussed/recommended (alarm, ESD).	5.24	Pressure release during loading and unloading	1.1.1.1	- mechanical damage of valve□	10	10
3	To avoid the probability of failures during connection a QCDC should be considered.	3.2.12	Loss of connection	1.1.1.1	e.g. ERC will not be activated	15	15
4	Bunker station design: the unused bunker station must be separated from the rest of the gas system (gas safe zone), otherwise the ex-zones will influence the terminal operation (according ex-zone no harbour operation in this area possible).	1.17	Difficult to arrange large safety zones on quay areas	1.1.1.1	see action		
5	Operational Manual: the terminal should be informed, if LNG bunker operations are planned during loading and unloading.	2.16.24	Pressure release during loading and unloading	1.1.1.1	- safety valves will open e. g. in case of fire or overfilling, active safety systems will avoid opening of safety valves, safety valves are the last level of protection□ - mechanical damage of valve□	8	8
5	Operational Manual: the terminal should be informed, if LNG bunker operations are planned during loading and unloading.	5.24	Pressure release during loading and unloading	1.1.1.1	- mechanical damage of valve□	10	10

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Actions (Summary)

Action #	Action	Item #	Item Name	Cause #	Cause	Cause RPN (Initial)	Cause RPN (Revised)
6	Operational Manual: the local traffic control should be informed about the planned bunkering	6.25	restriction of shipping channel	1.1.1.1	e.g. wide of vessel, additional safety distance	10	10
7	Bunker Standard: a major incident, e.g. big release of gas, should be communicated to the port authority.	2.16.24	Pressure release during loading and unloading	1.1.1.1	- safety valves will open e. g. in case of fire or overfilling, active safety systems will avoid opening of safety valves, safety valves are the last level of protection□ - mechanical damage of valve□	8	8
7	Bunker Standard: a major incident, e.g. big release of gas, should be communicated to the port authority.	5.24	Pressure release during loading and unloading	1.1.1.1	- mechanical damage of valve□	10	10
8	Hard Arm Design: a second energy source for the hard arm should be considered (emergency switchboard)	5.28	Black-Out	1.1.1.1	e.g. short cut	12	12
9	Design: pressure surge for shut down scenario must be calculated and shut down times shall be optimized accordingly.	4.13	Long shut-down times for ESD	1.1.1.1	LNG leakage	10	10
10	Bunker Procedure: The responsibilities have to be clearly defined in the bunker check lists prior to bunkering	4.5	Unclear Responsibilities	1.1.1.1	see action		
11	Legislation: the bunkering must be clearly regulated.	4.6	Regulation Gaps	1.1.1.1	see action		
12	Rules - STCW: training of crew should be clearly defined.	4.4	Lack of Training	1.1.1.1	see action		
12	Rules - STCW: training of crew should be clearly defined.	4.19	Deviations from Bunker Procedures	1.1.1.1	see action		
13	Bunker Procedure: the bunker vessel must have a safe possibility for transfer of people to the receiving vessel.	4.20	Crew member falling over board	1.1.1.1	e.g. falling crew member	16	16
14	Bunker procedure: the bunker vessel should be moored with a sufficient number of mooring lines (comp. and Exxon mooring requirements). Mooring lines should be supplied by bunker vessel (regularly checked).	5.2.21	Loss of mooring	1.1.1.1	e.g. pre damaged mooring line	24	12
14	Bunker procedure: the bunker vessel should be moored with a sufficient number of mooring lines (comp. and Exxon mooring requirements). Mooring lines should be supplied by bunker vessel (regularly checked).	6.1.14	Surge from passing vessels	1.1.1.1	e.g. pre damaged mooring line	24	12
15	Bunker Vessel: The manoeuvrability of the bunker vessel should ensure always a safe approach and departure to the receiving vessel under all foreseeable conditions.	5.2.21	Loss of mooring	1.1.1.1	e.g. pre damaged mooring line	24	12

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Actions (Summary)

Action #	Action	Item #	Item Name	Cause #	Cause	Cause RPN (Initial)	Cause RPN (Revised)
15	Bunker Vessel: The manoeuvrability of the bunker vessel should ensure always a safe approach and departure to the receiving vessel under all foreseeable conditions.	6.1.14	Surge from passing vessels	1.1.1.1	e.g. pre damaged mooring line	24	12
16	The probability for a collision can be lowered by using defined areas for bunkering or traffic restrictions. It should be considered, that this risk is no specific risk of the bunkering and bunker vessel, but similar to all gas fuelled vessel.	6.1.1	Collision	1.2.1.1	e.g. black out of passing vessel, loss of steering machinery	15	15

Annex 6

List of „Controls“

Source: Germanischer Lloyd

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Controls

Controls

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)
GL Report Number: RD-ER 2011.31
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FMEA Date (Orig.): 2011-11-23 - 2011-11-24
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Control #	Control	Control Type	Item #	Item Name	Cause #	Cause
1	regular tightness test	Detection	3.1.1	Rupture of Filling Line	2.1.1.1	e.g. material failure
2	visual inspection	Detection	3.1.1	Rupture of Filling Line	2.1.1.1	e.g. material failure
3	regular inspection of piping system	Detection	3.1.1	Rupture of Filling Line	2.1.1.1	e.g. material failure
4	regular tightness test	Detection	3.1.1	Rupture of Filling Line	1.1.1.1	e.g. material failure
5	visual inspection	Detection	3.1.1	Rupture of Filling Line	1.1.1.1	e.g. material failure
6	regular inspection of piping system	Detection	3.1.1	Rupture of Filling Line	1.1.1.1	e.g. material failure
7	max. hose movements considered during design	Prevention	3.1.10	Excessive forces, stress on valves, hoses and pipes	1.1.1.1	e.g. relative movements between vessel
8	Force control on bunker connection	Detection	3.1.10	Excessive forces, stress on valves, hoses and pipes	1.1.1.1	e.g. relative movements between vessel
9	max. hose movements considered during design	Prevention	3.1.10	Excessive forces, stress on valves, hoses and pipes	2.1.1.1	e.g. relative movements between vessel
10	Force control on bunker connection	Detection	3.1.10	Excessive forces, stress on valves, hoses and pipes	2.1.1.1	e.g. relative movements between vessel
11	visual inspection	Detection	3.1.18	Leakage of filling line	1.1.1.1	e.g. untight gasket
12	tightness test before each bunkering	Detection	3.1.18	Leakage of filling line	1.1.1.1	e.g. untight gasket
13	visual inspection	Detection	3.1.18	Leakage of filling line	2.1.1.1	e.g. untight gasket
14	tightness test before each bunkering	Detection	3.1.18	Leakage of filling line	2.1.1.1	e.g. untight gasket
15	regular tightness test	Detection	3.3.1	Rupture of Vapour Return Line	2.1.1.1	e.g. material failure
16	visual inspection	Detection	3.3.1	Rupture of Vapour Return Line	2.1.1.1	e.g. material failure
17	regular inspection of piping system	Detection	3.3.1	Rupture of Vapour Return Line	2.1.1.1	e.g. material failure
18	regular tightness test	Detection	3.3.1	Rupture of Vapour Return Line	1.1.1.1	e.g. material failure
19	visual inspection	Detection	3.3.1	Rupture of Vapour Return Line	1.1.1.1	e.g. material failure
20	regular inspection of piping system	Detection	3.3.1	Rupture of Vapour Return Line	1.1.1.1	e.g. material failure
21	Emergency release coupling	Prevention	3.1.10	Excessive forces, stress on valves, hoses and pipes	1.1.1.1	e.g. relative movements between vessel
22	Emergency release coupling	Prevention	3.1.10	Excessive forces, stress on valves, hoses and pipes	2.1.1.1	e.g. relative movements between vessel
23	gas detection system	Detection	3.2.12	Loss of connection	1.1.1.1	e.g. ERC will not be activated
24	visual inspection	Detection	3.2.18	Leakage of connection	1.1.1.1	e.g. untight gasket
25	tightness test before each bunkering	Detection	3.2.18	Leakage of connection	1.1.1.1	e.g. untight gasket
26	gas detection system	Detection	3.2.18	Leakage of connection	1.1.1.1	e.g. untight gasket
27	Signal monitoring	Detection	3.4.1	Loss of ESD Connection	1.1.1.1	e.g. broken wire
28	Vetting list	Prevention	3.4.2	Communication problems between vessels	1.1.1.1	e.g. loss of VHF
29	Overfilling protection	Detection	3.4.2	Communication problems between vessels	1.1.1.1	e.g. loss of VHF
30	Bunker procedure: bunkering during heavy weather conditions (thunderstorm, waves, wind) should be forbidden	Prevention	4.1.1	Lightning	1.1.1.1	weather conditions
31	Bunker procedure: bunkering during heavy weather conditions (thunderstorm, waves, wind) should be forbidden	Prevention	4.1.2	Storm	1.1.1.1	weather conditions
32	Bunker procedure: bunkering during heavy weather conditions (thunderstorm, waves, wind) should be forbidden	Prevention	4.1.7	High Waves - Relative Movements between the Vessels	1.1.1.1	weather conditions
33	SeeSchStrO, Announcement to harbour traffic regulation (HVO), will restrict traffic during bad visibility conditions.	Prevention	4.1.27	Fog	1.1.1.1	weather conditions
34	Emergency disconnection if operation cycle is left	Prevention	4.1.7	High Waves - Relative Movements between the Vessels	1.1.1.1	weather conditions

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Controls

Control #	Control	Control Type	Item #	Item Name	Cause #	Cause
35	Emergency disconnection if operation cycle is left	Prevention	4.1.2	Storm	1.1.1.1	weather conditions
36	Visible inspection	Detection	4.2	Overpressure	1.1.1.1	e.g. loss of overpressure protection
38	Visible inspection	Detection	4.2	Overfilling	1.1.1.1	e.g. loss of overfilling protection
39	Redundant overfilling protection	Prevention	4.2	Overfilling	1.1.1.1	e.g. loss of overfilling protection
40	Pressure monitoring system of storage tanks	Detection	4.2	Overpressure	1.1.1.1	e.g. loss of overpressure protection
41	gas detection system	Detection	4.13	Long shut-down times for ESD	1.1.1.1	LNG leakage
42	piping is designed to handle ice loads	Prevention	4.15	Loads due to snow and icing of the piping	1.1.1.1	e.g. high humidity, spray from water curtain
43	Water sprinkler system for cooling of tanks	Prevention	5.1.1	Fire on Board	1.1.1.1	e.g. fire in accommodation
44	A60 insulation to storage tanks	Prevention	5.1.1	Fire on Board	1.1.1.1	e.g. fire in accommodation
45	fire detection system	Detection	5.1.1	Fire on Board	1.1.1.1	e.g. fire in accommodation
46	Water sprinkler system for cooling of tanks	Prevention	5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1.1.1.1	e.g. fire in accommodation
47	A60 insulation to storage tanks	Prevention	5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1.1.1.1	e.g. fire in accommodation
48	fire detection system	Detection	5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1.1.1.1	e.g. fire in accommodation
49	Water sprinkler system for cooling of tanks	Prevention	5.1.9	Big falling objects on the bunker vessel from terminal	1.1.1.1	e.g. bottom of container will break, container will fall down
50	Safety valves storage tank	Prevention	5.1.9	Big falling objects on the bunker vessel from terminal	1.1.1.1	e.g. bottom of container will break, container will fall down
53	Water sprinkler system for cooling of tanks	Prevention	2.1.1	Fire on Board	1.1.1.1	e.g. fire in accommodation
54	A60 insulation to storage tanks	Prevention	2.1.1	Fire on Board	1.1.1.1	e.g. fire in accommodation
55	fire detection system	Detection	2.1.1	Fire on Board	1.1.1.1	e.g. fire in accommodation
56	Water sprinkler system for cooling of tanks	Prevention	2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1.1.1.1	e.g. fire in accommodation
57	A60 insulation to storage tanks	Prevention	2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1.1.1.1	e.g. fire in accommodation
58	fire detection system	Detection	2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	1.1.1.1	e.g. fire in accommodation

Annex 7

Definitions for Severity, Occurrence and Detection

Source: Germanischer Lloyd

Failure Mode and Effects Analysis
HAZID LNG Bunkering
Rating Criteria

Severity Rating Scale

#	Description	Criteria
1	No effect	The failure does not affect the normal operation of the system.
2	Minor effect	No breakdown and disturbed operation of the system with the possibility of further operation.
3	Moderate effect	Damage and/or breakdown of the system, repair required, no damage of other system components.
4	Major effect	Injured people and/or major damage/loss of the system/other systems.
5	Hazardous effect	Fatalities and/or loss of the system as well as damage/loss of other systems.

Occurrence Rating Scale

#	Description	Criteria
1	At no time	Not possible: if a disturbance can not occur because of physical causes.
2	Very rare	Technical excluded: if a disturbance can only occur with appearance of a minimum of two failures. (characteristic experience: once in 100 years of operation)
3	Rare	Not probable: under the assumption that the disturbance will not occur during the lifetime of the component. (characteristic experiences: once in 10 to 100 years of operation)
4	Sometimes	Low probability: under the assumption that the disturbance will occur during the lifetime of the component. (characteristic experience: once in 1 to 10 years of operation)
5	Frequently	Probable: under the assumption that the disturbance will occur once or several times during one year of operation. (characteristic experience: more than once a year of operation)

Detection Rating Scale

#	Description	Criteria
1	Ever	The disturbance will cause an alert, will initiate a shutoff or will lead to damages.
2	Often	The disturbance is detectable according to deviations of process parameters. (e.g. increase of temperature)
3	Unlikely	The disturbance is detectable in principle. But currently there is no possibility to detect the disturbance. (e.g. corresponding sensor not present)
4	Very unlikely	It is possible to detect the disturbance physically. But it will not be assumed that the disturbance will be detected.
5	Never	Physically it is not possible to detect the disturbance.

Annex 8

FMEA Sheets

Source: Germanischer Lloyd

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Terminal - Berth

FMEA - Terminal - Berth

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)

GL Report Number: RD-ER 2011.31
Prepared by: Finn Vogler
FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised Sev	Revised Occ	Revised Det	Revised RPN	#	Action
1	Terminal - Berth (Alabasterkai 8)																			
1.1	External Influences																			
1.1.1	Fire on Terminal	Fire on Terminal	1	Fire on Terminal	local fires expected, no direct influence on bunker procedure, affects on berthed ships is not expected	2	e.g. burning van carrier	3	1	6					2	3	1	6		
1.17	Difficult to arrange large safety zones on quay areas	A safety zone on the terminal will not be necessary if no crossover to the unused bunker station is existing and the bunker station can be defined as safe area.	1	see action	see action		see action												11 - 4	Bunker station design: the unused bunker station must be separated from the rest of the gas system (gas safe zone), otherwise the ex-zones will influence the terminal operation (according ex-zone no harbour operation in this area possible).

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Receiving Vessel

FMEA - Receiving Vessel

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)

GL Report Number: RD-ER 2011.31
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FMEA Date (Orig.): 2011-11-23 - 2011-11-24
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#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised				#	Action
															Sev	Occ	Det	RPN		
2	Receiving Vessel																			
2.1	External Influences																			
2.1.1	Fire on Board	Fire on Board	1	Fire on the vessel	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel.	4	e.g. fire in accommodation	3	1	12	53	Water sprinkler system for cooling of tanks	Prevention	sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage on bunker vessel	4	3	1	12		
											54	A60 insulation to storage tanks	Prevention							
											55	fire detection system	Detection							
2.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board	1	Fire/Explosion in the machinery space of LNG system	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release, bunker vessel will leave receiving vessel	4	e.g. fire in accommodation	3	1	12	56	Water sprinkler system for cooling of tanks	Prevention	sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage on bunker vessel	4	3	1	12		
											57	A60 insulation to storage tanks	Prevention							
											58	fire detection system	Detection							
2.1.8	Big falling objects on the receiving vessel from terminal	Falling Objects	1	Big falling objects on bunker vessel from terminal	Big fallen objects may destroy components in the cargo area, gas system will not be affected	1	e.g. bottom of container will break, container will fall down	4	1	4					1	4	1	4		
2.2	Mooring																			
2.2.23	Loss of mooring	Loss of mooring	1	Loss of one mooring line	loss of proper mooring to berth, bigger relative movements to berth, master decision to stop bunkering	2	e.g. pre damaged mooring line	4	2	16					2	4	2	16		
2.16	Parallel loading and unloading of the vessel																			
2.16.24	Pressure release during loading and unloading	Pressure release during loading and unloading	1	unintended pressure release	location of vent exits above superstructure, gas cloud above vent exit, gas cloud could reach container bridge and may be ignited (double-failure, other safety systems act before safety valve, no difference to the vessel at normal operation)	4	- safety valves will open e. g. in case of fire or overfilling, active safety systems will avoid opening of safety valves, safety valves are the last level of protection - mechanical damage of valve	2	1	8					4	2	1	8	11 - 1	For the size off possible gas clouds the SIGTTO study should be checked

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Receiving Vessel

#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised Sev	Revised Occ	Revised Det	Revised RPN	#	Action
																			11 - 2	Terminal: a gas detection system on the container bridge should be discussed/recommended (alarm, ESD).
																			11 - 5	Operational Manual: the terminal should be informed, if LNG bunker operations are planned during loading and unloading.
																			11 - 7	Bunker Standard: a major incident, e.g. big release of gas, should be communicated to the port authority.

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunkering Interface

FMEA - Bunkering Interface

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)

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FMEA Date (Orig.): 2011-11-23 - 2011-11-24
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															Revised					
#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Sev	Occ	Det	RPN	#	Action
3	Bunkering Interface																			
3.1	Filling Line																			
3.1.1	Rupture of Filling Line	For bunker hose	1	rupture of pipe	hose of composite design, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded,	5	e.g. material failure	2	1	10	4	regular tightness test	Detection	hose will get small pinhole leakages before rupture, emergency shut down of bunker procedure.	3	2	1	6		
											5	visual inspection	Detection							
											6	regular inspection of piping system	Detection							
		For hard arm	1	rupture of pipe	flexible hose at the arm is of double walled design, rest of fixed piping is single walled, LNG spill on receiving and bunker vessel, big gas cloud, gas alarm, ESD initiated, bunkering stopped, structural damage of the vessels could not be excluded, ignition of gas cloud can not be excluded,	5	e.g. material failure	2	1	10	1	regular tightness test	Detection	According to the regular tests and qualification procedures of system a total rupture is no assumed	3	2	1	6		
											2	visual inspection	Detection							
											3	regular inspection of piping system	Detection							
3.1.10	Excessive forces, stress on valves, hoses and pipes	For bunker hose	1	Excessive forces	only tension, buckling of hose, damage of hose can not be excluded, leakage possible	4	e.g. relative movements between vessel	3	1	12	7	max. hose movements considered during design	Prevention	hose support excludes high tension forces and buckling of hoes Emergency release coupling will disconnect if forces exceed critical limits.	1	3	1	3		
											8	Force control on bunker connection	Detection							
											21	Emergency release coupling	Prevention							

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunkering Interface

															Revised					
#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Sev	Occ	Det	RPN	#	Action
		For hard arm	1	Excessive forces	hard arm, bunker manifold wil be mechanically damaged, double walled piping connection will break first, leakage	4	e.g. relative movements between vessel	3	1	12	9	max. hose movements considered during design	Prevention	hard arm will actively follow the movements of the bunker connection, forces at the connection monitored, disconnection in case of to high forces. Emergency release coupling will disconnect if forces exceed critical limits.	2	3	1	6		
											10	Force control on bunker connection	Detection							
											22	Emergency release coupling	Prevention							
3.1.18	Leakage of filling line	For bunker hose	1	small leakage	LNG will evaporate direct afte leakage	3	e.g. untight gasket	3	2	18	11	visual inspection	Detection	failure can be detected by visual inspection	3	3	2	18		
											12	tightness test before each bunkering	Detection							
		For hard arm	1	small leakage	LNG will evaporate direct afte leakage	3	e.g. untight gasket	3	2	18	13	visual inspection	Detection	failure can be detected by visual inspection	3	3	2	18		
											14	tightness test before each bunkering	Detection							
3.2	Bunker Connection																			
3.2.11	Excessive forces, stress on valves, connections	Failure similar to Filling Line																		
3.2.12	Loss of connection	Loss of connection	1	unintended disconnection	LNG spill, large gas cloud	5	e.g. ERC will not be activated	3	1	15	23	gas detection system	Detection	gas detection will detect leakage, ESD of bunkering	5	3	1	15	11 - 3	To avoid the probability of failures during connection a QCDC should be considered.
3.2.18	Leakage of connection	Leakage of connection	1	small leakage	LNG will evaporate direct afte leakage, drip tray will protect ship structure	3	e.g. untight gasket	3	2	18	24	visual inspection	Detection	failure will be detected by gas detection at bunker station	3	3	1	9		
											25	tightness test before each bunkering	Detection							
											26	gas detection system	Detection							
3.3	Vapour Return Line																			
3.3.1	Rupture of Vapour Return Line	For bunker hose	1	rupture of pipe	hose of composite design, big gas cloud, gas alarm, ESD initiated, bunkering stopped, ignition of gas cloud can not be excluded	5	e.g. material failure	2	1	10	18	regular tightness test	Detection	hose will get small pinhole leakages before rupture, emergency shut down of bunker procedure.	3	2	1	6		
											19	visual inspection	Detection							
											20	regular inspection of piping system	Detection							
		For hard arm	1	rupture of pipe	flexible hose at the arm is of double walled design, rest of fixed piping is single walled, big gas cloud, gas alarm, ESD initiated, bunkering stopped, ignition of gas cloud can not be excluded,	5	e.g. material failure	2	1	10	15	regular tightness test	Detection	According to the regular tests and qualification procedures of system a total rupture is no assumed	3	2	1	6		
											16	visual inspection	Detection							
											17	regular inspection of piping system	Detection							
3.3.10	Excessive forces, stress on valves, hoses and pipes	Failure similar to Filling Line																		
3.3.18	Leakage of vapour return line	Failure similar to Filling Line																		
3.4	Communication Interface																			
3.4.1	Loss of ESD Connection	Loss of ESD Connection	1	Loss of ESD Connection	parallel ESD of bunkering not possible	3	e.g. broken wire	3	2	18	27	Signal monitoring	Detection	Bunkering procedure will be automatically stopped	3	3	1	9		
3.4.2	Communication problems between vessels	Communication problems between vessels	1	Communication problems between vessels	may lead to overfilling if bunker crew is not informed probably about status in tank	4	e.g. loss of VHF	5	2	40	28	Vetting list	Prevention	Overfilling protection will close valves automatically.	3	5	1	15		

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunkering Interface

#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised Sev	Revised Occ	Revised Det	Revised RPN	#	Action
											29	Overfilling protection	Detection							
3.26	Equipotential bonding	Equipotential bonding	1	Loss of connection	Equipotential bonding not possible, sparks may be possible (but only in case of double failure, presence of gas, ignition possible)	2	e.g. broken wire	5	3	30					2	5	3	30		

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunker Operation

FMEA - Bunker Operation

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)

GL Report Number: RD-ER 2011.31
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FMEA Date (Orig.): 2011-11-23 - 2011-11-24
FMEA Date (Rev.) -

#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised				#	Action
															Sev	Occ	Det	RPN		
4	Bunker Operation																			
4.1	External Influences																			
4.1.1	Lightning	Lightning	1	Lightning's	lightning may ignite present gas clouds	4	weather conditions	5	1	20	30	Bunker procedure: bunkering during heavy weather conditions (thunderstorm, waves, wind) should be forbidden	Prevention	During thunderstorm and lightning the bunkering is not allowed (e.g. port of Hamburg)	2	5	1	10		
4.1.2	Storm	Storm	1	high wind velocities	mooring lines make break, strong movements of vessel, operation cycle of bunkering may be left, emergency disconnection	2	weather conditions	5	1	10	31	Bunker procedure: bunkering during heavy weather conditions (thunderstorm, waves, wind) should be forbidden	Prevention	During strong weather conditions the bunkering is not allowed (e.g. port of Hamburg)	2	5	1	10		
											35	Emergency disconnection if operation cycle is left	Prevention							
4.1.7	High Waves - Relative Movements between the Vessels	high waves	1	high relative movements between vessels	mooring lines make break, operation cycle of bunkering may be left, emergency disconnection	2	weather conditions	5	1	10	32	Bunker procedure: bunkering during heavy weather conditions (thunderstorm, waves, wind) should be forbidden	Prevention	During strong weather conditions the bunkering is not allowed (e.g. port of Hamburg)	2	5	1	10		
											34	Emergency disconnection if operation cycle is left	Prevention							
4.1.27	Fog	Fog	1	bad visibility	according to the higher risk of collision, bunkering during bad visibility condition is more critical	2	weather conditions	5	1	10	33	SeeSchStrO, Announcement to harbour traffic regulation (HVO), will restrict traffic during bad visibility conditions.	Prevention	According the visibility conditions the local traffic control will restrict the voyage of bunker vessel (e.g. port of Hamburg)	2	5	1	10		
4.2	Overpressure	Overpressure	1	Over pressurization of storage tanks	if critical pressure is reached safety valves will open and gas will be vented to atmosphere	4	e.g. loss of overpressure protection	4	2	32	36	Visible inspection	Detection	pressure monitoring system will give alarm to operator, tank shut-down if critical limit is reached (prior to opening of safety valves)	2	2	1	4		
											40	Pressure monitoring system of storage tanks	Detection							
4.2	Overfilling	Overfilling	1	Overfilling of storage tanks	in case of overfilling, LNG may be pressed through the safety valves and vent lines to atmosphere, big gas cloud	5	e.g. loss of overfilling protection	5	2	50	38	Visible inspection	Detection	Tank condition is permanently monitored by bunker crew on receiving vessel. Pre alarm for overfilling at 95 %. Bunkering will be stopped automatically by two independent systems at 98,5 % and 99 % filling level (SIGTTO guideline).	2	5	1	10		
											39	Redundant overfilling protection	Prevention							

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunker Operation

#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised				#	Action
															Sev	Occ	Det	RPN		
4.3	Emergency Release System activated	ESD activated	1	Emergency Release System activated	during Emergency Release Disconnection approximately 1,5 l LNG will leak into the drip tray. hard arm or hose crane will go to safe position.	2	e.g. strong relative movements between vessel	3	1	6					2	3	1	6		
4.4	Lack of Training	see action	1	see action	see action		see action												11 - 12	Rules - STCW: training of crew should be clearly defined.
4.5	Unclear Responsibilities	Unclear Responsibilities	1	see action	see action		see action												11 - 10	Bunker Procedure: The responsibilities have to be clearly defined in the bunker check lists prior to bunkering.
4.6	Regulation Gaps	Regulation Gaps	1	see action	see action		see action												11 - 11	Legislation: the bunkering must be clearly regulated.
4.13	Long shut-down times for ESD	Long shut-down times for ESD	1	Long shut down times (in case of leakage)	larger LNG leakage and big gas cloud, ignition possible	5	LNG leakage	2	1	10	41	gas detection system	Detection		5	2	1	10	11 - 9	Design: pressure surge for shut down scenario must be calculated and shut down times shall be optimized accordingly.
4.15	Loads due to snow and icing of the piping	Loads due to snow and icing of the piping	1	Loads due to snow and icing of the piping	icing around the hose, load of hoses will increase, if critical loads are reached, emergency release of piping	3	e.g. high humidity, spray from water curtain	5	1	15	42	piping is designed to handle ice loads	Prevention	Piping system is designed to handle ice loads on the piping.	1	5	1	5		
4.19	Deviations from Bunker Procedures	see action	1	see action	see action		see action												11 - 12	Rules - STCW: training of crew should be clearly defined.
4.20	Crew member falling over board	Crew member falling over board	1	Crew member falling over board	person will fall in the water of lower vessel, one heavily injured or dead person	4	e.g. falling crew member	4	1	16					4	4	1	16	11 - 13	Bunker Procedure: the bunker vessel must have a safe possibility for transfer of people to the receiving vessel

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunker Vessel

FMEA - Bunker Vessel

Core Team: Lutz Dreyer (WaPo HH), Dr. Haarmann-Kühn (TGE), Wolfgang Becker (HPA), Hendrik Hollstein (HPA), Katja Leuteritz (HPA), Gerhard Untiedt (MW), Johannes Beuse (MW), Meindert Bildhoff (Hartmann), Birgit Schwarz (HHLA), Peter Voltmann (HHLA), Egmont Piepiorka (Unifeeder), Lars Langfeldt (GL), Finn Vogler (GL)

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#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised Sev	Revised Occ	Revised Det	Revised RPN	#	Action
5	Bunker Vessel																			
5.1	External Influences																			
5.1.1	Fire on Board	Fire on Board	1	Fire on the vessel	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release	4	e.g. fire in accommodation	3	1	12	43	Water sprinkler system for cooling of tanks	Prevention	sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage	4	3	1	12		
											44	A60 insulation to storage tanks	Prevention							
											45	fire detection system	Detection							
5.1.2	Fire - Explosion in machine spaces - LNG system of vessel	Fire/Explosion on Board	1	Fire/Explosion in the machinery space of LNG system	fire will be extinguished by crew according common procedures, bunkering will be stopped by ESD, normal disconnection or emergency release,	4	e.g. fire in accommodation	3	1	12	46	Water sprinkler system for cooling of tanks	Prevention	sprinkler system for cooling of storage tanks and A60 insulation will protect LNG storage	4	3	1	12		
											47	A60 insulation to storage tanks	Prevention							
											48	fire detection system	Detection							
5.1.9	Big falling objects on the bunker vessel from terminal	Falling Objects	1	Big falling objects on bunker vessel from terminal	Big fallen objects may destroy piping on deck or the coverage of the tank system, LNG leakage and big gas cloud, fire must be assumed on deck area and in the adjacent open spaces, a damage of storage tank of bunker vessel will not be expected.	4	e.g. bottom of container will break, container will fall down	4	1	16	49	Water sprinkler system for cooling of tanks	Prevention	Bunker ship will separated by fender system from the vessel (approximately 2 m) emergency shut down of bunkering, sprinkler system for storage tanks activated. Storage tank is protected by safety valves for the fire case	4	4	1	16		
											50	Safety valves storage tank	Prevention							
5.2	Mooring																			
5.2.21	Loss of mooring	Loss of mooring	1	Loss of one mooring line	loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection	3	e.g. pre damaged mooring line	4	2	24				According sufficient number of mooring lines the probability for overload is lower. A single loss of line should not influence the mooring.	2	3	2	12	11 - 14	Bunker procedure: the bunker vessel should be moored with a sufficient number of mooring lines (comp. and Exxon mooring requirements). Mooring lines should be supplied by bunker vessel (regularly checked).
																			11 - 15	Bunker Vessel: The manoeuvrability of the bunker vessel should ensure always a safe approach and departure to the receiving vessel under all foreseeable conditions.

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Bunker Vessel

#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised				#	Action
															Sev	Occ	Det	RPN		
5.2.22	Release of mooring in wrong way	See failure 3 Collision																		
5.24	Pressure release during loading and unloading	Pressure release during loading and unloading	1	unintended pressure release	location of vent exits in cargo area, big gas cloud assumed, gas cloud may be ignited	5	- mechanical damage of valve	2	1	10					5	2	1	10	11 - 1	For the size off possible gas clouds the SIGTTO study should be checked
																			11 - 2	Terminal: a gas detection system on the container bridge should be discussed/recommended (alarm, ESD).
																			11 - 5	Operational Manual: the terminal should be informed, if LNG bunker operations are planned during loading and unloading.
																			11 - 7	Bunker Standard: a major incident, e.g. big release of gas, should be communicated to the port authority.
5.28	Black-Out	Hard arm	1	Black out of bunker vessel	hard arm stays in last position, if critical forces are reached connections emergency release couplings will open, mechanical damages can not be excluded. According to black out bunkering has stopped and all valves go to fail safe position, no LNG leakage possible	4	e.g. short cut	3	1	12					4	3	1	12	11 - 8	Hard Arm Design: a second energy source for the hard arm should be considered (emergency switchboard)

Failure Mode and Effects Analysis
HAZID LNG Bunkering
FMEA - Waterway River Elbe

FMEA - Waterway River Elbe

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#	Item Name	Function	#	Failure	Effect	Sev	Cause	Occ	Det	RPN	#	Control	Control Type	Revised Effect	Revised Sev	Revised Occ	Revised Det	Revised RPN	#	Action
6	Waterway River Elbe																			
6.1	External Influences																			
6.1.1	Collision	Collision	1	Passing vessel collides with ships during bunkering (fore/aft collision, side collision)	bunker vessel will be heavily mechanically damaged, a damage of storage tank will not be assumed (no difference to normal operated vessel), possible break of mooring lines, bunker envelope will be left, Emergency shut down and disconnection of bunker line.	3	failure of passing vessel	4	1	12					3	4	1	12		
			2	Passing vessel collides with bunker vessel from side (90°) (only smaller vessel assumed (< 160 m), bigger vessel will not turn so quickly, most of the vessel will already supplied by a tug).	Damage of outer shell and LNG storage tank of bunker vessel, LNG leakage and gas cloud, ignition assumed, big fire, low flame velocity, structural damage of ship structure according to leaking LNG, rapid phase transition could be expected.	5	e.g. black out of passing vessel, loss of steering machinery	3	1	15					5	3	1	15	11 - 16	The probability for a collision can be lowered by using defined areas for bunkering or traffic restrictions. It should be considered, that this risk is no specific risk of the bunkering and bunker vessel, but similar to all gas fuelled vessel.
			3	Collision of bunker vessel during approach or leave	Vessel will approach with low speed, mechanical damage of the outer hull possible, damage of storage tank and gas system not expected	3	operator failure	4	1	12				vessel is designed for high manoeuvrability. Safety distances of storage tanks to outside are designed for smal collisions	3	4	1	12		
6.1.2	Vessel entering Safety Zone	Vessel entering Safety Zone	1	Vessel entering safety zone	no effect, no reaction time for crew on bunker vessel and passing vessels, local traffic control may inform passing vessels prior to entering safety zone	2	e.g. wrong master decision	5	2	20					2	5	2	20		

Failure Mode and Effects Analysis
HAZID LNG Bunkering
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															Revised					
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6.1.14	Surge from passing vessels	Surge of passing vessel	1	Surge of passing vessel	strong relative movements, loss of one mooring line, loss of proper mooring to receiving vessel, bigger relative movements between vessel, bunker connection will leave operation envelope, emergency shut down and disconnection it could be assumed, that the feeder vessel will lose the mooring to the berth prior to the loss of mooring between feeder and bunker barge.	3	e.g. pre damaged mooring line	4	2	24				According sufficient number of mooring lines the probability for overload is lower. A single loss of line should not influence the mooring.	2	3	2	12	11 - 14	Bunker procedure: the bunker vessel should be moored with a sufficient number of mooring lines (comp. and Exxon mooring requirements). Mooring lines should be supplied by bunker vessel (regularly checked).
																			11 - 15	Bunker Vessel: The manoeuvrability of the bunker vessel should ensure always a safe approach and departure to the receiving vessel under all foreseeable conditions.
6.25	restriction of shipping channel	Restriction of shipping channel	1	Restriction of shipping channel	passing traffic may be restricted according to the bunkering procedure	2	e.g. wide of vessel, additional safety distance	5	1	10				Traffic will be organized by local traffic control	2	5	1	10	11 - 6	Operational Manual: the local traffic control should be informed about the planned bunkering.